34

Electromagnetic Waves

CHAPTER OUTLINE

ANSWERS TO QUESTIONS

***Q34.1** Maxwell included a term in Ampère's law to account for the contributions to the magnetic field by changing electric fields, by treating those changing electric fields as "displacement currents."

***Q34.2** No, they do not. Specifically, Gauss's law in magnetism prohibits magnetic monopoles. If magnetic monopoles existed, then the magnetic field lines would not have to be closed loops, but could begin or terminate on a magnetic monopole, as they can in Gauss's law in electrostatics.

Q34.3 Radio waves move at the speed of light. They can travel around the curved surface of the Earth, bouncing between the ground and the ionosphere, which has an altitude that is small when compared to the radius of the Earth. The distance across the lower forty-eight states is approximately 5 000 km, requiring a transit time of $\frac{5\times10^{6}\text{ m}}{3\times10^{8}\text{ m/s}} \sim 10^{-2}\text{ s}$. To go halfway around the Earth takes only 0.07 s. In other words, a speech can be heard on the other side of the world before it is heard at the back of a large room.

Q34.4 Energy moves. No matter moves. You could say that electric and magnetic fields move, but it is nicer to say that the fields at one point stay at that point and oscillate. The fields vary in time, like sports fans in the grandstand when the crowd does the wave. The fields constitute the medium for the wave, and energy moves.

Q34.5 The changing magnetic field of the solenoid induces eddy currents in the conducting core. This is accompanied by I^2R conversion of electrically-transmitted energy into internal energy in the conductor.

***Q34.6** (i) According to $f = (2\pi)^{-1}\,(LC)^{-1/2}$, to make f half as large, the capacitance should be made four times larger. Answer (a).

(ii) Answer (b).

***Q34.7** Answer (e). Accelerating charge, changing electric field, or changing magnetic field can be the source of a radiated electromagnetic wave.

***Q34.8** (i) Answer (c). (ii) Answer (c). (iii) Answer (c). (iv) Answer (b). (v) Answer (b).

***Q34.9** (i) through (v) have the same answer (c).

Q34.10

Sound	*Light*
The world of sound extends to the top of the atmosphere and stops there; sound requires a material medium. Sound propagates by a chain reaction of density and pressure disturbances recreating each other. Sound in air moves at hundreds of meters per second. Audible sound has frequencies over a range of three decades (ten octaves) from 20 Hz to 20 kHz. Audible sound has wavelengths of ordinary size (1.7 cm to 17 m). Sound waves are longitudinal.	The universe of light fills the whole universe. Light moves through materials, but faster in a vacuum. Light propagates by a chain reaction of electric and magnetic fields recreating each other. Light in air moves at hundreds of millions of meters per second. Visible light has frequencies over a range of less than one octave, from 430 to 750 **Tera**hertz. Visible light has wavelengths of very small size (400 nm to 700 nm). Light waves are transverse.

Sound and light can both be reflected, refracted, or absorbed to produce internal energy. Both have amplitude and frequency set by the source, speed set by the medium, and wavelength set by both source and medium. Sound and light both exhibit the Doppler effect, standing waves, beats, interference, diffraction, and resonance. Both can be focused to make images. Both are described by wave functions satisfying wave equations. **Both carry energy.** If the source is small, their intensities both follow an inverse-square law. Both are waves.

Q34.11 The Poynting vector $\vec{\mathbf{S}}$ describes the energy flow associated with an electromagnetic wave. The direction of $\vec{\mathbf{S}}$ is along the direction of propagation and the magnitude of $\vec{\mathbf{S}}$ is the rate at which electromagnetic energy crosses a unit surface area perpendicular to the direction of $\vec{\mathbf{S}}$.

***Q34.12** (i) Answer (b). Electric and magnetic fields must both carry the same energy, so their amplitudes are proportional to each other. (ii) Answer (a). The intensity is proportional to the square of the amplitude.

***Q34.13** (i) Answer (c). Both the light intensity and the gravitational force follow inverse-square laws.

(ii) Answer (a). The smaller grain presents less face area and feels a smaller force due to light pressure.

Q34.14 Photons carry momentum. Recalling what we learned in Chapter 9, the impulse imparted to a particle that bounces elastically is twice that imparted to an object that sticks to a massive wall. Similarly, the impulse, and hence the pressure exerted by a photon reflecting from a surface must be twice that exerted by a photon that is absorbed.

Q34.15 Different stations have transmitting antennas at different locations. For best reception align your rabbit ears perpendicular to the straight-line path from your TV to the transmitting antenna. The transmitted signals are also polarized. The polarization direction of the wave can be changed by reflection from surfaces—including the atmosphere—and through Kerr rotation—a change in polarization axis when passing through an organic substance. In your home, the plane of polarization is determined by your surroundings, so antennas need to be adjusted to align with the polarization of the wave.

Q34.16 Consider a typical metal rod antenna for a car radio. The rod detects the electric field portion of the carrier wave. Variations in the amplitude of the incoming radio wave cause the electrons in the rod to vibrate with amplitudes emulating those of the carrier wave. Likewise, for frequency modulation, the variations of the frequency of the carrier wave cause constant-amplitude vibrations of the electrons in the rod but at frequencies that imitate those of the carrier.

***Q34.17** (i) Gamma rays have the shortest wavelength. The ranking is a < g < e < f < b < c < d.

(ii) Gamma rays have the highest frequency: d < c < b < f < e < g < a.

(iii) All electromagnetic waves have the same physical nature. a = b = c = d = e = f = g.

Q34.18 The frequency of EM waves in a microwave oven, typically 2.45 GHz, is chosen to be in a band of frequencies absorbed by water molecules. The plastic and the glass contain no water molecules. Plastic and glass have very different absorption frequencies from water, so they may not absorb any significant microwave energy and remain cool to the touch.

Q34.19 People of all the world's races have skin the same color in the infrared. When you blush or exercise or get excited, you stand out like a beacon in an infrared group picture. The brightest portions of your face show where you radiate the most. Your nostrils and the openings of your ear canals are bright; brighter still are just the pupils of your eyes.

Q34.20 Light bulbs and the toaster shine brightly in the infrared. Somewhat fainter are the back of the refrigerator and the back of the television set, while the TV screen is dark. The pipes under the sink show the same weak sheen as the walls until you turn on the faucets. Then the pipe on the right turns very black while that on the left develops a rich glow that quickly runs up along its length. The food on your plate shines; so does human skin, the same color for all races. Clothing is dark as a rule, but your bottom glows like a monkey's rump when you get up from a chair, and you leave behind a patch of the same blush on the chair seat. Your face shows you are lit from within, like a jack-o-lantern: your nostrils and the openings of your ear canals are bright; brighter still are just the pupils of your eyes.

Q34.21 12.2-cm waves have a frequency of 2.46 GHz. If the Q value of the phone is low (namely if it is cheap), and your microwave oven is not well shielded (namely, if it is also cheap), the phone can likely pick up interference from the oven. If the phone is well constructed and has a high Q value, then there should be no interference at all.

SOLUTIONS TO PROBLEMS

Section 34.1 **Displacement Current and the General Form of Ampère's Law**

***P34.1** (a) $$\frac{d\Phi_E}{dt}=\frac{dQ/dt}{\epsilon_0}=\frac{I}{\epsilon_0}=\frac{(0.100\text{ A})}{8.85\times10^{-12}\text{ C}^2/\text{N}\cdot\text{m}^2}=\boxed{11.3\times10^9\text{ V}\cdot\text{m/s}}$$

(b) $$I_d=\epsilon_0\frac{d\Phi_E}{dt}=I=\boxed{0.100\text{ A}}$$

***P34.2** $$\frac{d\Phi_E}{dt}=\frac{d}{dt}(EA)=\frac{dQ/dt}{\epsilon_0}=\frac{I}{\epsilon_0}$$

(a) $$\frac{dE}{dt}=\frac{I}{\epsilon_0 A}=\boxed{7.19\times10^{11}\text{ V/m}\cdot\text{s}}$$

(b) $$\oint B\cdot ds=\epsilon_0\,\mu_0\frac{d\Phi_E}{dt}\quad\text{so } 2\pi rB=\epsilon_0\,\mu_0\frac{d}{dt}\left[\frac{Q}{\epsilon_0 A}\cdot\pi r^2\right]$$

$$B=\frac{\mu_0 Ir}{2A}=\frac{\mu_0(0.200)\left(5.00\times10^{-2}\right)}{2\pi(0.100)^2}=\boxed{2.00\times10^{-7}\text{ T}}$$

***P34.3** We use the extended form of Ampère's law, Equation 34.7. Since no moving charges are present, $I = 0$ and we have

$$\oint \vec{\mathbf{B}} \cdot d\vec{\ell} = \mu_0 \in_0 \frac{d\Phi_E}{dt}.$$

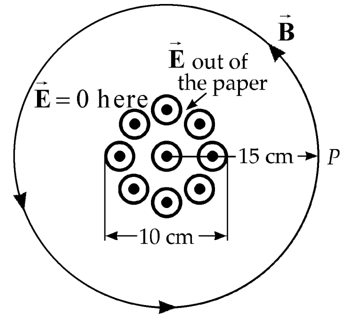


FIG. P34.3

In order to evaluate the integral, we make use of the symmetry of the situation. Symmetry requires that no particular direction from the center can be any different from any other direction. Therefore, there must be *circular symmetry* about the central axis. We know the magnetic field lines are circles about the axis. Therefore, as we travel around such a magnetic field circle, the magnetic field remains constant in magnitude. Setting aside until later the determination of the *direction* of $\vec{\mathbf{B}}$, we integrate $\oint \vec{\mathrm{B}} \cdot d\vec{l}$ around the circle

at $\quad R = 0.15\text{ m}$

to obtain $\quad 2\pi RB$

Differentiating the expression $\quad \Phi_E = AE$

we have
$$\frac{d\Phi_E}{dt} = \left(\frac{\pi d^2}{4}\right)\frac{dE}{dt}$$

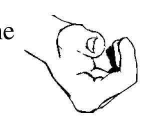
Thus,
$$\oint \vec{\mathbf{B}} \cdot d\vec{\ell} = 2\pi\, RB = \mu_0 \in_0 \left(\frac{\pi d^2}{4}\right)\frac{dE}{dt}$$

Solving for B gives
$$B = \frac{\mu_0 \in_0}{2\pi R}\left(\frac{\pi d^2}{4}\right)\frac{dE}{dt}$$

Substituting numerical values,
$$B = \frac{\left(4\pi \times 10^{-7}\text{ H/m}\right)\left(8.85 \times 10^{-12}\text{ F/m}\right)\left[\pi(0.10\text{ m})^2\right](20\text{ V/m}\cdot\text{s})}{2\pi(0.15\text{ m})(4)}$$

$$B = \boxed{1.85 \times 10^{-18}\text{ T}}$$

In Figure P34.3, the direction of the *increase* of the electric field is out the plane of the paper. By the right-hand rule, this implies that the direction of $\vec{\mathbf{B}}$ is *counterclockwise*. Thus, the direction of $\vec{\mathbf{B}}$ at P is $\boxed{\text{upwards}}$.



Section 34.2 **Maxwell's Equations and Hertz's Discoveries**

P34.4 (a) The rod creates the same electric field that it would if stationary. We apply Gauss's law to a cylinder of radius $r = 20$ cm and length ℓ:

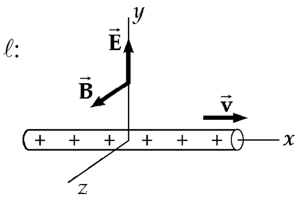


FIG. P34.4

$$\oint \vec{\mathbf{E}} \cdot d\vec{\mathbf{A}} = \frac{q_{\text{inside}}}{\epsilon_0}$$

$$E(2\pi r l)\cos 0° = \frac{\lambda l}{\epsilon_0}$$

$$\vec{\mathbf{E}} = \frac{\lambda}{2\pi \epsilon_0 r} \text{ radially outward} = \frac{\left(35\times10^{-9}\text{ C/m}\right)\text{ N}\cdot\text{m}^2}{2\pi\left(8.85\times10^{-12}\text{ C}^2\right)(0.2\text{ m})}\hat{\mathbf{j}} = \boxed{3.15\times10^3\,\hat{\mathbf{j}}\text{ N/C}}$$

(b) The charge in motion constitutes a current of $\left(35\times10^{-9}\text{ C/m}\right)\left(15\times10^6\text{ m/s}\right) = 0.525$ A. This current creates a magnetic field.

$$\vec{\mathbf{B}} = \frac{\mu_0 I}{2\pi r} = \frac{\left(4\pi\times10^{-7}\text{ T}\cdot\text{m/A}\right)(0.525\text{ A})}{2\pi(0.2\text{ m})}\hat{\mathbf{k}} = \boxed{5.25\times10^{-7}\,\hat{\mathbf{k}}\text{ T}}$$

(c) The Lorentz force on the electron is $\vec{\mathbf{F}} = q\vec{\mathbf{E}} + q\vec{\mathbf{v}}\times\vec{\mathbf{B}}$

$$\vec{\mathbf{F}} = \left(-1.6\times10^{-19}\text{ C}\right)\left(3.15\times10^3\,\hat{\mathbf{j}}\text{ N/C}\right)$$
$$+\left(-1.6\times10^{-19}\text{ C}\right)\left(240\times10^6\,\hat{\mathbf{i}}\text{ m/s}\right)$$
$$\times\left(5.25\times10^{-7}\,\hat{\mathbf{k}}\,\frac{\text{N}\cdot\text{s}}{\text{C}\cdot\text{m}}\right)$$

$$\vec{\mathbf{F}} = 5.04\times10^{-16}\left(-\hat{\mathbf{j}}\right)\text{ N} + 2.02\times10^{-17}\left(+\hat{\mathbf{j}}\right)\text{ N} = \boxed{4.83\times10^{-16}\left(-\hat{\mathbf{j}}\right)\text{ N}}$$

***P34.5** $\vec{\mathbf{F}} = m\vec{\mathbf{a}} = q\vec{\mathbf{E}} + q\vec{\mathbf{v}}\times\vec{\mathbf{B}}$

$$\vec{\mathbf{a}} = \frac{e}{m}\left[\vec{\mathbf{E}} + \vec{\mathbf{v}}\times\vec{\mathbf{B}}\right] \text{ where } \vec{\mathbf{v}}\times\vec{\mathbf{B}} = \begin{vmatrix} \hat{\mathbf{i}} & \hat{\mathbf{j}} & \hat{\mathbf{k}} \\ 200 & 0 & 0 \\ 0.200 & 0.300 & 0.400 \end{vmatrix} = -200(0.400)\hat{\mathbf{j}} + 200(0.300)\hat{\mathbf{k}}$$

$$\vec{\mathbf{a}} = \frac{1.60\times10^{-19}}{1.67\times10^{-27}}\left[50.0\hat{\mathbf{j}} - 80.0\hat{\mathbf{j}} + 60.0\hat{\mathbf{k}}\right] = 9.58\times10^7\left[-30.0\hat{\mathbf{j}} + 60.0\hat{\mathbf{k}}\right]$$

$$\vec{\mathbf{a}} = 2.87\times10^9\left[-\hat{\mathbf{j}} + 2\hat{\mathbf{k}}\right]\text{ m/s}^2 = \boxed{\left(-2.87\times10^9\,\hat{\mathbf{j}} + 5.75\times10^9\hat{\mathbf{k}}\right)\text{ m/s}^2}$$

***P34.6** $\vec{\mathbf{F}} = m\vec{\mathbf{a}} = q\vec{\mathbf{E}} + q\vec{\mathbf{v}}\times\vec{\mathbf{B}}$ so $\vec{\mathbf{a}} = \frac{-e}{m}\left[\vec{\mathbf{E}} + \vec{\mathbf{v}}\times\vec{\mathbf{B}}\right]$ where $\vec{\mathbf{v}}\times\vec{\mathbf{B}} = \begin{vmatrix} \hat{\mathbf{i}} & \hat{\mathbf{j}} & \hat{\mathbf{k}} \\ 10.0 & 0 & 0 \\ 0 & 0 & 0.400 \end{vmatrix} = -4.00\hat{\mathbf{j}}$

$$\vec{\mathbf{a}} = \frac{\left(-1.60\times10^{-19}\right)}{9.11\times10^{-31}}\left[2.50\hat{\mathbf{i}} + 5.00\hat{\mathbf{j}} - 4.00\hat{\mathbf{j}}\right] = \left(-1.76\times10^{11}\right)\left[2.50\hat{\mathbf{i}} + 1.00\hat{\mathbf{j}}\right]$$

$$\vec{\mathbf{a}} = \boxed{\left(-4.39\times10^{11}\,\hat{\mathbf{i}} - 1.76\times10^{11}\,\hat{\mathbf{j}}\right)\text{m/s}^2}$$

Section 34.3 Plane Electromagnetic Waves

P34.7 (a) Since the light from this star travels at 3.00×10^{8} m/s

the last bit of light will hit the Earth in $\dfrac{6.44\times10^{18}\text{ m}}{3.00\times10^{8}\text{ m/s}}=2.15\times10^{10}\text{ s}=680$ years.

Therefore, it will disappear from the sky in the year $2\,007+680=\boxed{2.69\times10^{3}\text{ A.D.}}$
The star is 680 light-years away.

(b) $\Delta t=\dfrac{\Delta x}{v}=\dfrac{1.496\times10^{11}\text{ m}}{3\times10^{8}\text{ m/s}}=\boxed{499\text{ s}}=8.31\text{ min}$

(c) $\Delta t=\dfrac{\Delta x}{v}=\dfrac{2\left(3.84\times10^{8}\text{ m}\right)}{3\times10^{8}\text{ m/s}}=\boxed{2.56\text{ s}}$

(d) $\Delta t=\dfrac{\Delta x}{v}=\dfrac{2\pi\left(6.37\times10^{6}\text{ m}\right)}{3\times10^{8}\text{ m/s}}=\boxed{0.133\text{ s}}$

(e) $\Delta t=\dfrac{\Delta x}{v}=\dfrac{10\times10^{3}\text{ m}}{3\times10^{8}\text{ m/s}}=\boxed{3.33\times10^{-5}\text{ s}}$

P34.8 $v=\dfrac{1}{\sqrt{\kappa\mu_0\in_0}}=\dfrac{1}{\sqrt{1.78}}c=0.750c=\boxed{2.25\times10^{8}\text{ m/s}}$

P34.9 (a) $f\lambda=c$ or $f(50.0\text{ m})=3.00\times10^{8}\text{ m/s}$

so $\boxed{f=6.00\times10^{6}\text{ Hz}=6.00\text{ MHz}}$

(b) $\dfrac{E}{B}=c$ or $\dfrac{22.0}{B_{\max}}=3.00\times10^{8}$

so $\vec{\mathbf{B}}_{\max}=\boxed{-73.3\hat{\mathbf{k}}\text{ nT}}$

(c) $k=\dfrac{2\pi}{\lambda}=\dfrac{2\pi}{50.0}=0.126\text{ m}^{-1}$

and $\omega=2\pi f=2\pi\left(6.00\times10^{6}\text{ s}^{-1}\right)=3.77\times10^{7}\text{ rad/s}$

$$\vec{\mathbf{B}}=\vec{\mathbf{B}}_{\max}\cos(kx-\omega t)=\boxed{-73.3\cos\left(0.126x-3.77\times10^{7}t\right)\hat{\mathbf{k}}\text{ nT}}$$

P34.10 $\dfrac{E}{B}=c$ or $\dfrac{220}{B}=3.00\times10^{8}$

so $B=7.33\times10^{-7}\text{ T}=\boxed{733\text{ nT}}$

P34.11 (a) $B = \dfrac{E}{c} = \dfrac{100\text{ V/m}}{3.00\times10^{8}\text{ m/s}} = 3.33\times10^{-7}\text{ T} = \boxed{0.333\ \mu\text{T}}$

(b) $\lambda = \dfrac{2\pi}{k} = \dfrac{2\pi}{1.00\times10^{7}\text{ m}^{-1}} = \boxed{0.628\ \mu\text{m}}$

(c) $f = \dfrac{c}{\lambda} = \dfrac{3.00\times10^{8}\text{ m/s}}{6.28\times10^{-7}\text{ m}} = \boxed{4.77\times10^{14}\text{ Hz}}$

P34.12 $E = E_{\max}\cos(kx-\omega t)$

$$\frac{\partial E}{\partial x} = -E_{\max}\sin(kx-\omega t)(k)$$
$$\frac{\partial E}{\partial t} = -E_{\max}\sin(kx-\omega t)(-\omega)$$
$$\frac{\partial^2 E}{\partial x^2} = -E_{\max}\cos(kx-\omega t)\left(k^2\right)$$
$$\frac{\partial^2 E}{\partial t^2} = -E_{\max}\cos(kx-\omega t)(-\omega)^2$$

We must show: $\dfrac{\partial E}{\partial x^2} = \mu_0 \in_0 \dfrac{\partial^2 E}{\partial t^2}$

That is, $-\left(k^2\right)E_{\max}\cos(kx-\omega t) = -\mu_0 \in_0 (-\omega)^2 E_{\max}\cos(kx-\omega t)$

But this is true, because $\dfrac{k^2}{\omega^2} = \left(\dfrac{1}{f\lambda}\right)^2 = \dfrac{1}{c^2} = \mu_0 \in_0$

The proof for the wave of magnetic field follows precisely the same steps.

P34.13 In the fundamental mode, there is a single loop in the standing wave between the plates. Therefore, the distance between the plates is equal to half a wavelength.

$$\lambda = 2L = 2(2.00\text{ m}) = 4.00\text{ m}$$

Thus, $f = \dfrac{c}{\lambda} = \dfrac{3.00\times10^{8}\text{ m/s}}{4.00\text{ m}} = 7.50\times10^{7}\text{ Hz} = \boxed{75.0\text{ MHz}}$

P34.14 $d_{\text{A to A}} = 6\text{ cm}\pm5\% = \dfrac{\lambda}{2}$

$\lambda = 12\text{ cm}\pm5\%$

$v = \lambda f = (0.12\text{ m}\pm5\%)\left(2.45\times10^{9}\text{ s}^{-1}\right) = \boxed{2.9\times10^{8}\text{ m/s}\pm5\%}$

Section 34.4 **Energy Carried by Electromagnetic Waves**

P34.15 $S = I = \dfrac{U}{At} = \dfrac{Uc}{V} = uc \qquad \dfrac{\text{Energy}}{\text{Unit Volume}} = u = \dfrac{I}{c} = \dfrac{1\,000 \text{ W/m}^2}{3.00\times10^8 \text{ m/s}} = \boxed{3.33 \;\mu\text{J/m}^3}$

P34.16 $S_{\text{av}} = \dfrac{\overline{\mathcal{P}}}{4\pi r^2} = \dfrac{4.00\times10^3 \text{ W}}{4\pi(4.00\times1\,609 \text{ m})^2} = 7.68 \;\mu\text{W/m}^2$

$E_{\max} = \sqrt{2\mu_0 c S_{\text{av}}} = 0.076\,1 \text{ V/m}$

$\Delta V_{\max} = E_{\max} L = (76.1 \text{ mV/m})(0.650 \text{ m}) = \boxed{49.5 \text{ mV (amplitude)}}$ or 35.0 mV (rms)

P34.17 $r = (5.00 \text{ mi})(1\,609 \text{ m/mi}) = 8.04\times10^3 \text{ m}$

$S = \dfrac{\overline{\mathcal{P}}}{4\pi r^2} = \dfrac{250\times10^3 \text{ W}}{4\pi\left(8.04\times10^3 \text{ W}\right)^2} = \boxed{307 \;\mu\text{W/m}^2}$

***P34.18** (a) $\dfrac{\mathcal{P}}{\text{area}} = \dfrac{\text{energy}}{\Delta t\cdot\text{area}} = \dfrac{600 \text{ kWh}}{(30 \text{ d})(13 \text{ m})(9.5 \text{ m})} = \dfrac{600\times10^3 (\text{J/s})\text{h}}{30 \text{ d}\left(123.5 \text{ m}^2\right)}\left(\dfrac{1 \text{ d}}{24 \text{ h}}\right) = \boxed{6.75 \text{ W/m}^2}$

(b) The car uses gasoline at the rate $(55 \text{ mi/h})\left(\dfrac{\text{gal}}{25 \text{ mi}}\right)$. Its rate of energy conversion is

$\mathcal{P} = 44\times10^6 \text{ J/kg}\left(\dfrac{2.54 \text{ kg}}{1 \text{ gal}}\right)(55 \text{ mi/h})\left(\dfrac{\text{gal}}{25 \text{ mi}}\right)\left(\dfrac{1 \text{ h}}{3\,600 \text{ s}}\right) = 6.83\times10^4 \text{ W}$. Its power-per-footprint-area is $\dfrac{\mathcal{P}}{\text{area}} = \dfrac{6.83\times10^4 \text{ W}}{2.10 \text{ m}(4.90 \text{ m})} = \boxed{6.64\times10^3 \text{ W/m}^2}$.

(c) For an automobile of typical weight and power to run on sunlight, it would have to carry a solar panel huge compared to its own size. Rather than running a conventional car, it is much more natural to use solar energy for agriculture, forestry, lighting, space heating, drying, water purification, water heating, and small appliances.

P34.19 Power output = (power input)(efficiency).

Thus, $\quad$ Power input $= \dfrac{\text{Power out}}{\text{eff}} = \dfrac{1.00\times10^6 \text{ W}}{0.300} = 3.33\times10^6 \text{ W}$

and $\quad A = \dfrac{\mathcal{P}}{I} = \dfrac{3.33\times10^6 \text{ W}}{1.00\times10^3 \text{ W/m}^2} = \boxed{3.33\times10^3 \text{ m}^2}$

P34.20 $I = \dfrac{B_{\max}^2 c}{2\mu_0} = \dfrac{\mathcal{P}}{4\pi r^2}$

$B_{\max} = \sqrt{\left(\dfrac{\mathcal{P}}{4\pi r^2}\right)\left(\dfrac{2\mu_0}{c}\right)} = \sqrt{\dfrac{\left(10.0\times10^3\right)(2)\left(4\pi\times10^{-7}\right)}{4\pi\left(5.00\times10^3\right)^2\left(3.00\times10^8\right)}} = \boxed{5.16\times10^{-10} \text{ T}}$

Since the magnetic field of the Earth is approximately 5×10^{-5} T, the Earth's field is some 100 000 times stronger.

P34.21 (a) $\mathcal{P} = I^2 R = 150\ \text{W}$

$$A = 2\pi rL = 2\pi\left(0.900\times10^{-3}\ \text{m}\right)\left(0.080\ 0\ \text{m}\right) = 4.52\times10^{-4}\ \text{m}^2$$

$$S = \frac{\mathcal{P}}{A} = \boxed{332\ \text{kW/m}^2}\ \text{(points radially inward)}$$

(b) $$B = \frac{\mu_0 I}{2\pi r} = \frac{\mu_0\,(1.00)}{2\pi\left(0.900\times10^{-3}\right)} = \boxed{222\ \mu\text{T}}$$

$$E = \frac{\Delta V}{\Delta x} = \frac{IR}{L} = \frac{150\ \text{V}}{0.080\ 0\ \text{m}} = \boxed{1.88\ \text{kV/m}}$$

Note: $S = \dfrac{EB}{\mu_0} = 332\ \text{kW/m}^2$

P34.22 (a) $$I = \frac{E_{\max}^2}{2\mu_0 c} = \frac{\left(3\times10^6\ \text{V/m}\right)^2}{2\left(4\pi\times10^{-7}\ \text{T}\cdot\text{m/A}\right)\left(3\times10^8\ \text{m/s}\right)}\left(\frac{\text{J}}{\text{V}\cdot\text{C}}\right)^2\left(\frac{\text{C}}{\text{A}\cdot\text{s}}\right)\left(\frac{\text{T}\cdot\text{C}\cdot\text{m}}{\text{N}\cdot\text{s}}\right)\left(\frac{\text{N}\cdot\text{m}}{\text{J}}\right)$$

$$I = \boxed{1.19\times10^{10}\ \text{W/m}^2}$$

(b) $$\mathcal{P} = IA = \left(1.19\times10^{10}\ \text{W/m}^2\right)\pi\left(\frac{5\times10^{-3}\ \text{m}}{2}\right)^2 = \boxed{2.34\times10^5\ \text{W}}$$

P34.23 (a) $$\vec{\mathbf{E}}\cdot\vec{\mathbf{B}} = \left(80.0\hat{\mathbf{i}} + 32.0\hat{\mathbf{j}} - 64.0\hat{\mathbf{k}}\right)(\text{N/C})\cdot\left(0.200\hat{\mathbf{i}} + 0.080\ 0\hat{\mathbf{j}} + 0.290\hat{\mathbf{k}}\right)\ \mu\text{T}$$

$$\vec{\mathbf{E}}\cdot\vec{\mathbf{B}} = (16.0 + 2.56 - 18.56)\ \text{N}^2\cdot\text{s/C}^2\cdot\text{m} = \boxed{0}$$

(b) $$\vec{\mathbf{S}} = \frac{1}{\mu_0}\vec{\mathbf{E}}\times\vec{\mathbf{B}} = \frac{\left[\left(80.0\hat{\mathbf{i}} + 32.0\hat{\mathbf{j}} - 64.0\hat{\mathbf{k}}\right)\ \text{N/C}\right]\times\left[\left(0.200\hat{\mathbf{i}} + 0.080\ 0\hat{\mathbf{j}} + 0.290\hat{\mathbf{k}}\right)\ \mu\text{T}\right]}{4\pi\times10^{-7}\ \text{T}\cdot\text{m/A}}$$

$$\vec{\mathbf{S}} = \frac{\left(6.40\hat{\mathbf{k}} - 23.2\hat{\mathbf{j}} - 6.40\hat{\mathbf{k}} + 9.28\hat{\mathbf{i}} - 12.8\hat{\mathbf{j}} + 5.12\hat{\mathbf{i}}\right)\times10^{-6}\ \text{W/m}^2}{4\pi\times10^{-7}}$$

$$\vec{\mathbf{S}} = \boxed{\left(11.5\hat{\mathbf{i}} - 28.6\hat{\mathbf{j}}\right)\ \text{W/m}^2} = 30.9\ \text{W/m}^2\ \text{at}\ -68.2^\circ\ \text{from the } +x \text{ axis}$$

P34.24 The energy put into the water in each container by electromagnetic radiation can be written as $e\mathcal{P}\,\Delta t = eIA\Delta t$ where e is the percentage absorption efficiency. This energy has the same effect as heat in raising the temperature of the water:

$$eIA\Delta t = mc\Delta T = \rho Vc\Delta T$$

$$\Delta T = \frac{eI\ell^2\Delta t}{\rho\ell^3 c} = \frac{eI\Delta t}{\rho\ell c}$$

where ℓ is the edge dimension of the container and c the specific heat of water. For the small container,

$$\Delta T = \frac{0.7\left(25\times10^3\ \text{W/m}^2\right)480\ \text{s}}{\left(10^3\ \text{kg/m}^3\right)(0.06\ \text{m})4\ 186\ \text{J/kg}\cdot{}^\circ\text{C}} = \boxed{33.4^\circ\text{C}}$$

For the larger,

$$\Delta T = \frac{0.91\left(25\ \text{J/s}\cdot\text{m}^2\right)480\ \text{s}}{\left(0.12/\text{m}^2\right)4\ 186\ \text{J/}^\circ\text{C}} = \boxed{21.7^\circ\text{C}}$$

P34.25 (a) $B_{\max} = \dfrac{E_{\max}}{c}$: $\quad B_{\max} = \dfrac{7.00 \times 10^5 \text{ N/C}}{3.00 \times 10^8 \text{ m/s}} = \boxed{2.33 \text{ mT}}$

(b) $I = \dfrac{E_{\max}^2}{2\mu_0 c}$: $\quad I = \dfrac{\left(7.00 \times 10^5\right)^2}{2\left(4\pi \times 10^{-7}\right)\left(3.00 \times 10^8\right)} = \boxed{650 \text{ MW/m}^2}$

(c) $I = \dfrac{\mathcal{P}}{A}$: $\quad \mathcal{P} = IA = \left(6.50 \times 10^8 \text{ W/m}^2\right)\left[\dfrac{\pi}{4}\left(1.00 \times 10^{-3} \text{ m}\right)^2\right] = \boxed{510 \text{ W}}$

P34.26 (a) $E = cB = \left(3.00 \times 10^8 \text{ m/s}\right)\left(1.80 \times 10^{-6} \text{ T}\right) = \boxed{540 \text{ V/m}}$

(b) $u_{\text{av}} = \dfrac{B^2}{\mu_0} = \dfrac{\left(1.80 \times 10^{-6}\right)^2}{4\pi \times 10^{-7}} = \boxed{2.58 \ \mu\text{J/m}^3}$

(c) $S_{\text{av}} = cu_{\text{av}} = \left(3.00 \times 10^8\right)\left(2.58 \times 10^{-6}\right) = \boxed{773 \text{ W/m}^2}$

***P34.27** (a) We assume that the starlight moves through space without any of it being absorbed. The radial distance is

$$20 \text{ ly} = 20c(1 \text{ yr}) = 20\left(3 \times 10^8 \text{ m/s}\right)\left(3.156 \times 10^7 \text{ s}\right) = 1.89 \times 10^{17} \text{ m}$$

$$I = \frac{\mathcal{P}}{4\pi r^2} = \frac{4 \times 10^{28} \text{ W}}{4\pi\left(1.89 \times 10^{17} \text{ m}\right)^2} = \boxed{8.88 \times 10^{-8} \text{ W/m}^2}$$

(b) The Earth presents the projected target area of a flat circle:

$$\mathcal{P} = IA = \left(8.88 \times 10^{-8} \text{ W/m}^2\right)\pi\left(6.37 \times 10^6 \text{ m}\right)^2 = \boxed{1.13 \times 10^7 \text{ W}}$$

Section 34.5 **Momentum and Radiation Pressure**

***P34.28** (a) The radiation pressure is $\dfrac{2\left(1\,370 \text{ W/m}^2\right)}{3.00 \times 10^8 \text{ m/s}^2} = 9.13 \times 10^{-6} \text{ N/m}^2$.

Multiplying by the total area, $A = 6.00 \times 10^5 \text{ m}^2$ gives: $F = \boxed{5.48 \text{ N}}$.

(b) The acceleration is: $\quad a = \dfrac{F}{m} = \dfrac{5.48 \text{ N}}{6\,000 \text{ kg}} = \boxed{9.13 \times 10^{-4} \text{ m/s}^2}$

(c) It will arrive at time t where $d = \dfrac{1}{2}at^2$

or $\quad t = \sqrt{\dfrac{2d}{a}} = \sqrt{\dfrac{2\left(3.84 \times 10^8 \text{ m}\right)}{\left(9.13 \times 10^{-4} \text{ m/s}^2\right)}} = 9.17 \times 10^5 \text{ s} = \boxed{10.6 \text{ days}}$

P34.29 For complete absorption, $P = \dfrac{S}{c} = \dfrac{25.0}{3.00 \times 10^8} = \boxed{83.3 \text{ nPa}}$.

***P34.30** (a) The magnitude of the momentum transferred to the assumed totally reflecting surface in time t is $p = 2T_{ER}/c = 2SAt/c$. Then the vector momentum is

$$\vec{\mathbf{p}} = 2\vec{\mathbf{S}}At/c = 2(6\ \hat{\mathbf{i}}\ \text{W/m}^2)(40\times10^{-4}\ \text{m}^2)(1\ \text{s})/(3\times10^8\ \text{m/s})$$

$$= \boxed{1.60\times10^{-10}\,\hat{\mathbf{i}}\ \text{kg}\cdot\text{m/s each second}}$$

(b) The pressure on the assumed totally reflecting surface is $P = 2S/c$. Then the force is

$PA\hat{\mathbf{i}} = 2SA\hat{\mathbf{i}}/c = 2(6\ \text{W/m}^2)(40\times10^{-4}\ \text{m}^2)(1\ \text{s})/(3\times10^8\ \text{m/s}) = \boxed{1.60\times10^{-10}\,\hat{\mathbf{i}}\ \text{N}}$

(c) The answers are the same. Force is the time rate of momentum transfer.

P34.31 $I = \dfrac{\mathcal{P}}{\pi r^2} = \dfrac{E_{\max}^2}{2\mu_0 c}$

(a) $E_{\max} = \sqrt{\dfrac{\mathcal{P}(2\mu_0 c)}{\pi r^2}} = \boxed{1.90\ \text{kN/C}}$

(b) $\dfrac{15\times10^{-3}\ \text{J/s}}{3.00\times10^8\ \text{m/s}}(1.00\ \text{m}) = \boxed{50.0\ \text{pJ}}$

(c) $p = \dfrac{U}{c} = \dfrac{5\times10^{-11}}{3.00\times10^8} = \boxed{1.67\times10^{-19}\ \text{kg}\cdot\text{m/s}}$

***P34.32** (a) The light pressure on the absorbing Earth is $P = \dfrac{S}{c} = \dfrac{I}{c}$.

The force is $F = PA = \dfrac{I}{c}\left(\pi R^2\right) = \dfrac{(1370\ \text{W/m}^2)\pi(6.37\times10^6\ \text{m})^2}{3.00\times10^8\ \text{m/s}} = \boxed{5.82\times10^8\ \text{N}}$ away from the Sun.

(b) The attractive gravitational force exerted on Earth by the Sun is

$$F_g = \frac{GM_S M_M}{r_M^2} = \frac{\left(6.67\times10^{-11}\ \text{N}\cdot\text{m}^2/\text{kg}^2\right)\left(1.991\times10^{30}\ \text{kg}\right)\left(5.98\times10^{24}\ \text{kg}\right)}{\left(1.496\times10^{11}\ \text{m}\right)^2}$$

$$= 3.55\times10^{22}\ \text{N}$$

which is $\boxed{6.10\times10^{13}\ \text{times stronger and in the opposite direction}}$ compared to the repulsive force in part (a).

***P34.33** (a) If $\mathcal{P}_S$ is the total power radiated by the Sun, and r_E and r_M are the radii of the orbits of the planets Earth and Mars, then the intensities of the solar radiation at these planets are:

$$I_E = \frac{\mathcal{P}_S}{4\pi r_E^2}$$

and $$I_M = \frac{\mathcal{P}_S}{4\pi r_M^2}$$

Thus, $$I_M = I_E\left(\frac{r_E}{r_M}\right)^2 = \left(1\,370\text{ W/m}^2\right)\left(\frac{1.496\times10^{11}\text{ m}}{2.28\times10^{11}\text{ m}}\right)^2 = \boxed{590\text{ W/m}^2}$$

(b) Mars intercepts the power falling on its circular face:

$$\mathcal{P}_M = I_M\left(\pi R_M^2\right) = \left(590\text{ W/m}^2\right)\left[\pi\left(3.37\times10^6\text{ m}\right)^2\right] = \boxed{2.10\times10^{16}\text{ W}}$$

(c) If Mars behaves as a perfect absorber, it feels pressure $P = \frac{S_M}{c} = \frac{I_M}{c}$

and force $$F = PA = \frac{I_M}{c}\left(\pi R_M^2\right) = \frac{\mathcal{P}_M}{c} = \frac{2.10\times10^{16}\text{ W}}{3.00\times10^8\text{ m/s}} = \boxed{7.01\times10^7\text{ N}}$$

(d) The attractive gravitational force exerted on Mars by the Sun is

$$F_g = \frac{GM_SM_M}{r_M^2} = \frac{\left(6.67\times10^{-11}\text{ N}\cdot\text{m}^2/\text{kg}^2\right)\left(1.991\times10^{30}\text{ kg}\right)\left(6.42\times10^{23}\text{ kg}\right)}{\left(2.28\times10^{11}\text{ m}\right)^2}$$

$$= 1.64\times10^{21}\text{ N}$$

which is $\boxed{\sim10^{13}\text{ times stronger}}$ than the repulsive force of part (c).

(e) The relationship between the gravitational force and the light-pressure force is similar at very different distances because both forces follow inverse-square laws. The force ratios are not identical for the two planets because of their different radii and densities.

P34.34 The radiation pressure on the disk is $P = \frac{S}{c} = \frac{I}{c} = \frac{F}{A} = \frac{F}{\pi r^2}$.

Then $F = \frac{\pi r^2 I}{c}$.

Take torques about the hinge: $\sum \tau = 0$

$$H_x(0) + H_y(0) - mgr\sin\theta + \frac{\pi r^2 Ir}{c} = 0$$

$$\theta = \sin^{-1}\frac{\pi r^2 I}{mgc} = \sin^{-1}\frac{\pi(0.4\text{ m})^2\,10^7\text{ W s}^2\text{ s}}{(0.024\text{ kg})\text{ m}^2(9.8\text{ m})\left(3\times10^8\text{ m}\right)}\left(\frac{1\text{ kg m}^2}{1\text{ W s}^3}\right)$$

$$= \sin^{-1}0.0712 = \boxed{4.09°}$$

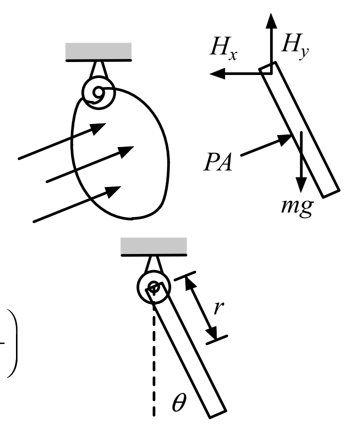


FIG. P34.34

Section 34.6 Production of Electromagnetic Waves by an Antenna

P34.35 $\lambda = \frac{c}{f} = 536\text{ m}$ so $h = \frac{\lambda}{4} = \boxed{134\text{ m}}$

$\lambda = \frac{c}{f} = 188\text{ m}$ so $h = \frac{\lambda}{4} = \boxed{46.9\text{ m}}$

P34.36 $\mathcal{P} = \dfrac{(\Delta V)^2}{R}$ or $\mathcal{P} \propto (\Delta V)^2$

$$\Delta V = (-)E_y \cdot \Delta y = E_y \cdot \ell \cos\theta$$

$\Delta V \propto \cos\theta$ so $\mathcal{P} \propto \cos^2\theta$

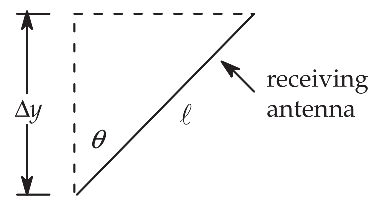


FIG. P34.36

(a) $\theta = 15.0°$: $\mathcal{P} = \mathcal{P}_{\max}\cos^2(15.0°) = 0.933\mathcal{P}_{\max} = \boxed{93.3\%}$

(b) $\theta = 45.0°$: $\mathcal{P} = \mathcal{P}_{\max}\cos^2(45.0°) = 0.500\mathcal{P}_{\max} = \boxed{50.0\%}$

(c) $\theta = 90.0°$: $\mathcal{P} = \mathcal{P}_{\max}\cos^2(90.0°) = \boxed{0}$

P34.37 (a) Constructive interference occurs when $d\cos\theta = n\lambda$ for some integer n.

$$\cos\theta = n\frac{\lambda}{d} = n\left(\frac{\lambda}{\lambda/2}\right) = 2n$$

$$n = 0,\ \pm1,\ \pm2,\ \ldots$$

$\therefore$ $\boxed{\text{strong signal @ } \theta = \cos^{-1} 0 = 90^\circ,\ 270^\circ}$

(b) Destructive interference occurs when

$$d\cos\theta = \left(\frac{2n+1}{2}\right)\lambda: \qquad \cos\theta = 2n+1$$

$\therefore$ $\boxed{\text{weak signal @ } \theta = \cos^{-1}(\pm1) = 0^\circ,\ 180^\circ}$

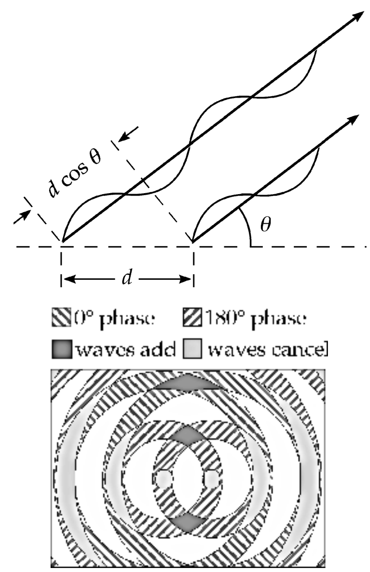


FIG. P34.37

P34.38 For the proton, $\Sigma F = ma$ yields $qvB\sin 90.0^\circ = \dfrac{mv^2}{R}$

The period of the proton's circular motion is therefore: $T = \dfrac{2\pi R}{v} = \dfrac{2\pi m}{qB}$

The frequency of the proton's motion is $f = \dfrac{1}{T}$

The charge will radiate electromagnetic waves at this frequency, with $\lambda = \dfrac{c}{f} = cT = \boxed{\dfrac{2\pi mc}{qB}}$

P34.39 (a) The magnetic field $\vec{\mathbf{B}} = \frac{1}{2}\mu_0 J_{\max}\cos(kx - \omega t)\hat{\mathbf{k}}$ applies for $x > 0$, since it describes a wave moving in the $\hat{\mathbf{i}}$ direction. The electric field direction must satisfy $\vec{\mathbf{S}} = \frac{1}{\mu_0}\vec{\mathbf{E}} \times \vec{\mathbf{B}}$ as $\hat{\mathbf{i}} = \hat{\mathbf{j}} \times \hat{\mathbf{k}}$ so the direction of the electric field is $\hat{\mathbf{j}}$ when the cosine is positive. For its magnitude we have $E = cB$, so altogether we have $\boxed{\vec{\mathbf{E}} = \frac{1}{2}\mu_0 c J_{\max}\cos(kx - \omega t)\hat{\mathbf{j}}}$.

continued on next page

(b) $$\vec{\mathbf{S}} = \frac{1}{\mu_0}\vec{\mathbf{E}}\times\vec{\mathbf{B}} = \frac{1}{\mu_0}\frac{1}{4}\mu_0^2 c J_{\max}^2 \cos^2(kx-\omega t)\hat{\mathbf{i}}$$

$$\boxed{\vec{\mathbf{S}} = \frac{1}{4}\mu_0 c J_{\max}^2 \cos^2(kx-\omega t)\hat{\mathbf{i}}}$$

(c) The intensity is the magnitude of the Poynting vector averaged over one or more cycles.

The average of the cosine-squared function is $\frac{1}{2}$, so $\boxed{I = \frac{1}{8}\mu_0 c J_{\max}^2}$.

(d) $$J_{\max} = \sqrt{\frac{8I}{\mu_0 c}} = \sqrt{\frac{8(570\ \text{W/m}^2)}{4\pi\times10^{-7}\,(\text{Tm/A})\,3\times10^8\ \text{m/s}}} = \boxed{3.48\ \text{A/m}}$$

Section 34.7 **The Spectrum of Electromagnetic Waves**

P34.40 From the electromagnetic spectrum chart and accompanying text discussion, the following identifications are made:

Frequency, f	Wavelength, $\lambda = \frac{c}{f}$	Classification
2 Hz = 2×10^0 Hz	150 Mm	Radio
2 kHz = 2×10^3 Hz	150 km	Radio
2 MHz = 2×10^6 Hz	150 m	Radio
2 GHz = 2×10^9 Hz	15 cm	Microwave
2 THz = 2×10^{12} Hz	150 μm	Infrared
2 PHz = 2×10^{15} Hz	150 nm	Ultraviolet
2 EHz = 2×10^{18} Hz	150 pm	X-ray
2 ZHz = 2×10^{21} Hz	150 fm	Gamma ray
2 YHz = 2×10^{24} Hz	150 am	Gamma ray

Wavelengh, λ	Frequency, $f = \frac{c}{\lambda}$	Classification
2 km = 2×10^3 m	1.5×10^5 Hz	Radio
2 m = 2×10^0 m	1.5×10^8 Hz	Radio
2 mm = 2×10^{-3} m	1.5×10^{11} Hz	Microwave
2 μm = 2×10^{-6} m	1.5×10^{14} Hz	Infrared
2 nm = 2×10^{-9} m	1.5×10^{17} Hz	Ultraviolet or X-ray
2 pm = 2×10^{-12} m	1.5×10^{20} Hz	X-ray or Gamma ray
2 fm = 2×10^{-15} m	1.5×10^{23} Hz	Gamma ray
2 am = 2×10^{-18} m	1.5×10^{26} Hz	Gamma ray

P34.41 (a) $f\lambda = c$ gives $\left(5.00\times10^{19}\text{ Hz}\right)\lambda = 3.00\times10^{8}\text{ m/s}$:

$\boxed{\lambda = 6.00\times10^{-12}\text{ m} = 6.00\text{ pm}}$

(b) $f\lambda = c$ gives $\left(4.00\times10^{9}\text{ Hz}\right)\lambda = 3.00\times10^{8}\text{ m/s}$:

$\boxed{\lambda = 0.075\text{ m} = 7.50\text{ cm}}$

P34.42 (a) $f = \dfrac{c}{\lambda} = \dfrac{3\times10^{8}\text{ m/s}}{1.7\text{ m}}$ $\boxed{\sim10^{8}\text{ Hz}}$ $\boxed{\text{radio wave}}$

(b) 1 000 pages, 500 sheets, is about 3 cm thick so one sheet is about 6×10^{-5} m thick.

$f = \dfrac{3.00\times10^{8}\text{ m/s}}{6\times10^{-5}\text{ m}}$ $\boxed{\sim10^{13}\text{ Hz}}$ $\boxed{\text{infrared}}$

***P34.43** (a) Channel 4: $f_{\min} = 66\text{ MHz}$ $\lambda_{\max} = \boxed{4.55\text{ m}}$

$f_{\max} = 72\text{ MHz}$ $\lambda_{\min} = \boxed{4.17\text{ m}}$

(b) Channel 6: $f_{\min} = 82\text{ MHz}$ $\lambda_{\max} = \boxed{3.66\text{ m}}$

$f_{\max} = 88\text{ MHz}$ $\lambda_{\min} = \boxed{3.41\text{ m}}$

(c) Channel 8: $f_{\min} = 180\text{ MHz}$ $\lambda_{\max} = \boxed{1.67\text{ m}}$

$f_{\max} = 186\text{ MHz}$ $\lambda_{\min} = \boxed{1.61\text{ m}}$

P34.44 The time for the radio signal to travel 100 km is: $\Delta t_r = \dfrac{100\times10^{3}\text{ m}}{3.00\times10^{8}\text{ m/s}} = 3.33\times10^{-4}\text{ s}$

The sound wave travels 3.00 m across the room in: $\Delta t_s = \dfrac{3.00\text{ m}}{343\text{ m/s}} = 8.75\times10^{-3}\text{ s}$

Therefore, $\boxed{\text{listeners 100 km away}}$ will receive the news before the people in the newsroom by a total time difference of $\Delta t = 8.75\times10^{-3}\text{ s} - 3.33\times10^{-4}\text{ s} = 8.41\times10^{-3}\text{ s}$.

P34.45 The wavelength of an ELF wave of frequency 75.0 Hz is $\lambda = \dfrac{c}{f} = \dfrac{3.00\times10^{8}\text{ m/s}}{75.0\text{ Hz}} = 4.00\times10^{6}\text{ m}$.

The length of a quarter-wavelength antenna would be $L = 1.00\times10^{6}\text{ m} = \boxed{1.00\times10^{3}\text{ km}}$

or $L = \left(1\,000\text{ km}\right)\left(\dfrac{0.621\text{ mi}}{1.00\text{ km}}\right) = \boxed{621\text{ mi}}$

Thus, while the project may be theoretically possible, it is not very practical.

Additional Problems

P34.46 $\omega = 2\pi f = 6.00\pi \times 10^9 \text{ s}^{-1} = 1.88 \times 10^{10} \text{ s}^{-1}$

$$k = \frac{2\pi}{\lambda} = \frac{\omega}{c} = \frac{6.00\pi \times 10^9 \text{ s}^{-1}}{3.00 \times 10^8 \text{ m/s}} = 20.0\pi = 62.8 \text{ m}^{-1} \qquad B_{\max} = \frac{E}{c} = \frac{300 \text{ V/m}}{3.00 \times 10^8 \text{ m/s}} = 1.00\ \mu\text{T}$$

$$\boxed{E = (300 \text{ V/m})\cos\left(62.8x - 1.88 \times 10^{10} t\right)} \qquad \boxed{B = (1.00\ \mu\text{T})\cos\left(62.8x - 1.88 \times 10^{10} t\right)}$$

***P34.47** (a) $\mathcal{P} = SA$: $\quad \mathcal{P} = \left(1\,370 \text{ W/m}^2\right)\left[4\pi\left(1.496 \times 10^{11} \text{ m}\right)^2\right] = \boxed{3.85 \times 10^{26} \text{ W}}$

(b) $S = \dfrac{cB_{\max}^2}{2\mu_0}$ so $B_{\max} = \sqrt{\dfrac{2\mu_0 S}{c}} = \sqrt{\dfrac{2\left(4\pi \times 10^{-7} \text{ N/A}^2\right)\left(1\,370 \text{ W/m}^2\right)}{3.00 \times 10^8 \text{ m/s}}} = \boxed{3.39\ \mu\text{T}}$

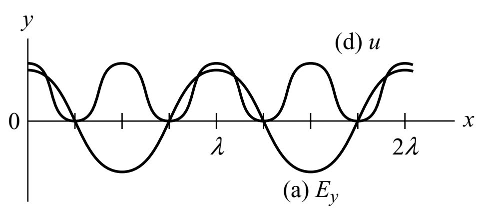
$S = \dfrac{E_{\max}^2}{2\mu_0 c}$ so $E_{\max} = \sqrt{2\mu_0 cS} = \sqrt{2\left(4\pi \times 10^{-7}\right)\left(3.00 \times 10^8\right)\left(1\,370\right)} = \boxed{1.02 \text{ kV/m}}$

***P34.48** Suppose you cover a 1.7 m × 0.3 m section of beach blanket. Suppose the elevation angle of the Sun is 60°. Then the target area you fill in the Sun's field of view is

$$(1.7 \text{ m})(0.3 \text{ m})\cos 30° = 0.4 \text{ m}^2$$

Now $I = \dfrac{\mathcal{P}}{A} = \dfrac{U}{At}$ $\qquad U = IAt = \left(1\,370 \text{ W/m}^2\right)\left[(0.6)(0.5)\left(0.4 \text{ m}^2\right)\right](3\,600 \text{ s}) \boxed{\sim 10^6 \text{ J}}$

***P34.49** (a)



(b) $u_E = \frac{1}{2}\epsilon_0 E^2 = \boxed{\frac{1}{2}\epsilon_0 E_{\max}^2 \cos^2(kx)}$

(c) $u_B = \dfrac{1}{2\mu_0}B^2 = \dfrac{1}{2\mu_0}B_{\max}^2\cos^2(kx) = \dfrac{1}{2\mu_0}\dfrac{E_{\max}^2}{c^2}\cos^2(kx) = \dfrac{\mu_0\epsilon_0}{2\mu_0}E_{\max}^2\cos^2(kx) = \boxed{u_E}$

(d) $u = u_E + u_B = \boxed{\epsilon_0 E_{\max}^2 \cos^2(kx)}$

(e)
$$E_\lambda = \int_0^\lambda \epsilon_0 E_{\max}^2 \cos^2(kx) A\,dx = \int_0^\lambda \epsilon_0 E_{\max}^2 \left[\tfrac{1}{2} + \tfrac{1}{2}\cos(2kx)\right] A\,dx$$
$$= \tfrac{1}{2}\epsilon_0 E_{\max}^2 A\,x\Big|_0^\lambda + \frac{\epsilon_0 E_{\max}^2 A}{4k}\sin(2kx)\Big|_0^\lambda = \tfrac{1}{2}\epsilon_0 E_{\max}^2 A\lambda + \frac{\epsilon_0 E_{\max}^2 A}{4k}\left[\sin(4\pi) - \sin(0)\right]$$
$$= \boxed{\tfrac{1}{2}\epsilon_0 E_{\max}^2 A\lambda}$$

(f) $I = \dfrac{E_\lambda}{AT} = \dfrac{\epsilon_0 E_{\max}^2 A\lambda}{2AT} = \boxed{\tfrac{1}{2}\epsilon_0 c E_{\max}^2}$

This result agrees with equation 34.24, $I = \dfrac{E_{\max}^2}{2\mu_0 c} = \dfrac{cE_{\max}^2}{2\mu_0 c^2} = \dfrac{cE_{\max}^2 \mu_0 \epsilon_0}{2\mu_0}$.

P34.50 (a) $F_{\text{grav}} = \dfrac{GM_S m}{R^2} = \left(\dfrac{GM_S}{R^2}\right)\left[\rho\left(\dfrac{4}{3}\pi r^3\right)\right]$

where M_S = mass of Sun, r = radius of particle, and R = distance from Sun to particle.

Since $F_{rad} = \dfrac{S\pi r^2}{c}$,

$$\frac{F_{rad}}{F_{\text{grav}}} = \left(\frac{1}{r}\right)\left(\frac{3SR^2}{4cGM_S\rho}\right) \propto \frac{1}{r}$$

(b) From the result found in part (a), when $F_{\text{grav}} = F_{rad}$,

we have $r = \dfrac{3SR^2}{4cGM_S\rho}$

$$r = \frac{3\left(214\ \text{W/m}^2\right)\left(3.75\times10^{11}\ \text{m}\right)^2}{4\left(6.67\times10^{-11}\ \text{N}\cdot\text{m}^2/\text{kg}^2\right)\left(1.991\times10^{30}\ \text{kg}\right)\left(1\,500\ \text{kg/m}^3\right)\left(3.00\times10^8\ \text{m/s}\right)}$$

$$= \boxed{3.78\times10^{-7}\ \text{m}}$$

P34.51 (a) $B_{\max} = \dfrac{E_{\max}}{c} = \boxed{6.67\times10^{-16}\ \text{T}}$

(b) $S_{\text{av}} = \dfrac{E_{\max}^2}{2\mu_0 c} = \boxed{5.31\times10^{-17}\ \text{W/m}^2}$

(c) $\mathcal{P} = S_{\text{av}}A = \boxed{1.67\times10^{-14}\ \text{W}}$

(d) $F = PA = \left(\dfrac{S_{\text{av}}}{c}\right)A = \boxed{5.56\times10^{-23}\ \text{N}}$ (approximately the weight of 3 000 hydrogen atoms!)

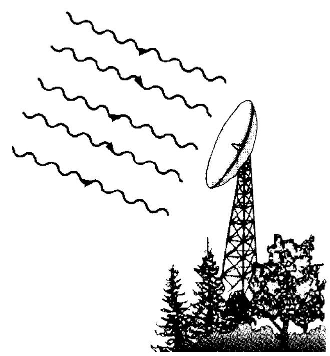


FIG. P34.51

***P34.52** (a) In $E = q/4\pi\epsilon_0 r^2$, the net flux is q/ϵ_0, so

$\vec{\mathbf{E}} = \Phi\,\hat{\mathbf{r}}/4\pi r^2 = (487\ \text{N}\cdot\text{m}^2/\text{C})\,\hat{\mathbf{r}}/4\pi r^2 = \boxed{(38.8/r^2)\,\hat{\mathbf{r}}\ \text{N}\cdot\text{m}^2/\text{C}}$

(b) The radiated intensity is $I = \mathcal{P}/4\pi r^2 = E^2_{\max}/2\mu_0 c$. Then

$E_{\max} = (\mathcal{P}\mu_0 c/2\pi)^{1/2}/r$

$= [(25\ \text{N}\cdot\text{m/s})(4\pi\times10^{-7}\ \text{T}\cdot\text{m}/2\pi\ \text{A})(3\times10^8\ \text{m/s})(1\ \text{N}\cdot\text{s}/1\ \text{T}\cdot\text{C}\cdot\text{m})(1\ \text{A}\cdot\text{s}/1\ \text{C})]^{1/2}/r$

$= \boxed{(38.7/r)\ \text{N}\cdot\text{m/C}}$

(c) For 3×10^6 N/C = (38.7 N·m/C)/r we find $r = \boxed{12.9\ \mu\text{m}}$, but the expression in part (b) does not apply if this point is inside the source.

(d) In the radiated wave, the field amplitude is inversely proportional to distance. As the distance doubles, the amplitude is cut in half and the intensity is reduced by a factor of 4. In the static case, the field is inversely proportional to the square of distance. As the distance doubles, the field is reduced by a factor of 4. The intensity of radiated energy is everywhere zero.

P34.53 $u = \frac{1}{2} \in_0 E_{\max}^2$ $\quad E_{\max} = \sqrt{\frac{2u}{\in_0}} = \boxed{95.1 \text{ mV/m}}$

P34.54 The area over which we model the antenna as radiating is the lateral surface of a cylinder,

$$A = 2\pi r\ell = 2\pi\left(4.00\times10^{-2} \text{ m}\right)\left(0.100 \text{ m}\right) = 2.51\times10^{-2} \text{ m}^2$$

(a) The intensity is then: $S = \frac{\mathcal{P}}{A} = \frac{0.600 \text{ W}}{2.51\times10^{-2} \text{ m}^2} = \boxed{23.9 \text{ W/m}^2}$.

(b) The standard is

$$0.570 \text{ mW/cm}^2 = 0.570\left(\text{mW/cm}^2\right)\left(\frac{1.00\times10^{-3} \text{ W}}{1.00 \text{ mW}}\right)\left(\frac{1.00\times10^4 \text{ cm}^2}{1.00 \text{ m}^2}\right) = 5.70 \text{ W/m}^2$$

While it is on, the telephone is over the standard by $\frac{23.9 \text{ W/m}^2}{5.70 \text{ W/m}^2} = \boxed{4.19 \text{ times}}$.

P34.55 (a) $B_{\max} = \frac{E_{\max}}{c} = \frac{175 \text{ V/m}}{3.00\times10^8 \text{ m/s}} = \boxed{5.83\times10^{-7} \text{ T}}$

$k = \frac{2\pi}{\lambda} = \frac{2\pi}{0.015\,0 \text{ m}} = \boxed{419 \text{ rad/m}}$ $\quad \omega = kc = \boxed{1.26\times10^{11} \text{ rad/s}}$

Since $\vec{\mathbf{S}}$ is along x, and $\vec{\mathbf{E}}$ is along y, $\vec{\mathbf{B}}$ must be in $\boxed{\text{the } z \text{ direction}}$. (That is, $\vec{\mathbf{S}} \propto \vec{\mathbf{E}}\times\vec{\mathbf{B}}$.)

(b) $S_{av} = \frac{E_{\max}B_{\max}}{2\mu_0} = 40.6 \text{ W/m}^2$ $\quad \vec{\mathbf{S}}_{av} = \boxed{\left(40.6 \text{ W/m}^2\right)\hat{\mathbf{i}}}$

(c) $P_r = \frac{2S}{c} = \boxed{2.71\times10^{-7} \text{ N/m}^2}$

(d) $a = \frac{\sum F}{m} = \frac{PA}{m} = \frac{\left(2.71\times10^{-7} \text{ N/m}^2\right)\left(0.750 \text{ m}^2\right)}{0.500 \text{ kg}} = 4.06\times10^{-7} \text{ m/s}^2$

$\vec{\mathbf{a}} = \boxed{\left(406 \text{ nm/s}^2\right)\hat{\mathbf{i}}}$

***P34.56** Of the intensity $\quad S = 1\,370 \text{ W/m}^2$

the 38.0% that is reflected exerts a pressure $\quad P_1 = \frac{2S_r}{c} = \frac{2(0.380)S}{c}$

The absorbed light exerts pressure $\quad P_2 = \frac{S_a}{c} = \frac{0.620S}{c}$

Altogether the pressure at the subsolar point on Earth is

(a) $P_{\text{total}} = P_1 + P_2 = \frac{1.38S}{c} = \frac{1.38\left(1\,370 \text{ W/m}^2\right)}{3.00\times10^8 \text{ m/s}} = \boxed{6.30\times10^{-6} \text{ Pa}}$

(b) $\frac{P_a}{P_{\text{total}}} = \frac{1.01\times10^5 \text{ N/m}^2}{6.30\times10^{-6} \text{ N/m}^2} = \boxed{1.60\times10^{10} \text{ times smaller than atmospheric pressure}}$

P34.57 (a) $P = \frac{F}{A} = \frac{I}{c}$ $\qquad F = \frac{IA}{c} = \frac{\mathcal{P}}{c} = \frac{100 \text{ J/s}}{3.00\times10^{8} \text{ m/s}} = 3.33\times10^{-7} \text{ N} = (110 \text{ kg})a$

$a = 3.03\times10^{-9} \text{ m/s}^2$ and $\qquad x = \frac{1}{2}at^2$

$$t = \sqrt{\frac{2x}{a}} = 8.12\times10^{4} \text{ s} = \boxed{22.6 \text{ h}}$$

(b) $0 = (107 \text{ kg})v - (3.00 \text{ kg})(12.0 \text{ m/s} - v) = (107 \text{ kg})v - 36.0 \text{ kg}\cdot\text{m/s} + (3.00 \text{ kg})v$

$v = \frac{36.0}{110} = 0.327 \text{ m/s}$ $\qquad t = \boxed{30.6 \text{ s}}$

P34.58 The mirror intercepts power $\mathcal{P} = I_1A_1 = (1.00\times10^{3} \text{ W/m}^2)\left[\pi(0.500 \text{ m})^2\right] = 785 \text{ W}$.
In the image,

(a) $I_2 = \frac{\mathcal{P}}{A_2}$: $\qquad I_2 = \frac{785 \text{ W}}{\pi(0.020\,0 \text{ m})^2} = \boxed{625 \text{ kW/m}^2}$

(b) $I_2 = \frac{E_{\max}^2}{2\mu_0 c}$ so $\qquad E_{\max} = \sqrt{2\mu_0 cI_2} = \sqrt{2(4\pi\times10^{-7})(3.00\times10^{8})(6.25\times10^{5})}$

$$= \boxed{21.7 \text{ kN/C}}$$

$$B_{\max} = \frac{E_{\max}}{c} = \boxed{72.4 \ \mu\text{T}}$$

(c) $0.400\ \mathcal{P}\Delta t = mc\Delta T$

$$0.400(785 \text{ W})\Delta t = (1.00 \text{ kg})(4\,186 \text{ J/kg}\cdot{}^\circ\text{C})(100^\circ\text{C} - 20.0^\circ\text{C})$$

$$\Delta t = \frac{3.35\times10^{5} \text{ J}}{314 \text{ W}} = 1.07\times10^{3} \text{ s} = \boxed{17.8 \text{ min}}$$

P34.59 Think of light going up and being absorbed by the bead which presents a face area πr_b^2
The light pressure is $P = \frac{S}{c} = \frac{I}{c}$.

(a) $F_\ell = \frac{I\pi r_b^2}{c} = mg = \rho\frac{4}{3}\pi r_b^3 g$ $\qquad$ and $\qquad I = \frac{4\rho gc}{3}\left(\frac{3m}{4\pi\rho}\right)^{1/3} = \boxed{8.32\times10^{7} \text{ W/m}^2}$

(b) $\mathcal{P} = IA = (8.32\times10^{7} \text{ W/m}^2)\pi(2.00\times10^{-3} \text{ m})^2 = \boxed{1.05 \text{ kW}}$

P34.60 Think of light going up and being absorbed by the bead, which presents face area πr_b^2.

If we take the bead to be perfectly absorbing, the light pressure is $P = \dfrac{S_{\text{av}}}{c} = \dfrac{I}{c} = \dfrac{F_\ell}{A}$.

(a) $F_\ell = F_g$

so $$I = \frac{F_\ell c}{A} = \frac{F_g c}{A} = \frac{mgc}{\pi r_b^2}$$

From the definition of density, $\rho = \dfrac{m}{V} = \dfrac{m}{(4/3)\pi r_b^3}$

so $$\frac{1}{r_b} = \left(\frac{(4/3)\pi\rho}{m}\right)^{1/3}$$

Substituting for r_b, $$I = \frac{mgc}{\pi}\left(\frac{4\pi\rho}{3m}\right)^{2/3} = gc\left(\frac{4\rho}{3}\right)^{2/3}\left(\frac{m}{\pi}\right)^{1/3} = \boxed{\frac{4\rho gc}{3}\left(\frac{3m}{4\pi\rho}\right)^{1/3}}$$

(b) $\mathcal{P} = IA$ $$\mathcal{P} = \boxed{\frac{4\pi r^2 \rho gc}{3}\left(\frac{3m}{4\pi\rho}\right)^{1/3}}$$

P34.61 (a) On the right side of the equation, $\dfrac{\text{C}^2(\text{m/s}^2)^2}{(\text{C}^2/\text{N}\cdot\text{m}^2)(\text{m/s})^3} = \dfrac{\text{N}\cdot\text{m}^2\cdot\text{C}^2\cdot\text{m}^2\cdot\text{s}^3}{\text{C}^2\cdot\text{s}^4\cdot\text{m}^3} = \dfrac{\text{N}\cdot\text{m}}{\text{s}} = \dfrac{\text{J}}{\text{s}} = \text{W}.$

(b) $F = ma = qE$ or $$a = \frac{qE}{m} = \frac{(1.60\times10^{-19}\text{ C})(100\text{ N/C})}{9.11\times10^{-31}\text{ kg}} = \boxed{1.76\times10^{13}\text{ m/s}^2}$$

The radiated power is then: $$\mathcal{P} = \frac{q^2a^2}{6\pi\epsilon_0 c^3} = \frac{(1.60\times10^{-19})^2(1.76\times10^{13})^2}{6\pi(8.85\times10^{-12})(3.00\times10^8)^3}$$
$$= \boxed{1.75\times10^{-27}\text{ W}}$$

(c) $F = ma_c = m\left(\dfrac{v^2}{r}\right) = qvB$ so $v = \dfrac{qBr}{m}$

The proton accelerates at $$a = \frac{v^2}{r} = \frac{q^2B^2r}{m^2} = \frac{(1.60\times10^{-19})^2(0.350)^2(0.500)}{(1.67\times10^{-27})^2}$$
$$= 5.62\times10^{14}\text{ m/s}^2$$

The proton then radiates $$\mathcal{P} = \frac{q^2a^2}{6\pi\epsilon_0 c^3} = \frac{(1.60\times10^{-19})^2(5.62\times10^{14})^2}{6\pi(8.85\times10^{-12})(3.00\times10^8)^3} = \boxed{1.80\times10^{-24}\text{ W}}$$

P34.62 $f = 90.0 \text{ MHz}, \; E_{\max} = 2.00 \times 10^{-3} \text{ V/m} = 200 \text{ mV/m}$

(a) $\lambda = \dfrac{c}{f} = \boxed{3.33 \text{ m}}$

$T = \dfrac{1}{f} = 1.11 \times 10^{-8} \text{ s} = \boxed{11.1 \text{ ns}}$

$B_{\max} = \dfrac{E_{\max}}{c} = 6.67 \times 10^{-12} \text{ T} = \boxed{6.67 \text{ pT}}$

(b) $\boxed{\vec{\mathbf{E}} = (2.00 \text{ mV/m}) \cos 2\pi \left(\dfrac{x}{3.33 \text{ m}} - \dfrac{t}{11.1 \text{ ns}} \right) \hat{\mathbf{j}}}$

$\boxed{\vec{\mathbf{B}} = (6.67 \text{ pT}) \hat{\mathbf{k}} \cos 2\pi \left(\dfrac{x}{3.33 \text{ m}} - \dfrac{t}{11.1 \text{ ns}} \right)}$

(c) $I = \dfrac{E_{\max}^2}{2\mu_0 c} = \dfrac{(2.00 \times 10^{-3})^2}{2(4\pi \times 10^{-7})(3.00 \times 10^8)} = \boxed{5.31 \times 10^{-9} \text{ W/m}^2}$

(d) $I = c u_{\text{av}}$ so $u_{\text{av}} = \boxed{1.77 \times 10^{-17} \text{ J/m}^3}$

(e) $P = \dfrac{2I}{c} = \dfrac{(2)(5.31 \times 10^{-9})}{3.00 \times 10^8} = \boxed{3.54 \times 10^{-17} \text{ Pa}}$

P34.63 (a) $\mathcal{E} = -\dfrac{d\Phi_B}{dt} = -\dfrac{d}{dt}(BA \cos\theta)$ $\quad \mathcal{E} = -A \dfrac{d}{dt}(B_{\max} \cos\omega t \cos\theta) = AB_{\max}\omega(\sin\omega t \cos\theta)$

$\mathcal{E}(t) = 2\pi f B_{\max} A \sin 2\pi f t \cos\theta$ $\quad \mathcal{E}(t) = 2\pi^2 r^2 f B_{\max} \cos\theta \sin 2\pi f t$

Thus, $\quad \boxed{\mathcal{E}_{\max} = 2\pi^2 r^2 f B_{\max} \cos\theta}$

where θ is the angle between the magnetic field and the normal to the loop.

(b) If $\vec{\mathbf{E}}$ is vertical, $\vec{\mathbf{B}}$ is horizontal, so $\boxed{\text{the plane of the loop should be vertical}}$

and $\boxed{\text{the plane should contain the line of sight of the transmitter}}$.

P34.64 (a) $m = \rho V = \rho \frac{1}{2}\frac{4}{3}\pi r^3$

$$r = \left(\frac{6m}{\rho 4\pi}\right)^{1/3} = \left(\frac{6(8.7\text{ kg})}{(990\text{ kg/m}^3)4\pi}\right)^{1/3} = \boxed{0.161\text{ m}}$$

(b) $A = \frac{1}{2}4\pi r^2 = 2\pi(0.161\text{ m})^2 = \boxed{0.163\text{ m}^2}$

(c) $I = e\sigma T^4 = 0.970\left(5.67\times10^{-8}\text{ W/m}^2\cdot\text{K}^4\right)(304\text{ K})^4 = \boxed{470\text{ W/m}^2}$

(d) $\mathcal{P} = IA = \left(470\text{ W/m}^2\right)0.163\text{ m}^2 = \boxed{76.8\text{ W}}$

(e) $I = \frac{E_{\text{max}}^2}{2\mu_0 c}$

$$E_{\text{max}} = \left(2\mu_0 cI\right)^{1/2} = \left[\left(8\pi\times10^{-7}\text{ Tm/A}\right)\left(3\times10^8\text{ m/s}\right)\left(470\text{ W/m}^2\right)\right]^{1/2} = \boxed{595\text{ N/C}}$$

(f) $E_{\text{max}} = cB_{\text{max}}$

$$B_{\text{max}} = \frac{595\text{ N/C}}{3\times10^8\text{ m/s}} = \boxed{1.98\ \mu\text{T}}$$

(g) The sleeping cats are uncharged and nonmagnetic. They carry no macroscopic current. They are a source of infrared radiation. They glow not by visible-light emission but by infrared emission.

(h) Each kitten has radius $r_k = \left(\frac{6(0.8)}{990\times4\pi}\right)^{1/3} = 0.072\,8\text{ m}$ and radiating area $2\pi(0.072\,8\text{ m})^2 = 0.033\,3\text{ m}^2$. Eliza has area $2\pi\left(\frac{6(5.5)}{990\times4\pi}\right)^{2/3} = 0.120\text{ m}$. The total glowing area is $0.120\text{ m}^2 + 4\left(0.033\,3\text{ m}^2\right) = 0.254\text{ m}^2$ and has power output

$$\mathcal{P} = IA = \left(470\text{ W/m}^2\right)0.254\text{ m}^2 = \boxed{119\text{ W}}$$

P34.65 (a) At steady state, $\mathcal{P}_{\text{in}} = \mathcal{P}_{\text{out}}$ and the power radiated out is $\mathcal{P}_{\text{out}} = e\sigma AT^4$.

Thus, $$0.900\left(1\,000\text{ W/m}^2\right)A = 0.700\left(5.67\times10^{-8}\text{ W/m}^2\cdot\text{K}^4\right)AT^4$$

or $$T = \left[\frac{900\text{ W/m}^2}{0.700\left(5.67\times10^{-8}\text{ W/m}^2\cdot\text{K}^4\right)}\right]^{1/4} = \boxed{388\text{ K}} = 115°\text{C}$$

(b) The box of horizontal area A presents projected area $A\sin50.0°$ perpendicular to the sunlight. Then by the same reasoning,

$$0.900\left(1\,000\text{ W/m}^2\right)A\sin50.0° = 0.700\left(5.67\times10^{-8}\text{ W/m}^2\cdot\text{K}^4\right)AT^4$$

or $$T = \left[\frac{\left(900\text{ W/m}^2\right)\sin50.0°}{0.700\left(5.67\times10^{-8}\text{ W/m}^2\cdot\text{K}^4\right)}\right]^{1/4} = \boxed{363\text{ K}} = 90.0°\text{C}$$

P34.66 We take R to be the planet's distance from its star. The planet, of radius r, presents a $\boxed{\text{projected area } \pi r^2}$ perpendicular to the starlight. $\boxed{\text{It radiates over area } 4\pi r^2.}$

At steady-state, $\mathcal{P}_{\text{in}} = \mathcal{P}_{\text{out}}$: $\quad eI_{\text{in}}\left(\pi r^2\right) = e\sigma\left(4\pi r^2\right)T^4$

$$e\left(\frac{6.00\times10^{23}\ \text{W}}{4\pi R^2}\right)\left(\pi r^2\right) = e\sigma\left(4\pi r^2\right)T^4 \text{ so that } 6.00\times10^{23}\ \text{W} = 16\pi\sigma R^2T^4$$

$$R = \sqrt{\frac{6.00\times10^{23}\ \text{W}}{16\pi\sigma T^4}} = \sqrt{\frac{6.00\times10^{23}\,\text{W}}{16\pi\left(5.67\times10^{-8}\ \text{W/m}^2\cdot\text{K}^4\right)(310\ \text{K})^4}} = \boxed{4.77\times10^9\,\text{m} = 4.77\ \text{Gm}}$$

ANSWERS TO EVEN PROBLEMS

P34.2 (a) $7.19\times10^{11}\ \text{V/m}\cdot\text{s}$ (b) $200\ \text{nT}$

P34.4 (a) $3.15\hat{\mathbf{j}}\ \text{kN/C}$ (b) $525\ \text{nT}\hat{\mathbf{k}}$ (c) $-483\hat{\mathbf{j}}\ \text{aN}$

P34.6 $\left(-4.39\hat{\mathbf{i}} - 1.76\hat{\mathbf{j}}\right)10^{11}\ \text{m/s}^2$

P34.8 $2.25\times10^8\ \text{m/s}$

P34.10 733 nT

P34.12 See the solution.

P34.14 $2.9\times10^8\ \text{m/s}\pm5\%$

P34.16 49.5 mV

P34.18 (a) 6.75 W/m^2 (b) 6.64 kW/m^2 (c) A powerful automobile running on sunlight would have to carry on its roof a solar panel huge compared to the size of the car. Agriculture and forestry for food and fuels, space heating of large and small buildings, water heating, and heating for drying and many other processes are clear present and potential applications of solar energy.

P34.20 516 pT, $\sim10^5$ times stronger than the Earth's field

P34.22 (a) 11.9 GW/m^2 (b) 234 kW

P34.24 33.4°C for the smaller container and 21.7°C for the larger

P34.26 (a) 540 V/m (b) 2.58 μJ/m^3 (c) 773 W/m^2

P34.28 (a) 5.48 N away from the Sun (b) 913 μm/s^2 away from the Sun (c) 10.6 d

P34.30 (a) $1.60\times10^{-10}\ \hat{\mathbf{i}}$ kg·m/s each second (b) $1.60\times10^{-10}\ \hat{\mathbf{i}}$ N (c) The answers are the same. Force is the time rate of momentum transfer.

P34.32 (a) 582 MN away from the Sun (b) The gravitational force is 6.10×10^{13} times stronger and in the opposite direction.

P34.34 4.09°

P34.36 (a) 93.3% (b) 50.0% (c) 0

P34.38 $\dfrac{2\pi m_p c}{eB}$

P34.40 radio, radio, radio, radio or microwave, infrared, ultraviolet, x-ray, γ-ray, γ-ray; radio, radio, microwave, infrared, ultraviolet or x-ray, x- or γ-ray, γ-ray, γ-ray

P34.42 (a) $\sim 10^8$ Hz radio wave (b) $\sim 10^{13}$ Hz infrared light

P34.44 The radio audience gets the news 8.41 ms sooner.

P34.46 $E = (300\ \text{V/m})\cos(62.8x - 1.88\times 10^{10}t)$ $B = (1.00\ \mu\text{T})\cos(62.8x - 1.88\times 10^{10}t)$

P34.48 $\sim 10^6$ J

P34.50 (a) See the solution. (b) 378 nm

P34.52 (a) $\vec{\mathbf{E}} = (38.8/r^2)\,\hat{\mathbf{r}}\ \text{N}\cdot\text{m}^2/\text{C}$ (b) $E_{\text{max}} = (38.7/r)\ (\text{W}\cdot\text{T}\cdot\text{m}^2/\text{A}\cdot\text{s})^{1/2} = (38.7/r)\ \text{N}\cdot\text{m/C}$
(c) 12.9 μm, but the expression in part (b) does not apply if this point is inside the source.
(d) In the radiated wave, the field amplitude is inversely proportional to distance. As the distance doubles, the amplitude is cut in half and the intensity is reduced by a factor of 4. In the static case, the field is inversely proportional to the square of distance. As the distance doubles, the field is reduced by a factor of 4. The intensity of radiated energy is everywhere zero in the static case.

P34.54 (a) $23.9\ \text{W/m}^2$ (b) 4.19 times the standard

P34.56 (a) 6.30 μPa (b) 1.60×10^{10} times less than atmospheric pressure

P34.58 (a) $625\ \text{kW/m}^2$ (b) 21.7 kN/C and 72.4 μT (c) 17.8 min

P34.60 (a) $\left(\dfrac{16m\rho^2}{9\pi}\right)^{1/3} gc$ (b) $\left(\dfrac{16\pi^2 m\rho^2}{9}\right)^{1/3} r^2 gc$

P34.62 (a) 3.33 m, 11.1 ns, 6.67 pT (b) $\vec{\mathbf{E}} = (2.00\ \text{mV/m})\cos 2\pi\left(\dfrac{x}{3.33\ \text{m}} - \dfrac{t}{11.1\ \text{ns}}\right)\hat{\mathbf{j}}$;

$\vec{\mathbf{B}} = (6.67\ \text{pT})\hat{\mathbf{k}}\cos 2\pi\left(\dfrac{x}{3.33\ \text{m}} - \dfrac{t}{11.1\ \text{ns}}\right)$ (c) $5.31\ \text{nW/m}^2$ (d) $1.77\times 10^{-17}\ \text{J/m}^3$

(e) 3.54×10^{-17} Pa

P34.64 (a) 16.1 cm (b) 0.163 m^2 (c) $470\ \text{W/m}^2$ (d) 76.8 W (e) 595 N/C (f) 1.98 μT
(g) The cats are nonmagnetic and carry no macroscopic charge or current. Oscillating charges within molecules make them emit infrared radiation. (h) 119 W

P34.66 πr^2; $4\pi r^2$ where r is the radius of the planet; 4.77 Gm