Chapter 34 Solutions

34.1 Since the light from this star travels at 3.00×10^8 m/s, the last bit of light will hit the Earth in $\dfrac{6.44 \times 10^{18}\ \text{m}}{3.00 \times 10^8\ \text{m/s}} = 2.15 \times 10^{10}$ s = 680 years. Therefore, it will disappear from the sky in the year 1999 + 680 = $\boxed{2.68 \times 10^3 \text{ A.D.}}$

34.2 $$v = \frac{1}{\sqrt{k\mu_0 e_0}} = \frac{1}{\sqrt{1.78}} c = 0.750c = \boxed{2.25 \times 10^8 \text{ m/s}}$$

34.3 $\dfrac{E}{B} = c$ or $\dfrac{220}{B} = 3.00 \times 10^8$; so $B = 7.33 \times 10^{-7}\ \text{T} = \boxed{733 \text{ nT}}$

34.4 $\dfrac{E_{max}}{B_{max}} = v$ is the generalized version of Equation 34.13.

$$B_{max} = \frac{E_{max}}{v} = \frac{7.60 \times 10^{-3}\ \text{V/m}}{(2/3)(3.00 \times 10^8\ \text{m/s})}\left(\frac{\text{N}\cdot\text{m}}{\text{V}\cdot\text{C}}\right)\left(\frac{\text{T}\cdot\text{C}\cdot\text{m}}{\text{N}\cdot\text{s}}\right) = 3.80 \times 10^{-11}\ \text{T} = \boxed{38.0 \text{ pT}}$$

34.5 (a) $f\lambda = c$ or $f(50.0\ \text{m}) = 3.00 \times 10^8$ m/s so $\boxed{f = 6.00 \times 10^6\ \text{Hz} = 6.00\ \text{MHz}}$

(b) $\dfrac{E}{B} = c$ or $\dfrac{22.0}{B_{max}} = 3.00 \times 10^8$ so $\mathbf{B}_{max} = \boxed{(73.3\ \text{nT})(-\mathbf{k})}$

(c) $k = \dfrac{2\pi}{\lambda} = \dfrac{2\pi}{50.0} = 0.126\ \text{m}^{-1}$ and $\omega = 2\pi f = 2\pi(6.00 \times 10^6\ \text{s}^{-1}) = 3.77 \times 10^7$ rad/s

$$\mathbf{B} = \mathbf{B}_{max}\cos(kx - \omega t) = \boxed{(73.3\ \text{nT})\cos(0.126x - 3.77 \times 10^7 t)(-\mathbf{k})}$$

34.6 $\omega = 2\pi f = 6.00\pi \times 10^9\ \text{s}^{-1} = 1.88 \times 10^{10}\ \text{s}^{-1}$

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

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

34.7 (a) $B = \frac{E}{c} = \frac{100 \text{ V/m}}{3.00 \times 10^{8} \text{ m/s}} = 3.33 \times 10^{-7} \text{ T} = \boxed{0.333\ \mu\text{T}}$

(b) $\lambda = \frac{2\pi}{k} = \frac{2\pi}{1.00 \times 10^{7} \text{ m}^{-1}} = \boxed{0.628\ \mu\text{m}}$

(c) $f = \frac{c}{\lambda} = \frac{3.00 \times 10^{8} \text{ m/s}}{6.28 \times 10^{-7} \text{ m}} = \boxed{4.77 \times 10^{14} \text{ Hz}}$

34.8 $E = E_{\max} \cos(kx - \omega t)$

$\frac{\partial E}{\partial x} = -E_{\max} \sin(kx - \omega t)(k)$ $\frac{\partial E}{\partial t} = -E_{\max} \sin(kx - \omega t)(-\omega)$

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

We must show: $\frac{\partial E}{\partial x^2} = \mu_0 \mathrm{e}_0 \frac{\partial^2 E}{\partial t^2}$

That is, $-\left(k^2\right) E_{\max} \cos\left(kx - \omega t\right) = -\mu_0 \mathrm{e}_0 (-\omega)^2 E_{\max} \cos\left(kx - \omega t\right)$

But this is true, because $\frac{k^2}{\omega^2} = \left(\frac{1}{f\lambda}\right)^2 = \frac{1}{c^2} = \mu_0 \mathrm{e}_0$

The proof for the wave of magnetic field is precisely similar.

***34.9** 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, $f = \frac{c}{\lambda} = \frac{3.00 \times 10^{8} \text{ m/s}}{4.00 \text{ m}} = 7.50 \times 10^{7} \text{ Hz} = \boxed{75.0 \text{ MHz}}$

***34.10** $d_{\text{A to A}} = 6 \text{ cm} \pm 5\% = \frac{\lambda}{2}$

$\lambda = 12 \text{ cm} \pm 5\%$

$$v = \lambda f = (0.12 \text{ m } \pm 5\%)(2.45 \times 10^9 \text{ s}^{-1}) = \boxed{2.9 \times 10^8 \text{ m/s } \pm 5\%}$$

34.11 $S = I = \dfrac{U}{At} = \dfrac{Uc}{V} = uc$

$$\frac{\text{Energy}}{\text{Unit Volume}} = u = \frac{I}{c} = \frac{1000 \text{ W/m}^2}{3.00 \times 10^8 \text{ m/s}} = \boxed{3.33 \ \mu\text{J/m}^3}$$

34.12 $S_{\text{av}} = \dfrac{\overline{\mathcal{P}}}{4\pi r^2} = \dfrac{4.00 \times 10^3 \text{ W}}{4\pi(4.00 \times 1609 \text{ m})^2} = 7.68 \ \mu\text{W/m}^2$

$$E_{\max} = \sqrt{2\mu_0 c S_{av}} = 0.0761 \text{ V/m}$$

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

34.13 $r = (5.00 \text{ mi})(1609 \text{ m/mi}) = 8.04 \times 10^3 \text{ m}$

$$S = \frac{\overline{\mathcal{P}}}{4\pi r^2} = \frac{250 \times 10^3 \text{ W}}{4\pi(8.04 \times 10^3 \text{ m})^2} = \boxed{307 \ \mu\text{W/m}^2}$$

Goal Solution

What is the average magnitude of the Poynting vector 5.00 miles from a radio transmitter broadcasting isotropically with an average power of 250 kW?

G: As the distance from the source is increased, the power per unit area will decrease, so at a distance of 5 miles from the source, the power per unit area will be a small fraction of the Poynting vector near the source.

O: The Poynting vector is the power per unit area, where A is the surface area of a sphere with a 5-mile radius.

A: The Poynting vector is $S_{av} = \frac{\mathcal{P}}{A} = \frac{\mathcal{P}}{4\pi r^2}$

In meters, $r = (5.00 \text{ mi})(1609 \text{ m / mi}) = 8045 \text{ m}$

and the magnitude is $S = \frac{250 \times 10^3 \text{ W}}{(4\pi)(8045)^2} = 3.07 \times 10^{-4} \text{ W / m}^2$

L: The magnitude of the Poynting vector ten meters from the source is 199 W / m^2, on the order of a million times larger than it is 5 miles away! It is surprising to realize how little power is actually received by a radio (at the 5-mile distance, the signal would only be about 30 nW, assuming a receiving area of about 1 cm^2).

34.14 $I = \frac{100 \text{ W}}{4\pi(1.00 \text{ m})^2} = 7.96 \text{ W / m}^2$

$u = \frac{I}{c} = 2.65 \times 10^{-8} \text{ J / m}^3 = 26.5 \text{ nJ / m}^3$

(a) $u_E = \frac{1}{2} u = \boxed{13.3 \text{ nJ / m}^3}$

(b) $u_B = \frac{1}{2} u = \boxed{13.3 \text{ nJ / m}^3}$

(c) $I = \boxed{7.96 \text{ W / m}^2}$

34.15 Power output = (power input)(efficiency)

Thus, Power input = $\frac{\text{power out}}{\text{eff}} = \frac{1.00 \times 10^6 \text{ W}}{0.300} = 3.33 \times 10^6 \text{ W}$

and $A = \frac{\mathcal{P}}{I} = \frac{3.33 \times 10^6 \text{ W}}{1.00 \times 10^3 \text{ W / m}^2} = \boxed{3.33 \times 10^3 \text{ m}^2}$

***34.16** $I = \dfrac{B_{\max}^2 c}{2\mu_0} = \dfrac{\mathcal{P}}{4\pi r^2}$

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

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

34.17 (a) $\mathcal{P} = I^2R = 150$ W; $A = 2\pi rL = 2\pi(0.900\times 10^{-3}\text{ m})(0.0800\text{ m}) = 4.52\times 10^{-4}\ \text{m}^2$

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

(b) $B = \mu_0 \dfrac{I}{2\pi r} = \dfrac{\mu_0(1.00)}{2\pi(0.900\times 10^{-3})} = \boxed{222\ \mu\text{T}}$

$E = \dfrac{\Delta V}{\Delta x} = \dfrac{IR}{L} = \dfrac{150\text{ V}}{0.0800\text{ m}} = \boxed{1.88\text{ kV/m}}$

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

34.18 (a) $\mathbf{E}\cdot\mathbf{B} = (80.0\mathbf{i} + 32.0\mathbf{j} - 64.0\mathbf{k})(\text{N/C})\cdot(0.200\mathbf{i} + 0.0800\mathbf{j} + 0.290\mathbf{k})\mu\text{T}$

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

(b) $$\mathbf{S} = \frac{1}{\mu_0}\,\mathbf{E}\times\mathbf{B} = \frac{(80.0\mathbf{i} + 32.0\mathbf{j} - 64.0\mathbf{k})(\text{N/C})\times(0.200\mathbf{i} + 0.0800\mathbf{j} + 0.290\mathbf{k})\mu\text{T}}{4\pi\times 10^{-7}\ \text{T}\cdot\text{m/A}}$$

$$\mathbf{S} = \frac{(6.40\mathbf{k} - 23.2\mathbf{j} - 6.40\mathbf{k} + 9.28\mathbf{i} - 12.8\mathbf{j} + 5.12\mathbf{i})10^{-6}\ \text{W/m}^2}{4\pi\times 10^{-7}}$$

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

34.19 We call the current I_{rms} and the intensity I. The power radiated at this frequency is

$$\mathcal{P} = (0.0100)(\Delta V_{\text{rms}})I_{\text{rms}} = \frac{0.0100(\Delta V_{\text{rms}})^2}{R} = 1.31\ \text{W}$$

If it is isotropic, the intensity one meter away is

$$I = \frac{\mathcal{P}}{A} = \frac{1.31\ \text{W}}{4\pi(1.00\ \text{m})^2} = 0.104\ \text{W/m}^2 = S_{\text{av}} = \frac{c}{2\mu_0}\ B_{\max}^2$$

$$B_{\max} = \sqrt{\frac{2\mu_0 I}{c}} = \sqrt{\frac{2\left(4\pi\times 10^{-7}\ \text{T}\cdot\text{m/A}\right)\left(0.104\ \text{W/m}^2\right)}{3.00\times 10^8\ \text{m/s}}} = \boxed{29.5\ \text{nT}}$$

***34.20** (a) $$\text{efficiency} = \frac{\text{useful power output}}{\text{total power input}}\times 100\% = \left(\frac{700\ \text{W}}{1400\ \text{W}}\right)\times 100\% = \boxed{50.0\%}$$

(b) $$S_{\text{av}} = \frac{\mathcal{P}}{A} = \frac{700\ \text{W}}{(0.0683\ \text{m})(0.0381\ \text{m})} = 2.69\times 10^5\ \text{W/m}^2$$

$$\mathbf{S}_{\text{av}} = \boxed{269\ \text{kW/m}^2 \text{ toward the oven chamber}}$$

(c) $$S_{\text{av}} = \frac{E_{\max}^2}{2\mu_0 c}$$

$$E_{\max} = \sqrt{2\left(4\pi\times 10^{-7}\ \frac{\text{T}\cdot\text{m}}{\text{A}}\right)\left(3.00\times 10^8\ \frac{\text{m}}{\text{s}}\right)\left(2.69\times 10^5\ \frac{\text{W}}{\text{m}^2}\right)} = 1.42\times 10^4\ \frac{\text{V}}{\text{m}} = \boxed{14.2\ \text{kV/m}}$$

34.21 (a) $B_{max} = \dfrac{E_{max}}{c} = \dfrac{7.00\times10^5 \text{ N/C}}{3.00\times10^8 \text{ m/s}} = \boxed{2.33 \text{ mT}}$

(b) $I = \dfrac{E_{max}^2}{2\mu_0 c} = \dfrac{(7.00\times10^5)^2}{2(4\pi\times10^{-7})(3.00\times10^8)} = \boxed{650 \text{ MW/m}^2}$

(c) $I = \dfrac{\mathcal{P}}{A}$: $\mathcal{P} = IA = (6.50\times10^8 \text{ W/m}^2)\dfrac{\pi}{4}(1.00\times10^{-3}\text{ m})^2 = \boxed{510 \text{ W}}$

34.22 Power $= SA = \dfrac{E_{max}^2}{2\mu_0 c}(4\pi r^2)$; solving for r, $r = \sqrt{\dfrac{\mathcal{P}\mu_0 c}{E_{max}^2 2\pi}} = \sqrt{\dfrac{(100\text{ W})\mu_0 c}{2\pi(15.0\text{ V/m})^2}} = \boxed{5.16 \text{ m}}$

34.23 (a) $I = \dfrac{(10.0\times10^{-3})\text{W}}{\pi(0.800\times10^{-3}\text{ m})^2} = \boxed{4.97 \text{ kW/m}^2}$

(b) $u_{av} = \dfrac{I}{c} = \dfrac{4.97\times10^3 \text{ J/m}^2\cdot\text{s}}{3.00\times10^8 \text{ m/s}} = \boxed{16.6\ \mu\text{J/m}^3}$

34.24 (a) $E = cB = (3.00\times10^8 \text{ m/s})(1.80\times10^{-6}\text{ T}) = \boxed{540 \text{ V/m}}$

(b) $u_{av} = \dfrac{B^2}{\mu_0} = \dfrac{(1.80\times10^{-6})^2}{4\pi\times10^{-7}} = \boxed{2.58\ \mu\text{J/m}^3}$

(c) $S_{av} = cu_{av} = (3.00\times10^8)(2.58\times10^{-6}) = \boxed{773 \text{ W/m}^2}$

(d) This is $\boxed{\text{77.3\% of the flux in Example 34.5}}$. It may be cloudy, or the Sun may be setting.

34.25 For complete absorption, $P = \dfrac{S}{c} = \dfrac{25.0}{3.00\times10^8} = \boxed{83.3 \text{ nPa}}$

***34.26** (a) $\mathcal{P} = (S_{av})(A) = (6.00 \text{ W/m}^2)(40.0\times10^{-4}\text{ m}^2) = 2.40\times10^{-2}\text{ J/s}$

In one second, the total energy U impinging on the mirror is 2.40×10^{-2} J. The momentum p transferred each second for total reflection is

$p = \dfrac{2U}{c} = \dfrac{2(2.40\times10^{-2}\text{ J})}{3.00\times10^8 \text{ m/s}} = \boxed{1.60\times10^{-10}\ \dfrac{\text{kg}\cdot\text{m}}{\text{s}}}$ (each second)

(b) $F = \dfrac{dp}{dt} = \dfrac{1.60\times10^{-10}\text{ kg}\cdot\text{m/s}}{1\text{ s}} = \boxed{1.60\times10^{-10}\text{ N}}$

34.27 (a) The radiation pressure is $\frac{(2)(1340\text{ W / m}^2)}{3.00\times 10^8\text{ m / s}^2} = 8.93\times 10^{-6}\text{ N / m}^2$

Multiplying by the total area, $A = 6.00\times 10^5\text{ m}^2$ gives: $F = \boxed{5.36\text{ N}}$

(b) The acceleration is: $a = \frac{F}{m} = \frac{5.36\text{ N}}{6000\text{ kg}} = \boxed{8.93\times 10^{-4}\text{ m/s}^2}$

(c) It will take a time t where: $d = \frac{1}{2}at^2$

or $t = \sqrt{\frac{2d}{a}} = \sqrt{\frac{2\left(3.84\times 10^8\text{ m}\right)}{\left(8.93\times 10^{-4}\text{ m / s}^2\right)}} = 9.27\times 10^5\text{ s} = \boxed{10.7\text{ days}}$

34.28 The pressure P upon the mirror is $P = \frac{2S_{av}}{c}$

where A is the cross-sectional area of the beam and $S_{av} = \frac{\mathcal{P}}{A}$

The force on the mirror is then $F = PA = \frac{2}{c}\left(\frac{\mathcal{P}}{A}\right)A = \frac{2\mathcal{P}}{c}$

Therefore, $F = \frac{2(100\times 10^{-3})}{(3\times 10^8)} = \boxed{6.67\times 10^{-10}\text{ N}}$

34.29 $I = \frac{\mathcal{P}}{\pi r^2} = \frac{E_{max}^2}{2\mu_0 c}$

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

(b) $\frac{15\times 10^{-3}\text{ J/s}}{3.00\times 10^8\text{ m/s}}(1.00\text{ m}) = \boxed{50.0\text{ pJ}}$

(c) $p = \frac{U}{c} = \frac{5\times 10^{-11}}{3.00\times 10^8} = \boxed{1.67\times 10^{-19}\text{ kg}\cdot\text{m/s}}$

34.30 (a) If 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:

$$I_E = \frac{P_S}{4\pi r_E^2} \qquad \text{and} \qquad I_M = \frac{P_S}{4\pi r_M^2}$$

Thus, $$I_M = I_E\left(\frac{r_E}{r_M}\right)^2 = \left(1340\ \text{W/m}^2\right)\left(\frac{1.496\times10^{11}\ \text{m}}{2.28\times10^{11}\ \text{m}}\right)^2 = \boxed{577\ \text{W/m}^2}$$

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

$$P_M = I_M\left(\pi R_M^2\right) = \left(577\ \text{W/m}^2\right)\pi\left(3.37\times10^6\ \text{m}\right)^2 = \boxed{2.06\times10^{16}\ \text{W}}$$

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

and force $F = PA = \frac{I_M}{c}\left(\pi R_M^2\right) = \frac{P_M}{c} = \frac{2.06\times10^{16}\ \text{W}}{3.00\times10^8\ \text{m/s}} = \boxed{6.87\times10^7\ \text{N}}$

(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 (c).

34.31 (a) The total energy absorbed by the surface is

$$U = \left(\tfrac{1}{2}I\right)At = \left[\tfrac{1}{2}\left(750\ \frac{\text{W}}{\text{m}^2}\right)\right]\left(0.500\times1.00\ \text{m}^2\right)\left(60.0\ \text{s}\right) = \boxed{11.3\ \text{kJ}}$$

(b) The total energy incident on the surface in this time is $2U = 22.5$ kJ, with $U = 11.3$ kJ being absorbed and $U = 11.3$ kJ being reflected. The total momentum transferred to the surface is

$$p = \left(\text{momentum from absorption}\right) + \left(\text{momentum from reflection}\right)$$

$$p = \left(\frac{U}{c}\right) + \left(\frac{2U}{c}\right) = \frac{3U}{c} = \frac{3\left(11.3\times10^3\ \text{J}\right)}{3.00\times10^8\ \text{m/s}} = \boxed{1.13\times10^{-4}\ \text{kg}\cdot\text{m/s}}$$

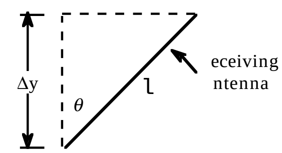
34.32 $S_{av} = \frac{\mu_0 J_{max}^2 c}{8}$ or $570 = \frac{(4\pi\times10^{-7})J_{max}^2(3.00\times10^8)}{8}$ so $\boxed{J_{max} = 3.48\ \text{A/m}^2}$

34.33 (a) $\mathcal{P} = S_{av}A = \left(\dfrac{\mu_0 J_{max}^2 c}{8}\right)A$

$$\mathcal{P} = \left(\frac{4\pi \times 10^{-7}(10.0)^2(3.00\times 10^8)}{8}\right)(1.20 \times 0.400) = \boxed{2.26\text{ kW}}$$

(b) $S_{av} = \dfrac{\mu_0 J_{max}^2 c}{8} = \dfrac{(4\pi \times 10^{-7}(10.0)^2(3.00\times 10^8)}{8} = \boxed{4.71\text{ kW/m}^2}$

***34.34** $\mathcal{P} = \dfrac{(\Delta V)^2}{R}$ or $\mathcal{P} \propto (\Delta V)^2$



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

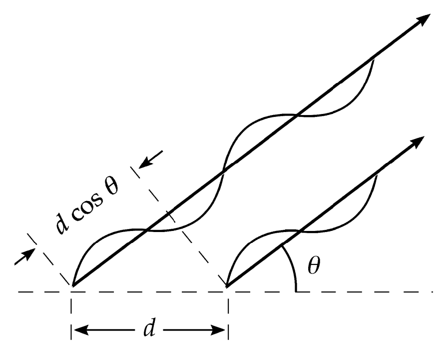
$\Delta V \propto \cos\theta$ so $\mathcal{P} \propto \cos^2\theta$

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

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

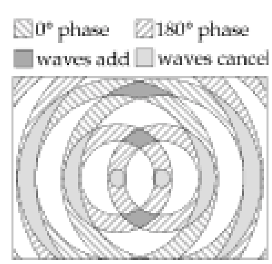


$\cos\theta = n\dfrac{\lambda}{d} = n\left(\dfrac{\lambda}{\lambda/2}\right) = 2n \quad n = 0, \pm 1, \pm 2, \ldots$

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

(b) Destructive interference occurs when

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



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

Goal Solution

Two radio-transmitting antennas are separated by half the broadcast wavelength and are driven in phase with each other. In which directions are (a) the strongest and (b) the weakest signals radiated?

G: The strength of the radiated signal will be a function of the location around the two antennas and will depend on the interference of the waves.

O: A diagram helps to visualize this situation. The two antennas are driven in phase, which means that they both create maximum electric field strength at the same time, as shown in the diagram. The radio EM waves travel radially outwards from the antennas, and the received signal will be the vector sum of the two waves.

A: (a) Along the perpendicular bisector of the line joining the antennas, the distance is the same to both transmitting antennas. The transmitters oscillate in phase, so along this line the two signals will be received in phase, constructively interfering to produce a maximum signal strength that is twice the amplitude of one transmitter.

(b) Along the extended line joining the sources, the wave from the more distant antenna must travel one-half wavelength farther, so the waves are received 180° out of phase. They interfere destructively to produce the weakest signal with zero amplitude.

L: Radio stations may use an antenna array to direct the radiated signal toward a highly-populated region and reduce the signal strength delivered to a sparsely-populated area.

34.36 $\lambda = \frac{c}{f} = 536 \text{ m}$ so $h = \frac{\lambda}{4} = \boxed{134 \text{ m}}$

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

34.37 For the proton: $\Sigma F = ma \Rightarrow qvB\sin 90.0° = mv^2/R$

The period and frequency of the proton's circular motion are therefore:

$$T = \frac{2\pi R}{v} = \frac{2\pi m}{qB} = \frac{2\pi(1.67\times10^{-27}\text{ kg})}{(1.60\times10^{-19}\text{ C})(0.350\text{ T})} = 1.87\times10^{-7}\text{ s} \qquad f = 5.34\times10^{6}\text{ Hz}.$$

The charge will radiate at this same frequency, with $\lambda = \frac{c}{f} = \frac{3.00\times10^{8}\text{ m/s}}{5.34\times10^{6}\text{ Hz}} = \boxed{56.2 \text{ m}}$

34.38 For the proton, $\Sigma F = ma$ yields $qvB\sin 90.0° = \frac{mv^2}{R}$

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

The frequency of the proton's motion is $f = 1/T$

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

***34.39** From the electromagnetic spectrum chart and accompanying text discussion, the following identifications are made:

Frequency f	Wavelength, $\lambda = c/f$	Classification
$2\text{ Hz} = 2\times10^{0}\text{ Hz}$	150 Mm	Radio
$2\text{ kHz} = 2\times10^{3}\text{ Hz}$	150 km	Radio
$2\text{ MHz} = 2\times10^{6}\text{ Hz}$	150 m	Radio
$2\text{ GHz} = 2\times10^{9}\text{ Hz}$	15 cm	Microwave
$2\text{ THz} = 2\times10^{12}\text{ Hz}$	150 μm	Infrared
$2\text{ PHz} = 2\times10^{15}\text{ Hz}$	150 nm	Ultraviolet
$2\text{ EHz} = 2\times10^{18}\text{ Hz}$	150 pm	x-ray
$2\text{ ZHz} = 2\times10^{21}\text{ Hz}$	150 fm	Gamma ray
$2\text{ YHz} = 2\times10^{24}\text{ Hz}$	150 am	Gamma Ray

Wavelength, λ	Frequency $f = c/\lambda$	Classification
$2\text{ km} = 2\times10^{3}\text{ m}$	$1.5\times10^{5}\text{ Hz}$	Radio
$2\text{ m} = 2\times10^{0}\text{ m}$	$1.5\times10^{8}\text{ Hz}$	Radio
$2\text{ mm} = 2\times10^{-3}\text{ m}$	$1.5\times10^{11}\text{ Hz}$	Microwave
$2\ \mu\text{m} = 2\times10^{-6}\text{ m}$	$1.5\times10^{14}\text{ Hz}$	Infrared
$2\text{ nm} = 2\times10^{-9}\text{ m}$	$1.5\times10^{17}\text{ Hz}$	Ultraviolet/x-ray
$2\text{ pm} = 2\times10^{-12}\text{ m}$	$1.5\times10^{20}\text{ Hz}$	x-ray/Gamma ray
$2\text{ fm} = 2\times10^{-15}\text{ m}$	$1.5\times10^{23}\text{ Hz}$	Gamma ray
$2\text{ am} = 2\times10^{-18}\text{ m}$	$1.5\times10^{26}\text{ Hz}$	Gamma ray

***34.40** (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) 1000 pages, 500 sheets, is about 3 cm thick so one sheet is about 6×10^{-5} m thick

$$f = \frac{3\times10^{8}\text{ m/s}}{6\times10^{-5}\text{ m}}\ \boxed{\sim10^{13}\text{ Hz}}\ \boxed{\text{infrared}}$$

***34.41** $f = \dfrac{c}{\lambda} = \dfrac{3.00\times10^{8}\text{ m/s}}{5.50\times10^{-7}\text{ m}} = \boxed{5.45\times10^{14}\text{ Hz}}$

34.42 (a) $\lambda = \dfrac{c}{f} = \dfrac{3.00\times10^{8}\text{ m/s}}{1150\times10^{3}/\text{s}} = 261\text{ m}$ so $\dfrac{180\text{ m}}{261\text{ m}} = \boxed{0.690\text{ wavelengths}}$

(b) $\lambda = \dfrac{c}{f} = \dfrac{3.00\times10^{8}\text{ m/s}}{98.1\times10^{6}/\text{s}} = 3.06\text{ m}$ so $\dfrac{180\text{ m}}{3.06\text{ m}} = \boxed{58.9\text{ wavelengths}}$

34.43 (a) $f\lambda = c$ gives $(5.00 \times 10^{19}\text{ Hz})\lambda = 3.00 \times 10^{8}\text{ m/s}$: $\boxed{\lambda = 6.00 \times 10^{-12}\text{ m} = 6.00\text{ pm}}$

(b) $f\lambda = c$ gives $(4.00 \times 10^{9}\text{ Hz})\lambda = 3.00 \times 10^{8}\text{ m/s}$: $\boxed{\lambda = 0.075\text{ m} = 7.50\text{ cm}}$

***34.44** Time to reach object $= \frac{1}{2}$(total time of flight) $= \frac{1}{2}(4.00 \times 10^{-4}\text{ s}) = 2.00 \times 10^{-4}\text{ s}$

Thus, $d = vt = (3.00 \times 10^{8}\text{ m/s})(2.00 \times 10^{-4}\text{ s}) = 6.00 \times 10^{4}\text{ m} = \boxed{60.0\text{ km}}$

34.45 The time for the radio signal to travel 100 km is: $t_r = \dfrac{100 \times 10^{3}\text{ m}}{3.00 \times 10^{8}\text{ m/s}} = 3.33 \times 10^{-4}\text{ s}$

The sound wave to travel 3.00 m across the room in: $t_s = \dfrac{3.00\text{ m}}{343\text{ m/s}} = 8.75 \times 10^{-3}\text{ s}$

Therefore, $\boxed{\text{listeners 100 km away}}$ will receive the news before the people in the newsroom by a total time difference of

$\Delta t = 8.75 \times 10^{-3}\text{ s} - 3.33 \times 10^{-4}\text{ s} = 8.41 \times 10^{-3}\text{ s}$

***34.46** The wavelength of an ELF wave of frequency 75.0 Hz is $\lambda = \dfrac{c}{f} = \dfrac{3.00 \times 10^{8}\text{ m/s}}{75.0\text{ Hz}} = 4.00 \times 10^{6}\text{ m}$

The length of a quarter-wavelength antenna would be $L = 1.00 \times 10^{6}\text{ m} = \boxed{1.00 \times 10^{3}\text{ km}}$

or $L = (1000\text{ km})\left(\dfrac{0.621\text{ mi}}{1.00\text{ km}}\right) = \boxed{621\text{ mi}}$

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

34.47 (a) For the AM band, $\lambda_{\max} = \dfrac{c}{f_{\min}} = \dfrac{3.00 \times 10^{8}\text{ m/s}}{540 \times 10^{3}\text{ Hz}} = \boxed{556\text{ m}}$

$$\lambda_{\min} = \frac{c}{f_{\max}} = \frac{3.00 \times 10^{8}\text{ m/s}}{1600 \times 10^{3}\text{ Hz}} = \boxed{187\text{ m}}$$

(b) For the FM band, $\lambda_{\max} = \dfrac{c}{f_{\min}} = \dfrac{3.00 \times 10^{8}\text{ m/s}}{88.0 \times 10^{6}\text{ Hz}} = \boxed{3.41\text{ m}}$

$$\lambda_{\min} = \frac{c}{f_{\max}} = \frac{3.00 \times 10^{8}\text{ m/s}}{108 \times 10^{6}\text{ Hz}} = \boxed{2.78\text{ m}}$$

34.48 CH_4: $f_{min} = 66$ MHz $\lambda_{max} = \boxed{4.55\text{ m}}$

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

CH_6: $f_{min} = 82$ MHz $\lambda_{max} = \boxed{3.66\text{ m}}$

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

CH_8: $f_{min} = 180$ MHz $\lambda_{max} = \boxed{1.67\text{ m}}$

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

34.49 (a) $\mathcal{P} = SA = (1340\text{ W/m}^2)4\pi(1.496\times10^{11}\text{ m})^2 = \boxed{3.77\times10^{26}\text{ W}}$

(b) $S = \dfrac{cB_{max}^2}{2\mu_0}$ so $B_{max} = \sqrt{\dfrac{2\mu_0 S}{c}} = \sqrt{\dfrac{2(4\pi\times10^{-7}\text{ N/A}^2)(1340\text{ W/m}^2)}{3.00\times10^8\text{ m/s}}} = \boxed{3.35\ \mu\text{T}}$

$S = \dfrac{E_{max}^2}{2\mu_0 c}$ so $E_{max} = \sqrt{2\mu_0 cS} = \sqrt{2\left(4\pi\times10^{-7}\right)\left(3.00\times10^8\right)(1340)} = \boxed{1.01\text{ kV/m}}$

***34.50** Suppose you cover a 1.7 m-by-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 $I = \dfrac{\mathcal{P}}{A} = \dfrac{E}{At}$: $E = IAt = 1340\ \dfrac{\text{W}}{\text{m}^2}(0.6)(0.5)(0.4\text{ m}^2)\ \ 3600\text{ s}\ \boxed{\sim10^6\text{ J}}$

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

$\mathcal{E}(t) = 2\pi fB_{max}A\sin 2\pi ft\cos\theta = 2\pi^2r^2fB_{max}\cos\theta\sin 2\pi ft$

Thus, $\boxed{\mathcal{E}_{max} = 2\pi^2r^2fB_{max}\cos\theta}$, where θ is the angle between the magnetic field and the normal to the loop.

(b) If **E** is vertical, then **B** is horizontal, so the $\boxed{\text{plane of the loop should be vertical}}$ and the $\boxed{\text{plane should contain the line of sight to the transmitter}}$.

34.52 (a) $F_{grav} = \frac{GM_s m}{R^2} = \left(\frac{GM_s}{R^2}\right)\rho(4/3)\pi r^3$

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

Since $F_{\text{rad}} = \frac{S\pi r^2}{c}$, $\quad \frac{F_{rad}}{F_{grav}} = \left(\frac{1}{r}\right)\left(\frac{3SR^2}{4cGM_s\rho}\right) \propto \frac{1}{r}$

(b) From the result found in part (a), when $F_{\text{grav}} = F_{\text{rad}}$, we have $\quad r = \frac{3SR^2}{4cGM_s\,\rho}$

$$r = \frac{3\left(214\text{ W/m}^2\right)\left(3.75\times10^{11}\text{ m}\right)^2}{4\left(6.67\times10^{-11}\text{ N}\cdot\text{m}^2/\text{kg}^2\right)\left(1.991\times10^{30}\text{ kg}\right)\left(1500\text{ kg/m}^3\right)\left(3.00\times10^8\text{ m/s}\right)} = \boxed{3.78\times10^{-7}\text{ m}}$$

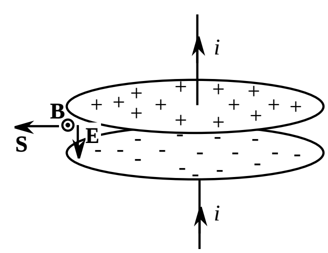
34.53 (a) $B_{\max} = \frac{E_{\max}}{c} = \boxed{6.67\times10^{-16}\text{ T}}$

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

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

(d) $F = PA = \left(\frac{S_{av}}{c}\right)A = \boxed{5.56\times10^{-23}\text{ N}}$ (≈ weight of 3000 H atoms!)

***34.54** (a) The electric field between the plates is $E = \Delta V/\ell$, directed downward in the figure. The magnetic field between the plate's edges is $B = \mu_0 i/2\pi r$ counterclockwise.



The Poynting vector is: $\quad \mathbf{S} = \frac{1}{\mu_0}\mathbf{E}\times\mathbf{B} = \boxed{\frac{(\Delta V)i}{2\pi r\ell}\text{ (radially outward)}}$

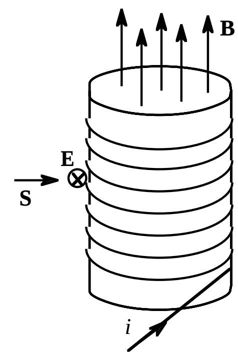
(b) The lateral surface area surrounding the electric field volume is

$A = 2\pi r\ell$, so the power output is $\mathcal{P} = SA = \left(\frac{(\Delta V)i}{2\pi r\ell}\right)(2\pi r\ell) = \boxed{(\Delta V)i}$

(c) As the capacitor charges, the polarity of the plates and hence the direction of the electric field is unchanged. Reversing the current reverses the direction of the magnetic field, and therefore the Poynting vector.

$\boxed{\text{The Poynting vector is now directed radially inward.}}$

***34.55** (a) The magnetic field in the enclosed volume is directed upward, with magnitude $B = \mu_0 ni$ and increasing at the rate $\frac{dB}{dt} = \mu_0 n \frac{di}{dt}$. The changing magnetic field induces an electric field around any circle of radius r, according to Faraday's Law:



$$E(2\pi r) = -\mu_0 n\left(\frac{di}{dt}\right)\left(\pi r^2\right) \qquad E = -\frac{\mu_0 nr}{2}\left(\frac{di}{dt}\right)$$

or $$\mathbf{E} = \frac{\mu_0 nr}{2}\left(\frac{di}{dt}\right) \text{ (clockwise)}$$

Then, $$\mathbf{S} = \frac{1}{\mu_0}\mathbf{E}\times\mathbf{B} = \frac{1}{\mu_0}\left[\frac{\mu_0 nr}{2}\left(\frac{di}{dt}\right)\right]\left(\mu_0 ni\right) \text{ inward,}$$

or the Poynting vector is $$\mathbf{S} = \boxed{\frac{\mu_0 n^2 ri}{2}\left(\frac{di}{dt}\right) \text{ (radially inward)}}$$

(b) The power flowing into the volume is $\mathcal{P} = SA_{\text{lat}}$ where A_{lat} is the lateral area perpendicular to $\mathbf{S}$. Therefore,

$$\mathcal{P} = \left[\frac{\mu_0 n^2 ri}{2}\left(\frac{di}{dt}\right)\right]\left(2\pi r\ell\right) = \boxed{\mu_0 \pi n^2 r^2 \ell i\left(\frac{di}{dt}\right)}$$

(c) Taking A_{cross} to be the cross-sectional area perpendicular to $\mathbf{B}$, the induced voltage between the ends of the inductor, which has $N = n\ell$ turns, is

$$\Delta V = |\mathcal{E}| = N\left(\frac{dB}{dt}\right)A_{\text{cross}} = n\ell\left(\mu_0 n\frac{di}{dt}\right)\left(\pi r^2\right) = \mu_0 \pi n^2 r^2 \ell\left(\frac{di}{dt}\right)$$

and it is observed that $\boxed{\mathcal{P} = (\Delta V)i}$

***34.56** (a) The power incident on the mirror is: $\mathcal{P}_I = IA = \left(1340\ \frac{\text{W}}{\text{m}^2}\right)\left[\pi(100\ \text{m})^2\right] = 4.21\times10^7\ \text{W}$

The power reflected through the atmosphere is $\mathcal{P}_R = 0.746\left(4.21\times10^7\ \text{W}\right) = \boxed{3.14\times10^7\ \text{W}}$

(b) $$S = \frac{\mathcal{P}_R}{A} = \frac{3.14\times10^7\ \text{W}}{\pi\left(4.00\times10^3\ \text{m}\right)^2} = \boxed{0.625\ \text{W/m}^2}$$

(c) Noon sunshine in Saint Petersburg produces this power-per-area on a horizontal surface:

$$\mathcal{P}_N = 0.746\left(1340\ \text{W / m}^2\right)\sin\ 7.00° = 122\ \text{W / m}^2$$

The radiation intensity received from the mirror is

$$\left(\frac{0.625\ \text{W/m}^2}{122\ \text{W/m}^2}\right)100\% = \boxed{0.513\%}$$ of that from the noon Sun in January.

34.57 $u = \frac{1}{2}\epsilon_0 E_{max}^2$ (Equation 34.21)

$$E_{max} = \sqrt{\frac{2u}{\epsilon_0}} = \boxed{95.1\text{ mV/m}}$$

***34.58** The area over which we model the antenna as radiating is the lateral surface of a cylinder,

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

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

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

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

$$k = \frac{2\pi}{\lambda} = \frac{2\pi}{(0.0150\text{ m})} = \boxed{419\text{ rad/m}}$$

$$\omega = kc = \boxed{1.26\times10^{11}\text{ rad/s}}$$

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

(b) $S_{av} = \frac{E_{max}B_{max}}{2\mu_0} = \boxed{40.6\text{ W/m}^2}$

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

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

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

Thus, $$0.900\left(1000\ \frac{\text{W}}{\text{m}^2}\right)A = (0.700)\left(5.67\times10^{-8}\ \frac{\text{W}}{\text{m}^2\cdot\text{K}^4}\right)AT^4$$

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 $A\sin 50.0°$ perpendicular to the sunlight. Then by the same reasoning,

$$0.900\left(1000\ \frac{\text{W}}{\text{m}^2}\right)A\sin 50.0° = (0.700)\left(5.67\times10^{-8}\ \frac{\text{W}}{\text{m}^2\cdot\text{K}^4}\right)AT^4$$

or $$T = \left[\frac{\left(900\ \text{W/m}^2\right)\sin 50.0°}{0.700\left(5.67\times10^{-8}\ \text{W/m}^2\cdot\text{K}^4\right)}\right]^{1/4} = \boxed{363\ \text{K}} = 90.0\ °\text{C}$$

34.61 (a) $P = \dfrac{F}{A} = \dfrac{I}{c}$

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

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

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

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

$$v = \frac{36.0}{110} = 0.327\ \text{m/s}$$

$t = \boxed{30.6\ \text{s}}$

Goal Solution

An astronaut, stranded in space 10.0 m from his spacecraft and at rest relative to it, has a mass (including equipment) of 110 kg. Since he has a 100-W light source that forms a directed beam, he decides to use the beam as a photon rocket to propel himself continuously toward the spacecraft. (a) Calculate how long it takes him to reach the spacecraft by this method. (b) Suppose, instead, he decides to throw the light source away in a direction opposite the spacecraft. If the mass of the light source has a mass of 3.00 kg and, after being thrown, moves at 12.0 m/s **relative to the recoiling astronaut**, how long does it take for the astronaut to reach the spacecraft?

G: Based on our everyday experience, the force exerted by photons is too small to feel, so it may take a very long time (maybe days!) for the astronaut to travel 10 m with his "photon rocket." Using the momentum of the thrown light seems like a better solution, but it will still take a while (maybe a few minutes) for the astronaut to reach the spacecraft because his mass is so much larger than the mass of the light source.

O: In part (a), the radiation pressure can be used to find the force that accelerates the astronaut toward the spacecraft. In part (b), the principle of conservation of momentum can be applied to find the time required to travel the 10 m.

A: (a) Light exerts on the astronaut a pressure $P = F/A = S/c$, and a force of

$$F = \frac{SA}{c} = \frac{\mathcal{P}}{c} = \frac{100\text{ J/s}}{3.00\times10^{8}\text{ m/s}} = 3.33\times10^{-7}\text{ N}$$

By Newton's 2nd law,

$$a = \frac{F}{m} = \frac{3.33\times10^{-7}\text{ N}}{110\text{ kg}} = 3.03\times10^{-9}\text{ m/s}^2$$

This acceleration is constant, so the distance traveled is $x = \frac{1}{2}at^2$, and the amount of time it travels is

$$t = \sqrt{\frac{2x}{a}} = \sqrt{\frac{2(10.0\text{ m})}{3.03\times10^{-9}\text{ m/s}^2}} = 8.12\times10^{4}\text{ s} = 22.6\text{ h}$$

(b) Because there are no external forces, the momentum of the astronaut before throwing the light is the same as afterwards when the now 107-kg astronaut is moving at speed v towards the spacecraft and the light is moving away from the spacecraft at $(12.0\text{ m/s} - v)$. Thus, $\mathbf{p}_i = \mathbf{p}_f$ gives

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

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

$$v = \frac{36.0}{110} = 0.327\text{ m/s}$$

$$t = \frac{x}{v} = \frac{10.0\text{ m}}{0.327\text{ m/s}} = 30.6\text{ s}$$

L: Throwing the light away is certainly a more expedient way to reach the spacecraft, but there is not much chance of retrieving the lamp unless it has a very long cord. How long would the cord need to be, and does its length depend on how hard the astronaut throws the lamp? (You should verify that the minimum cord length is 367 m, independent of the speed that the lamp is thrown.)

34.62 The 38.0% of the intensity $S = 1340\ \dfrac{\text{W}}{\text{m}^2}$ that is reflected exerts a pressure $P_1 = \dfrac{2S_r}{c} = \dfrac{2(0.380)S}{c}$

The absorbed light exerts pressure $P_2 = \dfrac{S_a}{c} = \dfrac{(0.620)S}{c}$

Altogether the pressure at the subsolar point on Earth is

(a) $P_{tot} = P_1 + P_2 = \dfrac{1.38S}{c} = \dfrac{1.38(1340\ \text{W/m}^2)}{3.00 \times 10^8\ \text{m/s}} = \boxed{6.16 \times 10^{-6}\ \text{Pa}}$

(b) $\dfrac{P_a}{P_{tot}} = \dfrac{1.01 \times 10^5\ \text{N/m}^2}{6.16 \times 10^{-6}\ \text{N/m}^2} = \boxed{1.64 \times 10^{10}\ \text{times smaller than atmospheric pressure}}$

34.63 Think of light going up and being absorbed by the bead which presents a face area πr_b^2.

The light pressure is $P = \dfrac{S}{c} = \dfrac{I}{c}$.

(a) $F_l = \dfrac{I\pi r_b^2}{c} = mg = \rho \dfrac{4}{3} \pi r_b^3 g$ and $I = \dfrac{4\rho gc}{3}\left(\dfrac{3m}{4\pi\rho}\right)^{1/3} = \boxed{8.32 \times 10^7\ \text{W/m}^2}$

(b) $\mathcal{P} = IA = (8.32 \times 10^7\ \text{W/m}^2)\pi(2.00 \times 10^{-3}\ \text{m})^2 = \boxed{1.05\ \text{kW}}$

34.64 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 $P = \dfrac{S_{av}}{c} = \dfrac{I}{c} = \dfrac{F_l}{A}$

(a) $F_l = F_g$ so $I = \dfrac{F_l c}{A} = \dfrac{F_g c}{A} = \dfrac{mgc}{\pi r_b^2}$

From the definition of density, $\rho = \dfrac{m}{V} = \dfrac{m}{\frac{4}{3}\pi r_b^3}$ so $\dfrac{1}{r_b} = \left(\frac{4}{3}\pi\rho/m\right)^{1/3}$

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

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

34.65 The mirror intercepts power

$$\mathcal{P} = I_1A_1 = (1.00\times10^3\ \text{W/m}^2)\pi(0.500\ \text{m})^2 = 785\ \text{W}$$

In the image,

(a) $I_2 = \dfrac{\mathcal{P}}{A_2} = \dfrac{785\ \text{W}}{\pi(0.0200\ \text{m})^2} = \boxed{625\ \text{kW/m}^2}$

(b) $I_2 = \dfrac{E_{\max}^2}{2\mu_0 c}$ so $E_{\max} = (2\mu_0 c\, I_2)^{1/2} = [2(4\pi\times10^{-7})(3.00\times10^8)(6.25\times10^5)]^{1/2} = \boxed{21.7\ \text{kN/C}}$

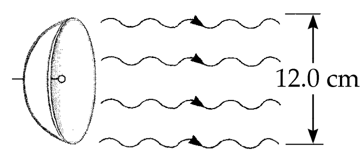
$B_{\max} = \dfrac{E_{\max}}{c} = \boxed{72.4\ \mu\text{T}}$

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

$0.400(785\ \text{W})t = (1.00\ \text{kg})\left(4186\ \dfrac{\text{J}}{\text{kg}\cdot\text{C}°}\right)(100°\text{C} - 20.0°\text{C})$

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

34.66 (a) $\lambda = \dfrac{c}{f} = \dfrac{3.00\times10^8\ \text{m/s}}{20.0\times10^9\ \text{s}^{-1}} = \boxed{1.50\ \text{cm}}$



(b) $U = \mathcal{P}(\Delta t) = \left(25.0\times10^3\ \dfrac{\text{J}}{\text{s}}\right)(1.00\times10^{-9}\ \text{s}) = 25.0\times10^{-6}\ \text{J} = \boxed{25.0\ \mu\text{J}}$

(c) $u_{\text{av}} = \dfrac{U}{V} = \dfrac{U}{(\pi r^2)l} = \dfrac{U}{(\pi r^2)c(\Delta t)} = \dfrac{25.0\times10^{-6}\ \text{J}}{\pi(0.0600\ \text{m})^2(3.00\times10^8\ \text{m/s})(1.00\times10^{-9}\ \text{s})}$

$u_{\text{av}} = 7.37\times10^{-3}\ \text{J/m}^3 = \boxed{7.37\ \text{mJ/m}^3}$

(d) $E_{\max} = \sqrt{\dfrac{2u_{\text{av}}}{\epsilon_0}} = \sqrt{\dfrac{2(7.37\times10^{-3}\ \text{J/m}^3)}{8.85\times10^{-12}\ \text{C}^2/\text{N}\cdot\text{m}^2}} = 4.08\times10^4\ \text{V m} = \boxed{40.8\ \text{kV/m}}$

$B_{\max} = \dfrac{E_{\max}}{c} = \dfrac{4.08\times10^4\ \text{V/m}}{3.00\times10^8\ \text{m/s}} = 1.36\times10^{-4}\ \text{T} = \boxed{136\ \mu\text{T}}$

(e) $F = PA = \left(\dfrac{S}{c}\right)A = \left(\dfrac{c\,u_{\text{av}}}{c}\right)A = u_{\text{av}}A = \left(7.37\times10^{-3}\ \dfrac{\text{J}}{\text{m}^3}\right)\pi(0.0600\ \text{m})^2 = 8.33\times10^{-5}\ \text{N} = \boxed{83.3\ \mu\text{N}}$

34.67 (a) On the right side of the equation, $\frac{C^2(m/s^2)^2}{(C^2/N\cdot m^2)(m/s)^3} = \frac{N\cdot m^2\cdot C^2\cdot m^2\cdot s^3}{C^2\cdot s^4\cdot m^3} = \frac{N\cdot m}{s} = \frac{J}{s} = W$

(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: $\mathcal{P} = \frac{q^2a^2}{6\pi\epsilon_0c^3} = \frac{(1.60\times10^{-19})^2(1.76\times10^{13})^2}{6\pi(8.85\times10^{-12})(3.00\times10^8)^3} = \boxed{1.75\times10^{-27}\text{ W}}$

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

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 $\mathcal{P} = \frac{q^2a^2}{6\pi\epsilon_0c^3} = \frac{(1.60\times10^{-19})^2(5.62\times10^{14})^2}{6\pi(8.85\times10^{-12})(3.00\times10^8)^3} = \boxed{1.80\times10^{-24}\text{ W}}$

34.68 $P = \frac{S}{c} = \frac{\text{Power}}{Ac} = \frac{\mathcal{P}}{2\pi r\ell c} = \frac{60.0\text{ W}}{2\pi(0.0500\text{ m})(1.00\text{ m})(3.00\times10^8\text{ m} \setminus \text{s})} = \boxed{6.37\times10^{-7}\text{ Pa}}$

34.69 $F = PA = \frac{SA}{c} = \frac{(\mathcal{P}/A)A}{c} = \frac{\mathcal{P}}{c}$, $\tau = F\left(\frac{\ell}{2}\right) = \frac{\mathcal{P}\ell}{2c}$, and $\tau = \kappa\theta$

Therefore, $\theta = \frac{\mathcal{P}\ell}{2c\kappa} = \frac{(3.00\times10^{-3})(0.0600)}{2(3.00\times10^8)(1.00\times10^{-11})} = \boxed{3.00\times10^{-2}\text{ deg}}$

***34.70** 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, $\mathcal{P}_{in} = \mathcal{P}_{out}$: $eI_{\text{in}}(\pi r^2) = e\sigma(4\pi r^2)T^4$

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

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

34.71 The light intensity is $I = S_{av} = \dfrac{E^2}{2\mu_0 c}$

The light pressure is $P = \dfrac{S}{c} = \dfrac{E^2}{2\mu_0 c^2} = \frac{1}{2}\epsilon_0 E^2$

For the asteroid, $PA = ma$ and $\boxed{a = \dfrac{\epsilon_0 E^2 A}{2m}}$

34.72 $f = 90.0\text{ MHz}$, $E_{max} = 2.00\times10^{-3}\text{ V/m} = 200\text{ mV/m}$

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

$T = \dfrac{1}{f} = 1.11\times10^{-8}\text{ s} = \boxed{11.1\text{ ns}}$

$B_{max} = \dfrac{E_{max}}{c} = 6.67\times10^{-12}\text{ T} = \boxed{6.67\text{ pT}}$

(b) $\boxed{\mathbf{E} = (2.00\text{ mV/m})\cos 2\pi\left(\dfrac{x}{3.33\text{ m}} - \dfrac{t}{11.1\text{ ns}}\right)\mathbf{j}}$ $\boxed{\mathbf{B} = (6.67\text{ pT})\mathbf{k}\cos 2\pi\left(\dfrac{x}{3.33\text{ m}} - \dfrac{t}{11.1\text{ ns}}\right)}$

(c) $I = \dfrac{E_{max}^2}{2\mu_0 c} = \dfrac{(2.00\times10^{-3})^2}{2(4\pi\times10^{-7})(3.00\times10^8)} = \boxed{5.31\times10^{-9}\text{ W/m}^2}$

(d) $I = cu_{av}$ so $u_{av} = \boxed{1.77\times10^{-17}\text{ J/m}^3}$

(e) $P = \dfrac{2I}{c} = \dfrac{(2)(5.31\times10^{-9})}{3.00\times10^8} = \boxed{3.54\times10^{-17}\text{ Pa}}$