CHAPTER 24

ANSWERS TO QUESTIONS

Q24.1 Acceleration of electric charge.

Q24.2 A wire connected to the terminals of a battery does not radiate electromagnetic waves. The battery establishes an electric field, which produces current in the wire. The current in the wire creates a magnetic field. Both fields are constant in time, so no electromagnetic induction or "magneto-electric induction" happens. Neither field creates a new cycle of the other field. No wave propagation occurs.

Q24.3 The Poynting vector **S** describes the energy flow associated with an electromagnetic wave. The direction of **S** is along the direction of propagation and the magnitude of **S** is the rate at which electromagnetic energy crosses a unit surface perpendicular to the direction of **S**.

Q24.4 The magnetic field of the solenoid induces eddy-currents in the conducting core. This is accompanied by I^2R conversion of electric energy into internal energy in the conductor.

Q24.5 Different stations have transmitting antennas at different locations. For best reception align your antenna along a straight-line path from your TV to the transmitting antenna.

Q24.6 No. Static electricity is just that. Without acceleration of the charge, there can be no electromagnetic wave.

Q24.7 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 do not absorb the microwave energy and remain cool to the touch.

Q24.8

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 focussed 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.

Q24.9 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 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.

Q24.10 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.

Q24.11 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.

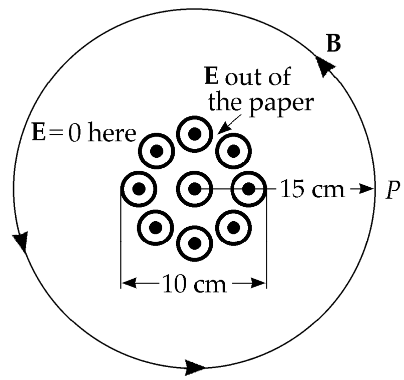
Q24.12 Welding produces ultraviolet light, along with lots of visible and infrared.

Q24.13 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 compared with the radius of the Earth. The distance across the lower forty-eight United States is about 5000 km, requiring travel time $(5\times10^6 \text{ m})/(3\times10^8 \text{ m/s}) \sim 10^{-2} \text{ s}$. To go halfway around the Earth takes only $7\times10^{-2} \text{ s}$. A speech can be heard on the other side of the world before it is heard in the back of the room.

Q24.14 The Sun's angular speed in our sky is our rate of rotation, $360°/24 \text{ h} = 15°/\text{h}$. In 8.3 minutes it moves west by $\theta = \omega t = (15° \ /\text{h})(1 \ \text{h}/60 \text{ min})(8.3 \text{ min}) = 2.1°$. This is about four times the angular diameter of the Sun.

PROBLEM SOLUTIONS

24.1 We use the extended form of Ampere's law, Equation 24.7. Since no moving charges are present,



$$I = 0$$

and we have $$\oint \mathbf{B} \cdot d\ell = \mu_0 \epsilon_0 \frac{d\Phi_E}{dt}$$

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, the 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 **B**, we integrate $\oint \mathbf{B} \cdot d\ell$ around the circle

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

to obtain $$2\pi RB$$

Differentiating the expression $$\Phi_E = AE$$

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

Thus, $$\oint \mathbf{B} \cdot d\ell = 2\pi RB = \mu_0 \epsilon_0 \left(\frac{\pi d^2}{4}\right)\frac{E}{dt}$$

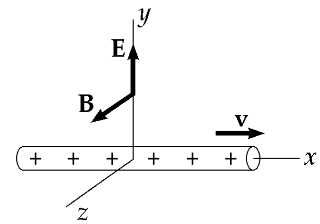
Solving for B gives $$B = \frac{\mu_0 \epsilon_0}{2\pi R}\left(\frac{\pi d^2}{4}\right)\frac{dE}{dt}$$

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

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

In Figure 24.1, 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 **B** is *counterclockwise*. Thus, the direction of **B** at P is upwards.

***24.2** (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:



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

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

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

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

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

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

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

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

***24.3** (a) Since the light from this star travels at $3.00\times10^8\text{ m/s}$

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

Therefore, it will disappear from the sky in the year $2002 + 680 = \boxed{2.68\times10^3\text{ C.E.}}$

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

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

24.4 $v = \dfrac{1}{\sqrt{\kappa\mu_0\epsilon_0}} = \dfrac{1}{\sqrt{1.78}}c = 0.750c = \boxed{2.25\times10^{8}\ \text{m/s}}$

24.5 (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 $\dfrac{22.0}{B_{\text{max}}} = 3.00\times10^{8}$

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

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

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

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

24.6 $\dfrac{E}{B} = c$

or $\dfrac{220}{B} = 3.00\times10^{8}$

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

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

24.8

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

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

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

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

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

We must show: $\dfrac{\partial E}{\partial x^2} = \mu_0\epsilon_0 \dfrac{\partial^2 E}{\partial t^2}$

That is, $-\left(k^2\right)E_{\max}\cos(kx - \omega t) = -\mu_0\epsilon_0(-\omega)^2 E_{\max}\cos(kx - \omega t)$

But this is true, because $\dfrac{k^2}{\omega^2} = \left(\dfrac{1}{f\lambda}\right)^2 = \dfrac{1}{c^2} = \mu_0\epsilon_0$

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

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

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

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

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

***24.11** (a) When the source moves away from an observer, the observed frequency is

$$f_{\text{observed}} = f_{\text{source}}\sqrt{\frac{c - v_s}{c + v_s}}$$

where $v_s = v_{\text{source}}$ is the negative of the velocity of approach.

When $v_s << c$, the binomial expansion gives

$$\left(\frac{c - v_s}{c + v_s}\right)^{1/2} = \left[1 - \left(\frac{v_s}{c}\right)\right]^{1/2}\left[1 + \left(\frac{v_s}{c}\right)\right]^{-1/2} \cong \left(1 - \frac{v_s}{2c}\right)\left(1 - \frac{v_s}{2c}\right) \cong \left(1 - \frac{v_s}{c}\right)$$

So, $f_{\text{observed}} \cong f_{\text{source}}\left(1 - \frac{v_s}{c}\right)$

The observed wavelength is found from $c = \lambda_{\text{observed}} f_{\text{observed}} = \lambda f_{\text{source}}$:

$$\lambda_{\text{observed}} = \frac{\lambda f_{\text{source}}}{f_{\text{observed}}} \cong \frac{\lambda f_{\text{source}}}{f_{\text{source}}\left(1 - \frac{v_s}{c}\right)} = \frac{\lambda}{1 - \frac{v_s}{c}}$$

$$\Delta\lambda = \lambda_{\text{observed}} - \lambda = \lambda\left(\frac{1}{1 - v_s / c} - 1\right) = \lambda\left(\frac{1}{1 - v_s / c} - 1\right) = \lambda\left(\frac{v_s / c}{1 - v_s / c}\right)$$

Since $1 - v_s / c \approx 1$, $\boxed{\frac{\Delta\lambda}{\lambda} \cong \frac{v_{\text{source}}}{c}}$

(b) $v_{\text{source}} = c\left(\frac{\Delta\lambda}{\lambda}\right) = c\left(\frac{20.0 \text{ nm}}{397 \text{ nm}}\right) = \boxed{0.0504\,c}$

***24.12** (a) $f_{\text{observed}} = f_{\text{source}}\sqrt{\frac{1 + v/c}{1 - v/c}}$

implies $\frac{c}{\lambda + \Delta\lambda} = \frac{c}{\lambda}\sqrt{\frac{1 + v/c}{1 - v/c}}$ or $\sqrt{\frac{1 - v/c}{1 + v/c}} = \frac{\lambda + \Delta\lambda}{\lambda}$

and $1 + \frac{\Delta\lambda}{\lambda} = \sqrt{\frac{1 - v/c}{1 + v/c}} = \boxed{\sqrt{\frac{c - v}{c + v}} = \frac{\Delta\lambda}{\lambda} + 1}$

(b) $1 + \frac{550 \text{ nm} - 650 \text{ nm}}{650 \text{ nm}} = \sqrt{\frac{1 - v/c}{1 + v/c}} = 0.846$

$$1 - \frac{v}{c} = (0.846)^2\left(1 + \frac{v}{c}\right) = 0.716 + 0.716\left(\frac{v}{c}\right)$$

$v = 0.166\,c = \boxed{4.97 \times 10^7 \text{ m/s}}$

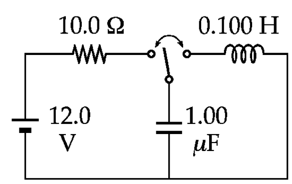
***24.13** This radio is a radiotelephone on a ship, according to frequency assignments made by international treaties, laws, and decisions of the National Telecommunications and Information Administration.

The resonance frequency is $f_0 = \dfrac{1}{2\pi\sqrt{LC}}$

Thus, $C = \dfrac{1}{(2\pi f_0)^2 L} = \dfrac{1}{\left[2\pi\left(6.30\times10^6\text{ Hz}\right)\right]^2\left(1.05\times10^{-6}\text{ H}\right)} = \boxed{608\text{ pF}}$

***24.14** $f = \dfrac{1}{2\pi\sqrt{LC}}$: $L = \dfrac{1}{(2\pi f)^2 C} = \dfrac{1}{[2\pi(120)]^2\left(8.00\times10^{-6}\right)} = \boxed{0.220\text{ H}}$

***24.15** (a) $f = \dfrac{1}{2\pi\sqrt{LC}} = \dfrac{1}{2\pi\sqrt{(0.100\text{ H})\left(1.00\times10^{-6}\text{F}\right)}} = \boxed{503\text{ Hz}}$



(b) $Q = C\mathcal{E} = \left(1.00\times10^{-6}\text{ F}\right)(12.0\text{ V}) = \boxed{12.0\ \mu\text{C}}$

(c) $\frac{1}{2}C\mathcal{E}^2 = \frac{1}{2}LI_{\max}{}^2$

$I_{\max} = \mathcal{E}\sqrt{\dfrac{C}{L}} = 12\text{ V}\sqrt{\dfrac{1.00\times10^{-6}\text{ F}}{0.100\text{ H}}} = \boxed{37.9\text{ mA}}$

(d) At all times $U = \frac{1}{2}C\mathcal{E}^2 = \frac{1}{2}\left(1.00\times10^{-6}\text{ F}\right)(12.0\text{ V})^2 = \boxed{72.0\ \mu\text{J}}$

24.16 $S = I = \dfrac{U}{At} = \dfrac{Uc}{V} = uc$ $\dfrac{\text{Energy}}{\text{Unit Volume}} = u = \dfrac{I}{c} = \dfrac{1000\text{ W/m}^2}{3.00\times10^8\text{ m/s}} = \boxed{3.33\ \mu\text{J/m}^3}$

24.17 $S_{av} = \dfrac{\overline{\mathcal{P}}}{4\pi r^2} = \dfrac{4.00\times10^3\text{ W}}{4\pi(4.00\times1609\text{ m})^2} = 7.68\ \mu\text{W/m}^2$

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

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

24.18 $r = (5.00\text{ mi})(1609\text{ m/mi}) = 8.04\times10^3\text{ m}$

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

24.19 Power output = (power input)(efficiency)

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

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

24.20 (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) $\mathbf{S} = \dfrac{1}{\mu_0}\mathbf{E}\times\mathbf{B} = \dfrac{\left[(80.0\mathbf{i} + 32.0\mathbf{j} - 64.0\mathbf{k})\ \text{N/C}\right]\left[(0.200\mathbf{i} + 0.0800\mathbf{j} + 0.290\mathbf{k})\ \mu\text{T}\right]}{4\pi\times10^{-7}\ \text{T}\cdot\text{m/A}}$

$\mathbf{S} = \dfrac{(6.40\mathbf{k} - 23.2\mathbf{j} - 6.40\mathbf{k} + 9.28\mathbf{i} - 12.8\mathbf{j} + 5.12\mathbf{i})\times10^{-6}\ \text{W/s}^2}{4\pi\times10^{-7}}$

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

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

$A = 2\pi rL = 2\pi\left(0.900\times10^{-3}\ \text{m}\right)(0.0800\ \text{m}) = 4.52\times10^{-4}\ \text{m}^2$

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

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

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

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

***24.22** $\text{Power} = SA = \dfrac{E_{\max}{}^2}{2\mu_0 c}\left(4\pi r^2\right)$

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

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

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

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

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

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

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

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

24.26 (a) The radiation pressure is $\dfrac{2(1340\ \text{W/m}^2)}{3.00\times10^8\ \text{m/s}^2} = 8.93\times10^{-6}\ \text{N/m}^2$

Multiplying by the total area, $A = 6.00\times10^5\ \text{m}^2$ gives: $F = \boxed{5.36\ \text{N}}$

(b) The acceleration is: $a = \dfrac{F}{m} = \dfrac{5.36\ \text{N}}{6000\ \text{kg}} = \boxed{8.93\times10^{-4}\ \text{m/s}^2}$

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

or $t = \sqrt{\dfrac{2d}{a}} = \sqrt{\dfrac{2\left(3.84\times10^8\ \text{m}\right)}{\left(8.93\times10^{-4}\ \text{m/s}^2\right)}} = 9.27\times10^5\ \text{s} = \boxed{10.7\ \text{days}}$

24.27 $I = \dfrac{\mathcal{P}}{\pi r^2} = \dfrac{E_{\max}{}^2}{2\mu_0 c}$

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

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

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

***24.28** (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, $$I_M = I_E\left(\frac{r_E}{r_M}\right)^2 = \left(1340\ \text{W/m}^2\right)\left(\frac{1.496 \times 10^{11}\ \text{m}}{2.28 \times 10^{11}\ \text{m}}\right)^2 = \boxed{577\ \text{W/m}^2}$$

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

$$\mathcal{P}_M = I_M\left(\pi R_M{}^2\right) = \left(577\ \text{W/m}^2\right)\left[\pi\left(3.37 \times 10^6\ \text{m}\right)^2\right] = \boxed{2.06 \times 10^{16}\ \text{W}}$$

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

and force $$F = PA = \frac{I_M}{c}\left(\pi R_M{}^2\right) = \frac{\mathcal{P}_M}{c} = \frac{2.06 \times 10^{16}\ \text{W}}{3.00 \times 10^8\ \text{m/s}} = \boxed{6.87 \times 10^7\ \text{N}}$$

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

$$F_g = \frac{GM_S M_M}{r_M{}^2} = \frac{\left(6.67 \times 10^{-11}\ \text{N} \cdot \text{m}^2/\text{kg}^2\right)\left(1.991 \times 10^{30}\ \text{kg}\right)\left(6.42 \times 10^{23}\ \text{kg}\right)}{\left(2.28 \times 10^{11}\ \text{m}\right)^2} = 1.64 \times 10^{21}\ \text{N}$$

which is $\boxed{\sim 10^{13}\ \text{times stronger}}$ than the repulsive force of (c).

***24.29** For the proton, $\Sigma F = ma$: $qvB\sin 90.0° = \dfrac{mv^2}{R}$

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

$$T = \frac{2\pi R}{v} = \frac{2\pi m}{qB} = \frac{2\pi\left(1.67\times10^{-27}\text{ kg}\right)}{\left(1.60\times10^{-19}\text{ C}\right)(0.350\text{ T})} = 1.87\times10^{-7}\text{ s}$$

$$f = 5.34\times10^{6}\text{ Hz}$$

The charge will radiate at this same frequency,

with $$\lambda = \frac{c}{f} = \frac{3.00\times10^{8}\text{ m/s}}{5.34\times10^{6}\text{ Hz}} = \boxed{56.2\text{ m}}$$

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

Frequency, f	Wavelength, $\lambda = c/f$	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
2PHz = 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

Wavelength, λ	Frequency, $f = c/\lambda$	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/X-ray
2 pm = 2×10^{-12} m	1.5×10^{20} Hz	X-ray/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

24.31 (a) $f = \dfrac{c}{\lambda} = \dfrac{3\times10^{8}\ \text{m/s}}{1.7\ \text{m}}$ $\boxed{\sim 10^{8}\ \text{Hz}}$ $\boxed{\text{radio wave}}$

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

$f = \dfrac{3.00\times10^{8}\ \text{m/s}}{6\times10^{-5}\ \text{m}}$ $\boxed{\sim 10^{13}\ \text{Hz}}$ $\boxed{\text{infrared}}$

24.32 $f = \dfrac{c}{\lambda} = \dfrac{3.00\times10^{8}\ \text{m/s}}{5.50\times10^{-7}\ \text{m}} = \boxed{5.45\times10^{14}\ \text{Hz}}$

***24.33** (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 $\left(4.00\times10^{9}\ \text{Hz}\right)\lambda = 3.00\times10^{8}\ \text{m/s}$: $\boxed{\lambda = 0.075\ \text{m} = 7.50\ \text{cm}}$

24.34 (a) $\lambda = \dfrac{c}{f} = \dfrac{3.00\times10^{8}\ \text{m/s}}{1150\times10^{3}\ \text{s}^{-1}} = 261\ \text{m}$ so $\dfrac{180\ \text{m}}{261\ \text{m}} = \boxed{0.690\ \text{wavelengths}}$

(b) $\lambda = \dfrac{c}{f} = \dfrac{3.00\times10^{8}\ \text{m/s}}{98.1\times10^{6}\ \text{s}^{-1}} = 3.06\ \text{m}$ so $\dfrac{180\ \text{m}}{3.06\ \text{m}} = \boxed{58.9\ \text{wavelengths}}$

***24.35** 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

$\Delta t = 8.75\times10^{-3}\ \text{s} - 3.33\times10^{-4}\ \text{s} = 8.41\times10^{-3}\ \text{s}$

***24.36** Channel 4: $f_{\min} = 66$ MHz $\lambda_{\max} = \boxed{4.55 \text{ m}}$

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

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

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

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

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

24.37 $I = I_{\max}\cos^2\theta \quad \Rightarrow \quad \theta = \cos^{-1}\sqrt{\dfrac{I}{I_{\max}}}$

(a) $\dfrac{I}{I_{\max}} = \dfrac{1}{3.00} \quad \Rightarrow \quad \theta = \cos^{-1}\sqrt{\dfrac{1}{3.00}} = \boxed{54.7°}$

(b) $\dfrac{I}{I_{\max}} = \dfrac{1}{5.00} \quad \Rightarrow \quad \theta = \cos^{-1}\sqrt{\dfrac{1}{5.00}} = \boxed{63.4°}$

(c) $\dfrac{I}{I_{\max}} = \dfrac{1}{10.0} \quad \Rightarrow \quad \theta = \cos^{-1}\sqrt{\dfrac{1}{10.0}} = \boxed{71.6°}$

24.38 The average value of the cosine-squared function is one-half, so the first polarizer transmits $\frac{1}{2}$ the light. The second transmits $\cos^2 30.0° = \frac{3}{4}$.

$I_f = \frac{1}{2} \times \frac{3}{4} I_i = \boxed{\frac{3}{8} I_i}$

***24.39** $\dfrac{I}{I_{\max}} = \frac{1}{2}\left(\cos^2 45.0°\right)\left(\cos^2 45.0°\right) = \boxed{\frac{1}{8}}$

24.40 Let the first sheet have its axis at angle θ to the original plane of polarization, and let each further sheet have its axis turned by the same angle.

The first sheet passes intensity $I_{\max}\cos^2\theta$

The second sheet passes $I_{\max}\cos^4\theta$

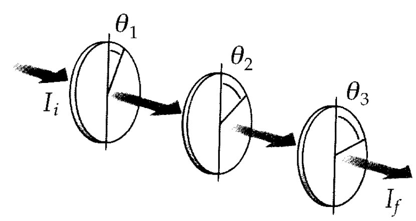
and the n^{th} sheet lets through $I_{\max}\cos^{2n}\theta \geq 0.90\,I_{\max}$ where $\theta = 45°/n$

Try different integers to find $\cos^{2\times 5}\left(\frac{45°}{5}\right) = 0.885$ $\cos^{2\times 6}\left(\frac{45°}{6}\right) = 0.902$

(a) So $n = \boxed{6}$

(b) $\theta = \boxed{7.50°}$

24.41 For incident unpolarized light of intensity $I_{\max}$:



After transmitting 1st disk: $I = \frac{1}{2}I_{\max}$

After transmitting 2nd disk: $I = \frac{1}{2}I_{\max}\cos^2\theta$

After transmitting 3rd disk: $I = \frac{1}{2}I_{\max}\cos^2\theta\cos^2(90° - \theta)$

where the angle between the first and second disk is $\theta = \omega t$.

Using trigonometric identities $\cos^2\theta = \frac{1}{2}(1 + \cos 2\theta)$

and $\cos^2(90° - \theta) = \sin^2\theta = \frac{1}{2}(1 - \cos 2\theta)$

we have $I = \frac{1}{2}I_{\max}\left[\frac{(1+\cos 2\theta)}{2}\right]\left[\frac{(1-\cos 2\theta)}{2}\right]$

$$I = \frac{1}{8}I_{\max}(1 - \cos^2 2\theta) = \frac{1}{8}I_{\max}\left(\frac{1}{2}\right)(1 - \cos 4\theta)$$

Since $\theta = \omega t$, the intensity of the emerging beam is given by $\boxed{I = \frac{1}{16}I_{\max}(1 - 4\omega t)}$

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

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

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

***24.43** $f = \dfrac{E}{h} = \dfrac{0.117\ \text{eV}}{6.630\times10^{-34}\ \text{J}\cdot\text{s}}\left(\dfrac{1.60\times10^{-19}\ \text{C}}{e}\right)\left(\dfrac{1\ \text{J}}{1\ \text{V}\cdot\text{C}}\right) = \boxed{2.82\times10^{13}\ \text{s}^{-1}}$

$\lambda = \dfrac{c}{f} = \dfrac{3.00\times10^{8}\ \text{m/s}}{2.82\times10^{13}\ \text{s}^{-1}} = \boxed{10.6\ \mu\text{m}}$, $\boxed{\text{infrared}}$

24.44 (a) $\dfrac{N_3}{N_2} = \dfrac{N_g e^{-E_3/(k_B\cdot 300\ \text{K})}}{N_g e^{-E_2/(k_B\cdot 300\ \text{K})}} = e^{-(E_3-E_2)/(k_B\cdot 300\ \text{K})} = e^{-hc/\lambda(k_B\cdot 300\ \text{K})}$

where λ is the wavelength of light radiated in the $3\to2$ transition.

$\dfrac{N_3}{N_2} = e^{-\left(6.63\times10^{-34}\ \text{J}\cdot\text{s}\right)\left(3\times10^{8}\ \text{m/s}\right)/\left(632.8\times10^{-9}\ \text{m}\right)\left(1.38\times10^{-23}\ \text{J/K}\right)(300\ \text{K})}$

$\dfrac{N_3}{N_2} = e^{-75.9} = \boxed{1.07\times10^{-33}}$

(b) $N_u / N_\ell = e^{-(E_u-E_\ell)/k_BT}$

where the subscript u refers to an upper energy state and the subscript ℓ to a lower energy state.

Since $E_u - E_\ell = E_{\text{photon}} = hc/\lambda$ $\qquad N_u/N_\ell = e^{-hc/\lambda k_BT}$

Thus, we require $\qquad 1.02 = e^{-hc/\lambda k_BT}$

or $\qquad \ln(1.02) = -\dfrac{\left(6.63\times10^{-34}\ \text{J}\cdot\text{s}\right)\left(3\times10^{8}\ \text{m/s}\right)}{\left(632.8\times10^{-9}\ \text{m}\right)\left(1.38\times10^{23}\ \text{J/K}\right)T}$

$T = -\dfrac{2.28\times10^{4}}{\ln(1.02)} = \boxed{-1.15\times10^{6}\ \text{K}}$

A negative-temperature state is not achieved by cooling the system below 0 K, but by heating it above $T=\infty$, for as $T\to\infty$ the populations of upper and lower states approach equality.

(c) Because $E_u - E_\ell > 0$, and in any real equilibrium state $T > 0$,

$e^{-(E_u-E_\ell)/k_BT} < 1$ and $N_u < N_\ell$

Thus, a population inversion cannot happen in thermal equilibrium.

24.45 (a) $I = \dfrac{\left(3.00\times10^{-3}\text{ J}\right)}{\left(1.00\times10^{-9}\text{ s}\right)\left[\pi\left(15.0\times10^{-6}\text{ m}\right)^2\right]} = \boxed{4.24\times10^{15}\text{ W/m}^2}$

(b) $\left(3.00\times10^{-3}\text{ J}\right)\dfrac{\left(0.600\times10^{-9}\text{ m}\right)^2}{\left(30.0\times10^{-6}\text{ m}\right)^2} = \boxed{1.20\times10^{-12}\text{ J}} = 7.50\text{ MeV}$

24.46 (a) $\left(3.00\times10^{8}\text{ m/s}\right)\left(14.0\times10^{-12}\text{ s}\right) = \boxed{4.20\text{ mm}}$

(b) $E = \dfrac{hc}{\lambda} = 2.86\times10^{-19}\text{ J}$

$N = \dfrac{3.00\text{ J}}{2.86\times10^{-19}\text{ J}} = \boxed{1.05\times10^{19}\text{ photons}}$

(c) $V = (4.20\text{ mm})\left[\pi(3.00\text{ mm})^2\right] = 119\text{ mm}^3$

$n = \dfrac{1.05\times10^{19}}{119} = \boxed{8.82\times10^{16}\text{ mm}^{-3}}$

***24.47** The photon energy is $E_4 - E_3 = (20.66 - 18.70)\text{ eV} = 1.96\text{ eV} = \dfrac{hc}{\lambda}$

$$\lambda = \frac{\left(6.626\times10^{-34}\text{ J}\cdot\text{s}\right)\left(3.00\times10^{8}\text{ m/s}\right)}{1.96\left(1.60\times10^{-19}\text{ J}\right)} = \boxed{633\text{ nm}}$$

24.48 (a) $\mathcal{P} = SA$: $\mathcal{P} = \left(1340\text{ W/m}^2\right)\left[4\pi\left(1.496\times10^{11}\text{ m}\right)^2\right] = \boxed{3.77\times10^{26}\text{ W}}$

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

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

24.49 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 $I = \dfrac{\mathcal{P}}{A} = \dfrac{E}{At}$: $E = IAt = \left(1340\text{ W/m}^2\right)\left[(0.6)(0.5)\left(0.4\text{ m}^2\right)\right](3600\text{ s})\ \boxed{\sim10^{6}\text{ J}}$

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

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

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

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

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

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

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

24.51 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 $P = \dfrac{S_{av}}{c} = \dfrac{I}{c} = \dfrac{F_\ell}{A}$

(a) $$F_\ell = F_g$$

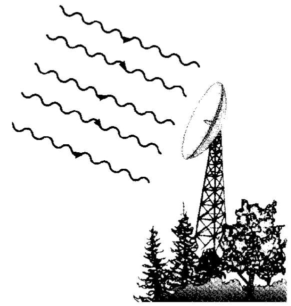
so $$I = \frac{F_\ell c}{A} = \frac{F_g c}{A} = \frac{mgc}{\pi r_b^2}$$

From the definition of density, $$\rho = \frac{m}{V} = \frac{m}{\frac{4}{3}\pi r_b^3}$$

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

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



24.52 (a) $B_{\max} = \dfrac{E_{\max}}{c} = \boxed{6.67 \times 10^{-16}\ \text{T}}$

(b) $S_{av} = \dfrac{E_{\max}{}^2}{2\mu_0 c} = \boxed{5.31 \times 10^{-17}\ \text{W/m}^2}$

(c) $\mathcal{P} = S_{av} A = \boxed{1.67 \times 10^{-14}\ \text{W}}$

(d) $F = PA = \left(\dfrac{S_{av}}{c}\right) A = \boxed{5.56 \times 10^{-23}\ \text{N}}$ ($\cong$ the weight of 3000 H atoms!)

24.53 $u = \frac{1}{2}\epsilon_0 E_{\max}{}^2$ (Equation 24.27) $E_{\max} = \sqrt{\dfrac{2u}{\epsilon_0}} = \boxed{95.1\ \text{mV/m}}$

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

$$A = 2\pi r \ell = 2\pi\left(4.00 \times 10^{-2}\ \text{m}\right)(0.100\ \text{m}) = 2.51 \times 10^{-2}\ \text{m}^2$$

(a) The intensity is then: $S = \dfrac{\mathcal{P}}{A} = \dfrac{0.600\ \text{W}}{2.51 \times 10^{-2}\ \text{m}^2} = \boxed{23.9\ \text{W/m}^2}$

(b) The standard is: $0.570\ \dfrac{\text{mW}}{\text{cm}^2} = 0.570\left(\dfrac{\text{mW}}{\text{cm}^2}\right)\left(\dfrac{1.00 \times 10^{-3}\ \text{W}}{1.00\ \text{mW}}\right)\left(\dfrac{1.00 \times 10^4\ \text{cm}^2}{1.00\ \text{m}^2}\right) = 5.70\ \dfrac{\text{W}}{\text{m}^2}$

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

24.55 (a) $B_{\max} = \dfrac{E_{\max}}{c} = \dfrac{175\ \text{V/m}}{3.00 \times 10^8\ \text{m/s}} = \boxed{5.83 \times 10^{-7}\ \text{T}}$

$k = \dfrac{2\pi}{\lambda} = \dfrac{2\pi}{0.0150\ \text{m}} = \boxed{419\ \text{rad/m}}$ $\omega = kc = \boxed{1.26 \times 10^{11}\ \text{rad/s}}$

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

(c) $P_r = \dfrac{2S}{c} = \boxed{2.71 \times 10^{-7}\ \text{N/m}^2}$

(d) $a = \dfrac{\Sigma F}{m} = \dfrac{PA}{m} = \dfrac{\left(2.71 \times 10^{-7}\ \text{N/m}^2\right)\left(0.750\ \text{m}^2\right)}{0.500\ \text{kg}} = \boxed{4.06 \times 10^{-7}\ \text{m/s}^2}$

***24.56** (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, $$0.900\left(1000\ \text{W/m}^2\right)A = 0.700\left(5.67\times10^{-8}\ \text{W/m}^2\cdot\text{K}^4\right)AT^4$$

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

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

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

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

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

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

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

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

24.58 Of the intensity $\qquad S = 1340\ \text{W/m}^2$

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

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

Altogether the pressure at the subsolar point on Earth is

(a) $$P_{\text{total}} = P_1 + P_2 = \frac{1.38S}{c} = \frac{1.38\left(1340\ \text{W/m}^2\right)}{3.00\times10^8\ \text{m/s}} = \boxed{6.16\times10^{-6}\ \text{Pa}}$$

(b) $$\frac{P_a}{P_{\text{total}}} = \frac{1.01\times10^5\ \text{N/m}^2}{6.16\times10^{-6}\ \text{N/m}^2} = \boxed{1.64\times10^{10}\ \text{times smaller than atmospheric pressure}}$$

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

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

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

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

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

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

24.60 The mirror intercepts power $\mathcal{P} = I_1 A_1 = \left(1.00\times10^3\ \text{W/m}^2\right)\left[\pi(0.500\ \text{m})^2\right] = 785\ \text{W}$

In the image,

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

(b) $I_2 = \frac{E_{\max}^2}{2\mu_0 c}$ so $E_{\max} = \sqrt{2\mu_0 c I_2} = \sqrt{2\left(4\pi\times10^{-7}\right)\left(3.00\times10^8\right)\left(6.25\times10^5\right)} = \boxed{21.7\ \text{kN/C}}$

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

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

$0.400(785\ \text{W})\Delta t = (1.00\ \text{kg})(4186\ \text{J/kg}\cdot{}^\circ\text{C})(100\ {}^\circ\text{C} - 20.0\ {}^\circ\text{C})$

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

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

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

The radiated power is then: $\mathcal{P} = \dfrac{q^2a^2}{6\pi\epsilon_0c^3} = \dfrac{\left(1.60\times10^{-19}\right)^2\left(1.76\times10^{13}\right)^2}{6\pi\left(8.85\times10^{-12}\right)\left(3.00\times10^8\right)^3} = \boxed{1.75\times10^{-27}\ W}$

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

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

The proton then radiates $\mathcal{P} = \dfrac{q^2a^2}{6\pi\epsilon_0c^3} = \dfrac{\left(1.60\times10^{-19}\right)^2\left(5.62\times10^{14}\right)^2}{6\pi\left(8.85\times10^{-12}\right)\left(3.00\times10^8\right)^3} = \boxed{1.80\times10^{-24}\ W}$

ANSWERS TO EVEN NUMBERED PROBLEMS

2. (a) 3.15 kN/C **j** (b) 525 nT **k** (c) –483 aN **j**

4. 2.25×10^{8} m/s

6. 733 nT

8. See the solution

10. 2.9×10^{8} m/s $\pm 5\%$

12. (a) See the solution (b) 4.97×10^{7} m/s

14. 0.220 H

16. 3.33 μJ/m^3

18. 307 μW/m^2

20. (a) $\mathbf{E}\cdot\mathbf{B}=0$ (b) $(11.5\,\mathbf{i}-28.6\,\mathbf{j})$ W/m^2

22. 5.16 m

24. (a) 1.60×10^{-10} kg·m/s (b) 1.60×10^{-10} N

26. (a) 5.36 N (b) 8.93×10^{-4} m/s^2 (c) 10.7 days

28. (a) 577 W/m^2 (b) 2.06×10^{16} W (c) 6.87×10^{7} N
(d) The gravitational force is $\sim10^{13}$ times stronger than the light force, and in the opposite direction.

30. 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

32. 545 THz

34. (a) 0.690 wavelengths (b) 58.9 wavelengths

36.	(a) 4.17 m to 4.55 m	(b) 3.41 m to 3.66 m	(c) 1.61 m to 1.67 m
38.	3/8		
40.	(a) 6	(b) 7.50°	
42.	(a) 2.33 mT	(b) 650 MW/m^2	(c) 510 W
44.	(a) 1.07×10^{-33}	(b) -1.15×10^{6} K	(c) no real T is below 0 K
46.	(a) 4.20 mm	(b) 1.05×10^{19} photons	(c) $8.82 \times 10^{16}\ /\text{mm}^3$
48.	(a) 3.77×10^{26} W	(b) 1.01 kV/m and 3.35 μT	
50.	(a) See the solution	(b) 378 nm	
52.	(a) 6.67×10^{-16} T (c) 1.67×10^{-14} W	(b) $5.31 \times 10^{-17}\ \text{W/m}^2$ (d) 5.56×10^{-23} N	
54.	(a) 23.9 W/m^2	(b) It is 4.19 times the standard	
56.	(a) 388 K	(b) 363 K	
58.	(a) 6.16×10^{-6} Pa	(b) 1.64×10^{10} times smaller than atmospheric pressure	
60.	(a) 625 kW/m^2	(b) 21.7 kN/C, 72.4 μT	(c) 17.8 min