Chapter 21
Alternating Current Circuits and Electromagnetic Waves

Quick Quizzes

1. (a), (c). The average power is proportional to the rms current which is non-zero even though the average current is zero. (a) is only valid for an open circuit, for which $R \to \infty$. (b) and (d) can never be true because $i_{\text{av}} = 0$ for AC currents.

2. (b). Choices (a) and (c) are incorrect because the unaligned sine curves in Figure 21.9 mean the voltages are out of phase, and so we cannot simply add the maximum (or rms) voltages across the elements. (In other words, $\Delta V \neq \Delta V_R + \Delta V_L + \Delta V_C$ even though $\Delta v = \Delta v_R + \Delta v_L + \Delta v_C \Delta$.)

3. (b). Note that this is a DC circuit. However, changing the amount of iron inside the solenoid changes the magnetic field strength in that region and results in a changing magnetic flux through the loops of the solenoid. This changing flux will generate a back emf that opposes the current in the circuit and decreases the brightness of the bulb. The effect will be present only while the rod is in motion. If the rod is held stationary at any position, the back emf will disappear, and the bulb will return to its original brightness.

4. (b), (c). The radiation pressure (a) does not change because pressure is force per unit area. In (b), the smaller disk absorbs less radiation, resulting in a smaller force. For the same reason, the momentum in (c) is reduced.

5. (b), (d). The frequency and wavelength of light waves are related by the equation $\lambda f = c$ or $f = c/\lambda$, where c is the speed of light is a constant within a given medium. Thus, the frequency and wavelength are inversely proportional to each other, when one increases the other must decrease.

Answers to Even Numbered Conceptual Questions

2. At resonance, $X_L = X_C$. This means that the impedance $Z = \sqrt{R^2 + \left(X_L - X_C\right)^2}$ reduces to $Z = R$.

4. The purpose of the iron core is to increase the flux and to provide a pathway in which nearly all the flux through one coil is led through the other.

6. The fundamental source of an electromagnetic wave is a moving charge. For example, in a transmitting antenna of a radio station, charges are caused to move up and down at the frequency of the radio station. These moving charges set up electric and magnetic fields, the electromagnetic wave, in the space around the antenna.

8. Energy moves. No matter moves. You could say that electric and magnetic fields move, but it is nicer to say that the fields 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.

10. The average value of an alternating current is zero because its direction is positive as often as it is negative, and its time average is zero. The average value of the square of the current is not zero, however, since the square of positive and negative values are always positive and cannot cancel.

12. The brightest portion of your face shows where you radiate the most. Your nostrils and the openings of your ear canals are particularly bright. Brighter still are the pupils of your eyes.

14. No, the only element that dissipates energy in an AC circuit is a resistor. Inductors and capacitors store energy during one half of a cycle and release that energy during the other half of the cycle, so they dissipate no net energy.

16. 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.

18. The voltages are not added in a scalar form, but in a vector form, as shown in the phasor diagrams throughout the chapter. Kirchhoff's loop rule is true at any instant, but the voltages across different circuit elements are not simultaneously at their maximum values. Do not forget that an inductor can induce an emf in itself and that the voltage across it is 90° *ahead* of the current in the circuit in phase.

20. Insulation and safety limit the voltage of a transmission line. For an underground cable, the thickness and dielectric strength of the insulation between the conductors determines the maximum voltage that can be applied, just as with a capacitor. For an overhead line on towers, the designer must consider electrical breakdown of the surrounding air, possible accidents, sparking across the insulating supports, ozone production, and inducing voltages in cars, fences, and the roof gutters of nearby houses. Nuisance effects include noise, electrical noise, and a prankster lighting a hand-held fluorescent tube under the line.

Answers to Even Numbered Problems

2. **(a)** 193 Ω **(b)** 145 Ω

4. $I_{1,\,\text{rms}} = I_{2,\,\text{rms}} = 1.25\text{ A}$, $R_1 = R_2 = 96.0\ \Omega$, $I_{3,\,\text{rms}} = 0.833\text{ A}$, $R_3 = 144\ \Omega$

6. **(a)** 106 V **(b)** 60.0 Hz **(c)** 0 **(d)** 3.00 A

8. **(a)** 141 mA **(b)** 235 mA

10. 100 mA

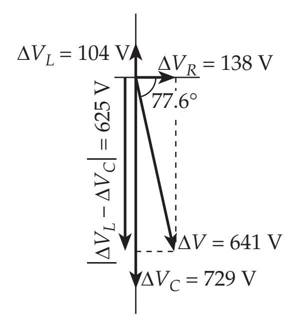
12. 224 mA

14. 2.63 A

16. $L > 7.03\text{ H}$

18. **(a)** 194 V **(b)** current leads by 49.9°

20. **(a)** 138 V **(b)** 104 V
(c) 729 V **(d)** 641 V **(e)**



22. **(a)** 0.11 A **(b)** $\Delta V_{R,\,\max} = 130\text{ V}, \Delta V_{C,\,\max} = 110\text{ V}$
(c) $\Delta v_R = 0,\quad \Delta v_C = \Delta v_{source} = 110\text{ V},\quad q_C = 280\ \mu\text{C}$
(d) $\Delta v_R = \Delta v_{source} = 130\text{ V},\quad \Delta v_C = 0,\quad q_C = 0$

24. **(a)** 0.11 A **(b)** $\Delta V_{R,\,\max} = 130\text{ V}, \Delta V_{L,\,\max} = 110\text{ V}$
(c) $\Delta v_R = \Delta v_{source} = 130\text{ V},\quad \Delta v_L = 0$
(d) $\Delta v_R = 0,\quad \Delta v_L = \Delta v_{source} = 110\text{ V}$

26. **(a)** 123 nF or 124 nF **(b)** 51.5 kV

28. **(a)** 0.492, 48.5 W **(b)** 0.404, 32.7 W

30. **(a)** 100 W, 0.633 **(b)** 156 W, 0.790

32. **(a)** $\Delta V_{R,\,\text{rms}} + \Delta V_{L,\,\text{rms}} + \Delta V_{C,\,\text{rms}} = 21\text{ V} \neq 10\text{ V}$, but accounting for phases and adding the voltages vectorially does yield 10 V. **(b)** The power loss delivered to the resistor. No power losses occur in an ideal capacitor or inductor. **(c)** 3.3 W

34. **(a)** $Z = R = 15\ \Omega$ **(b)** 41 Hz
(c) At resonance **(d)** 2.5 A

36. **(a)** 480 W **(b)** 0.192 W **(c)** 30.7 mW **(d)** 0.192 W **(e)** 30.7 mW
Maximum power is delivered at resonance frequency.

38. **(a)** 18 turns **(b)** 3.6 W

40. **(a)** Fewer turns **(b)** 25 mA **(c)** 20 turns

42. **(a)** 29.0 kW **(b)** 0.580%
(c) The maximum power that can be input to the line at 4.50 kV is far less than 5.00 MW, and it is all lost in the transmission line.

44. 2.998×10^8 m/s

46. 80%

48. 3.74×10^{26} W

50. 11.0 m

52. Radio listeners hear the news 8.4 ms before the studio audience because radio waves travel much faster than sound waves.

54. $6.003\,6 \times 10^{14}$ Hz, the frequency increases by 3.6×10^{11} Hz

56. 1.1×10^7 m/s

58. $\sim 10^6$ J

60. 2.5 mH, 26 μF

62. **(a)** 0.63 pF **(b)** 8.5 mm **(c)** 25 Ω

64. **(a)** 6.0 Ω **(b)** 12 mH

66. 32

68. $X_c = 3R$

Problem Solutions

21.1 (a) $\Delta V_{max} = \sqrt{2}(\Delta V_{rms}) = \sqrt{2}(100\ \text{V}) = \boxed{141\ \text{V}}$

(b) $I_{rms} = \dfrac{\Delta V_{rms}}{R} = \dfrac{100\ \text{V}}{5.00\ \Omega} = \boxed{20.0\ \text{A}}$

(c) $I_{max} = \dfrac{\Delta V_{max}}{R} = \dfrac{141\ \text{V}}{5.00\ \Omega} = \boxed{28.3\ \text{A}}$ or $I_{max} = \sqrt{2}\,I_{rms} = \sqrt{2}(20.0\ \text{A}) = \boxed{28.3\ \text{A}}$

(d) $\mathcal{P}_{av} = I_{rms}^2 R = (20.0\ \text{A})^2(5.00\ \Omega) = 2.00\times 10^3\ \text{W} = \boxed{2.00\ \text{kW}}$

21.2 $\mathcal{P}_{av} = I_{rms}^2 R = \left(\dfrac{I_{max}}{\sqrt{2}}\right)^2 R = \dfrac{1}{2}\left[\dfrac{\Delta V_{max}}{R}\right]^2 R = \dfrac{(\Delta V_{max})^2}{2R}$, so $R = \dfrac{(\Delta V_{max})^2}{2\mathcal{P}_{av}}$

(a) If $\mathcal{P}_{av} = 75.0\ \text{W}$, then $R = \dfrac{(170\ \text{V})^2}{2(75.0\ \text{W})} = \boxed{193\ \Omega}$

(b) If $\mathcal{P}_{av} = 100\ \text{W}$, then $R = \dfrac{(170\ \text{V})^2}{2(100\ \text{W})} = \boxed{145\ \Omega}$

21.3 The meters measure the rms values of potential difference and current. These are

$$\Delta V_{rms} = \frac{\Delta V_{max}}{\sqrt{2}} = \frac{100\ \text{V}}{\sqrt{2}} = \boxed{70.7\ \text{V}},\ \text{and}\ I_{rms} = \frac{\Delta V_{rms}}{R} = \frac{70.7\ \text{V}}{24.0\ \Omega} = \boxed{2.95\ \text{A}}$$

21.4 All lamps are connected in parallel with the voltage source, so $\Delta V_{rms} = 120\ \text{V}$ for each lamp. Also, the current is $I_{rms} = \mathcal{P}_{av}/\Delta V_{rms}$ and the resistance is $R = \Delta V_{rms}/I_{rms}$.

$$I_{1,\,rms} = I_{2,\,rms} = \frac{150\ \text{W}}{120\ \text{V}} = \boxed{1.25\ \text{A}}\ \text{and}\ R_1 = R_2 = \frac{120\ \text{V}}{1.25\ \text{A}} = \boxed{96.0\ \Omega}$$

$$I_{3,\,rms} = \frac{100\ \text{W}}{120\ \text{V}} = \boxed{0.833\ \text{A}}\ \text{and}\ R_3 = \frac{120\ \text{V}}{0.833\ \text{A}} = \boxed{144\ \Omega}$$

21.5 The total resistance (series connection) is $R_{eq} = R_1 + R_2 = 8.20\ \Omega + 10.4\ \Omega = 18.6\ \Omega$, so the current in the circuit is

$$I_{\text{rms}} = \frac{\Delta V_{\text{rms}}}{R_{eq}} = \frac{15.0\text{ V}}{18.6\ \Omega} = 0.806\text{ A}$$

The power to the speaker is then $\mathcal{P}_{\text{av}} = I_{\text{rms}}^2 R_{speaker} = (0.806\text{ A})^2 (10.4\ \Omega) = \boxed{6.76\text{ W}}$

21.6 (a) $\Delta V_{\max} = 150\text{ V}$, so $\Delta V_{\text{rms}} = \dfrac{\Delta V_{\max}}{\sqrt{2}} = \dfrac{150\text{ V}}{\sqrt{2}} = \boxed{106\text{ V}}$

(b) $f = \dfrac{\omega}{2\pi} = \dfrac{377\text{ rad/s}}{2\pi} = \boxed{60.0\text{ Hz}}$

(c) At $t = (1/120)\text{ s}$, $v = (150\text{ V})\sin\left[(377\text{ rad/s})(1/120\text{ s})\right] = (150\text{ V})\sin(\pi\text{ rad}) = \boxed{0}$

(d) $I_{\max} = \dfrac{\Delta V_{\max}}{R} = \dfrac{150\text{ V}}{50.0\ \Omega} = \boxed{3.00\text{ A}}$

21.7 $X_C = \dfrac{1}{2\pi f C}$, so its units are

$$\frac{1}{(1/\text{Sec})\text{Farad}} = \frac{1}{(1/\text{Sec})(\text{Coulomb/Volt})} = \frac{\text{Volt}}{\text{Coulomb/Sec}} = \frac{\text{Volt}}{\text{Amp}} = \text{Ohm}$$

21.8 $I_{\max} = \sqrt{2}\, I_{\text{rms}} = \dfrac{\sqrt{2}(\Delta V_{\text{rms}})}{X_C} = \sqrt{2}(\Delta V_{\text{rms}})2\pi f C$

(a) $I_{\max} = \sqrt{2}(120\text{ V})2\pi(60.0\text{ Hz})\left(2.20\times10^{-6}\text{ C/V}\right) = 0.141\text{ A} = \boxed{141\text{ mA}}$

(b) $I_{\max} = \sqrt{2}(240\text{ V})2\pi(50.0\text{ Hz})\left(2.20\times10^{-6}\text{ C/V}\right) = 0.235\text{ A} = \boxed{235\text{ mA}}$

21.9 $I_{\text{rms}} = \dfrac{\Delta V_{\text{rms}}}{X_C} = 2\pi f C(\Delta V_{\text{rms}})$, so

$$f = \frac{I_{\text{rms}}}{2\pi C(\Delta V_{\text{rms}})} = \frac{0.30\text{ A}}{2\pi\left(4.0\times10^{-6}\text{ F}\right)(30\text{ V})} = \boxed{4.0\times10^{2}\text{ Hz}}$$

21.10 $I_{\max} = \dfrac{\Delta V_{\max}}{X_C} = 2\pi f C\left(\Delta V_{\max}\right)$

$$= 2\pi\left(90.0\text{ Hz}\right)\left(3.70\times10^{-6}\text{ C/V}\right)\left(48.0\text{ V}\right) = 0.100\text{ A} = \boxed{100\text{ mA}}$$

21.11 $I_{\text{rms}} = \dfrac{\Delta V_{\text{rms}}}{X_C} = 2\pi f C\left(\dfrac{\Delta V_{\max}}{\sqrt{2}}\right) = \pi f C\left(\Delta V_{\max}\right)\sqrt{2}$

so $$C = \frac{I}{\pi f\left(\Delta V_{\max}\right)\sqrt{2}} = \frac{0.75\text{ A}}{\pi\left(60\text{ Hz}\right)\left(170\text{ V}\right)\sqrt{2}} = 1.7\times10^{-5}\text{ F} = \boxed{17\ \mu\text{F}}$$

21.12 $I_{\text{rms}} = \dfrac{\Delta V_{\text{rms}}}{X_C} = \left(\dfrac{\Delta V_{\max}}{\sqrt{2}}\right)\omega C$

or $$I_{\text{rms}} = \left(\frac{140\text{ V}}{\sqrt{2}}\right)\left(120\pi\text{ rad/s}\right)\left(6.00\times10^{-6}\text{ F}\right) = 0.224\text{ A} = \boxed{224\text{ mA}}$$

21.13 $X_L = 2\pi f L$, and from $|\mathcal{E}| = L\left(\dfrac{\Delta I}{\Delta t}\right)$, we have $L = \dfrac{|\mathcal{E}|\left(\Delta t\right)}{\Delta I}$. The units of self inductance are then $\left[L\right] = \dfrac{\left[\mathcal{E}\right]\left[\Delta t\right]}{\left[\Delta I\right]} = \dfrac{\text{Volt}\cdot\text{sec}}{\text{Amp}}$. The units of inductive reactance are given by

$$\left[X_L\right] = \left[f\right]\left[L\right] = \left(\frac{1}{\text{sec}}\right)\left(\frac{\text{Volt}\cdot\text{sec}}{\text{Amp}}\right) = \frac{\text{Volt}}{\text{Amp}} = \text{Ohm}$$

21.14 The maximum current in the purely inductive circuit is

$$I_{\max} = \frac{\Delta V_{\max}}{X_L} = \frac{\Delta V_{\max}}{\omega L} = \frac{140\text{ V}}{\left(120\pi\text{ rad/s}\right)\left(0.100\text{ H}\right)} = 3.71\text{ A}$$

so $$I_{\text{rms}} = \frac{I_{\max}}{\sqrt{2}} = \frac{3.71\text{ A}}{\sqrt{2}} = \boxed{2.63\text{ A}}$$

21.15 The ratio of inductive reactance at $f_2 = 50.0\text{ Hz}$ to that at $f_1 = 60.0\text{ Hz}$ is

$$\frac{(X_L)_2}{(X_L)_1} = \frac{2\pi f_2 L}{2\pi f_1 L} = \frac{f_2}{f_1}\text{, so } (X_L)_2 = \frac{f_2}{f_1}(X_L)_1 = \frac{50.0\text{ Hz}}{60.0\text{ Hz}}(54.0\ \Omega) = 45.0\ \Omega$$

The maximum current at $f_2 = 50.0\text{ Hz}$ is then

$$I_{\text{max}} = \frac{\Delta V_{\text{max}}}{X_L} = \frac{\sqrt{2}(\Delta V_{\text{rms}})}{X_L} = \frac{\sqrt{2}(100\text{ V})}{45.0\ \Omega} = \boxed{3.14\text{ A}}$$

21.16 The maximum current in this inductive circuit will be

$$I_{\text{max}} = \left(\sqrt{2}\right) I_{\text{rms}} = \frac{\sqrt{2}(\Delta V_{\text{rms}})}{X_L} = \frac{\sqrt{2}(\Delta V_{\text{rms}})}{2\pi f L}$$

Thus, if $I_{\text{max}} < 80.0\text{ mA}$, it is necessary that

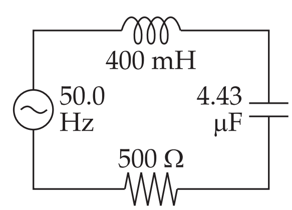
$$L > \frac{\sqrt{2}(\Delta V_{\text{rms}})}{2\pi f(80.0\text{ mA})} = \frac{\sqrt{2}(50.0\text{ V})}{2\pi(20.0\text{ Hz})\left(8.00\times10^{-2}\text{ A}\right)} \qquad \text{or} \qquad L > \boxed{7.03\text{ H}}$$

21.17 From $L = \dfrac{N\Phi_B}{I}$, the total flux through the coil is $\Phi_{B,\,total} = N\Phi_B = L\cdot I$ where Φ_B is the flux through a single turn on the coil. Thus,

$$\left(\Phi_{B,\,total}\right)_{\text{max}} = L\cdot I_{\text{max}} = L\cdot\left(\frac{\Delta V_{\text{max}}}{X_L}\right)$$

$$= L\cdot\frac{\sqrt{2}(\Delta V_{\text{rms}})}{2\pi f L} = \frac{\sqrt{2}(120\text{ V})}{2\pi(60.0\text{ Hz})} = \boxed{0.450\text{ T}\cdot\text{m}^2}$$

21.18 (a) $X_L = 2\pi f L = 2\pi(50.0\text{ Hz})\left(400\times10^{-3}\text{ H}\right) = 126\ \Omega$



$$X_C = \frac{1}{2\pi f C} = \frac{1}{2\pi(50.0\text{ Hz})\left(4.43\times10^{-6}\text{ F}\right)} = 719\ \Omega$$

$$Z = \sqrt{R^2 + (X_L - X_C)^2} = \sqrt{(500\ \Omega)^2 + (126\ \Omega - 719\ \Omega)^2} = 776\ \Omega$$

$$\Delta V_{\text{max}} = I_{\text{max}} Z = (0.250\text{ A})(776\ \Omega) = \boxed{194\text{ V}}$$

(b) $\phi = \tan^{-1}\left(\dfrac{X_L - X_C}{R}\right) = \tan^{-1}\left(\dfrac{126\ \Omega - 719\ \Omega}{500\ \Omega}\right) = -49.9°$

Thus, $\boxed{\text{the current leads the voltage by } 49.9°}$

21.19 $X_C = \dfrac{1}{2\pi f C} = \dfrac{1}{2\pi(60.0\ \text{Hz})(40.0\times10^{-6}\ \text{F})} = 66.3\ \Omega$

$Z = \sqrt{R^2 + (X_L - X_C)^2} = \sqrt{(50.0\ \Omega)^2 + (0 - 66.3\ \Omega)^2} = 83.1\ \Omega$

(a) $I_{\text{rms}} = \dfrac{\Delta V_{\text{rms}}}{Z} = \dfrac{30.0\ \text{V}}{83.1\ \Omega} = \boxed{0.361\ \text{A}}$

(b) $\Delta V_{R,\,\text{rms}} = I_{\text{rms}} R = (0.361\ \text{A})(50.0\ \Omega) = \boxed{18.1\ \text{V}}$

(c) $\Delta V_{C,\,\text{rms}} = I_{\text{rms}} X_C = (0.361\ \text{A})(66.3\ \Omega) = \boxed{23.9\ \text{V}}$

(d) $\phi = \tan^{-1}\left(\dfrac{X_L - X_C}{R}\right) = \tan^{-1}\left(\dfrac{0 - 66.3\ \Omega}{50.0\ \Omega}\right) = -53.0°$

so, $\boxed{\text{the voltage lags behind the current by } 53.0°}$

21.20 $X_L = 2\pi f L = 2\pi(60.0\ \text{Hz})(0.100\ \text{H}) = 37.7\ \Omega$

$X_C = \dfrac{1}{2\pi f C} = \dfrac{1}{2\pi(60.0\ \text{Hz})(10.0\times10^{-6}\ \text{F})} = 265\ \Omega$

$Z = \sqrt{R^2 + (X_L - X_C)^2} = \sqrt{(50.0\ \Omega)^2 + (37.7\ \Omega - 265\ \Omega)^2} = 233\ \Omega$

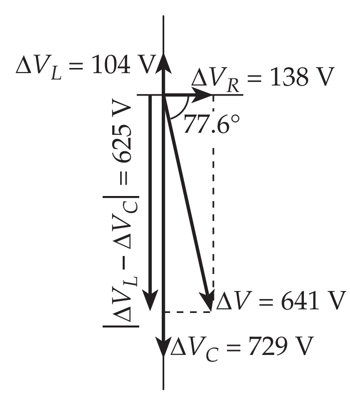
(a) $\Delta V_{R,\,\text{rms}} = I_{\text{rms}} R = (2.75\ \text{A})(50.0\ \Omega) = \boxed{138\ \text{V}}$

(b) $\Delta V_{L,\,\text{rms}} = I_{\text{rms}} X_L = (2.75\ \text{A})(37.7\ \Omega) = \boxed{104\ \text{V}}$

(c) $\Delta V_{C,\,\text{rms}} = I_{\text{rms}} X_C = (2.75\ \text{A})(265\ \Omega) = \boxed{729\ \text{V}}$

(d) $\Delta V_{\text{rms}} = I_{\text{rms}} Z = (2.75\ \text{A})(233\ \Omega) = \boxed{641\ \text{V}}$

(e)



21.21 (a) $X_L = 2\pi f L = 2\pi(240\text{ Hz})(2.5\text{ H}) = 3.8\times10^3\ \Omega$

$$X_C = \frac{1}{2\pi f C} = \frac{1}{2\pi(240\text{ Hz})(0.25\times10^{-6}\text{ F})} = 2.7\times10^3\ \Omega$$

$$Z = \sqrt{R^2 + (X_L - X_C)^2} = \sqrt{(900\ \Omega)^2 + \left[(3.8-2.7)\times10^3\ \Omega\right]^2} = \boxed{1.4\text{ k}\Omega}$$

(b) $I_{\max} = \dfrac{\Delta V_{\max}}{Z} = \dfrac{140\text{ V}}{1.4\times10^3\ \Omega} = \boxed{0.10\text{ A}}$

(c) $\phi = \tan^{-1}\left(\dfrac{X_L - X_C}{R}\right) = \tan^{-1}\left[\dfrac{(3.8-2.7)\times10^3\ \Omega}{900\ \Omega}\right] = \boxed{51^\circ}$

(d) $\phi > 0$, so $\boxed{\text{the voltage leads the current}}$

21.22 $X_C = \dfrac{1}{2\pi f C} = \dfrac{1}{2\pi(60\text{ Hz})(2.5\times10^{-6}\text{ F})} = 1.1\times10^3\ \Omega$

$$Z = \sqrt{R^2 + (X_L - X_C)^2} = \sqrt{(1.2\times10^3\ \Omega)^2 + (0 - 1.1\times10^3\ \Omega)^2} = 1.6\times10^3\ \Omega$$

(a) $I_{\max} = \dfrac{\Delta V_{\max}}{Z} = \dfrac{170\text{ V}}{1.6\times10^3\ \Omega} = \boxed{0.11\text{ A}}$

(b) $\Delta V_{R,\max} = I_{\max}R = (0.11\text{ A})(1.2\times10^3\ \Omega) = \boxed{1.3\times10^2\text{ V}}$

$$\Delta V_{C,\max} = I_{\max}X_C = (0.11\text{ A})(1.1\times10^3\ \Omega) = \boxed{1.1\times10^2\text{ V}}$$

(c) When the instantaneous current i is zero, the instantaneous voltage across the resistor is $\Delta v_R = iR = \boxed{0}$. The instantaneous voltage across a capacitor is always 90° or a quarter cycle out of phase with the instantaneous current. Thus, when $i = 0$,

$$\Delta v_C = \Delta V_{C,\max} = \boxed{1.1\times10^2\text{ V}}$$

and $\quad q_C = C(\Delta v_C) = (2.5\times10^{-6}\text{ F})(1.1\times10^2\text{ V}) = 2.8\times10^{-4}\text{ C} = \boxed{280\ \mu\text{C}}$

Kirchhoff's loop rule always applies to the instantaneous voltages around a closed path. Thus, for this series circuit, $\Delta v_{source} = \Delta v_R + \Delta v_C$ and at this instant when $i = 0$, we have $\Delta v_{source} = 0 + \Delta V_{C,\max} = \boxed{110\text{ V}}$

(d) When the instantaneous current is a maximum $(i = I_{\max})$, the instantaneous voltage across the resistor is $\Delta v_R = iR = I_{\max}R = \Delta V_{R,\max} = \boxed{1.3\times 10^2\text{ V}}$. Again, the instantaneous voltage across a capacitor is a quarter cycle out of phase with the current. Thus, when $i = I_{\max}$, we must have $\Delta v_C = \boxed{0}$ and $q_C = C(\Delta v_C) = \boxed{0}$. Then, applying Kirchhoff's loop rule to the instantaneous voltages around the series circuit at the instant when $i = I_{\max}$ gives

$$\Delta v_{source} = \Delta v_R + \Delta v_C = \Delta V_{R,\max} + 0 = \boxed{1.3\times 10^2\text{ V}}$$

21.23 $X_L = 2\pi fL = 2\pi(60.0\text{ Hz})(0.400\text{ H}) = 151\ \Omega$

$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(60.0\text{ Hz})(3.00\times 10^{-6}\text{ F})} = 884\ \Omega$$

$$Z_{RLC} = \sqrt{R^2 + (X_L - X_C)^2} = \sqrt{(60.0\ \Omega)^2 + (151\ \Omega - 884\ \Omega)^2} = 736\ \Omega$$

and $I_{\text{rms}} = \dfrac{\Delta V_{\text{rms}}}{Z_{RLC}}$

(a) $Z_{LC} = \sqrt{0 + (X_L - X_C)^2} = |X_L - X_C| = 733\ \Omega$

$$\Delta V_{LC,\text{rms}} = I_{\text{rms}}\cdot Z_{LC} = \left(\frac{\Delta V_{\text{rms}}}{Z_{RLC}}\right)Z_{LC} = \left(\frac{90.0\text{ V}}{736\ \Omega}\right)(733\ \Omega) = \boxed{89.6\text{ V}}$$

(b) $Z_{RC} = \sqrt{R^2 + (0 - X_C)^2} = \sqrt{(60.0\ \Omega)^2 + (884\ \Omega)^2} = 886\ \Omega$

$$\Delta V_{RC,\text{rms}} = I_{\text{rms}}\cdot Z_{RC} = \left(\frac{\Delta V_{\text{rms}}}{Z_{RLC}}\right)Z_{RC} = \left(\frac{90.0\text{ V}}{736\ \Omega}\right)(886\ \Omega) = \boxed{108\text{ V}}$$

21.24 $X_L = 2\pi fL = 2\pi(60\text{ Hz})(2.8\text{ H}) = 1.1\times 10^3\ \Omega$

$$Z = \sqrt{R^2 + (X_L - X_C)^2} = \sqrt{(1.2\times 10^3\ \Omega)^2 + (1.1\times 10^3\ \Omega - 0)^2} = 1.6\times 10^3\ \Omega$$

(a) $I_{\max} = \dfrac{\Delta V_{\max}}{Z} = \dfrac{170\text{ V}}{1.6\times 10^3\ \Omega} = \boxed{0.11\text{ A}}$

(b) $\Delta V_{R,\max} = I_{\max} R = (0.11 \text{ A})(1.2\times10^3\ \Omega) = \boxed{1.3\times10^2\ \text{V}}$

$\Delta V_{L,\max} = I_{\max} X_L = (0.11 \text{ A})(1.1\times10^3\ \Omega) = \boxed{1.1\times10^2\ \text{V}}$

(c) When the instantaneous current is a maximum $(i = I_{\max})$, the instantaneous voltage across the resistor is $\Delta v_R = iR = I_{\max}R = \Delta V_{R,\max} = \boxed{1.3\times10^2\ \text{V}}$. The instantaneous voltage across an inductor is always 90° or a quarter cycle out of phase with the instantaneous current. Thus, when $i = I_{\max}$, $\Delta v_L = \boxed{0}$.

Kirchhoff's loop rule always applies to the instantaneous voltages around a closed path. Thus, for this series circuit, $\Delta v_{source} = \Delta v_R + \Delta v_L$ and at this instant when $i = I_{\max}$ we have $\Delta v_{source} = I_{\max}R + 0 = \boxed{1.3\times10^2\ \text{V}}$

(d) When the instantaneous current i is zero, the instantaneous voltage across the resistor is $\Delta v_R = iR = \boxed{0}$. Again, the instantaneous voltage across an inductor is a quarter cycle out of phase with the current. Thus, when $i = 0$, we must have $\Delta v_L = \Delta V_{L,\max} = \boxed{1.1\times10^2\ \text{V}}$. Then, applying Kirchhoff's loop rule to the instantaneous voltages around the series circuit at the instant when $i = 0$ gives $\Delta v_{source} = \Delta v_R + \Delta v_L = 0 + \Delta V_{L,\max} = \boxed{1.1\times10^2\ \text{V}}$

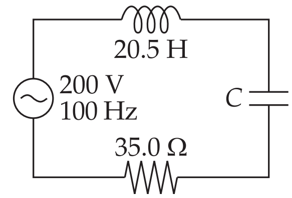
21.25 $$X_C = \frac{1}{2\pi f C} = \frac{1}{2\pi(60.0\text{ Hz})(20.0\times10^{-12}\text{ F})} = 1.33\times10^8\ \Omega$$

$$Z_{RC} = \sqrt{R^2 + X_C^2} = \sqrt{(50.0\times10^3\ \Omega)^2 + (1.33\times10^8\ \Omega)^2} = 1.33\times10^8\ \Omega$$

and $$I_{\text{rms}} = \frac{(\Delta V_{secondary})_{\text{rms}}}{Z_{RC}} = \frac{5\,000\text{ V}}{1.33\times10^8\ \Omega} = 3.76\times10^{-5}\text{ A}$$

Therefore, $$\Delta V_{b,\text{rms}} = I_{\text{rms}} R_b = (3.76\times10^{-5}\text{ A})(50.0\times10^3\ \Omega) = \boxed{1.88\text{ V}}$$

21.26 (a) $X_L = 2\pi f L = 2\pi(100 \text{ Hz})(20.5 \text{ H}) = 1.29\times10^4 \ \Omega$



$$Z = \frac{\Delta V_{\text{rms}}}{I_{\text{rms}}} = \frac{200 \text{ V}}{4.00 \text{ A}} = 50.0 \ \Omega$$

Thus,

$$X_L - X_C = \pm\sqrt{Z^2 - R^2} = \pm\sqrt{(50.0 \ \Omega)^2 - (35.0 \ \Omega)^2} = \pm 35.7 \ \Omega$$

and $X_C = X_L \pm 35.7 \ \Omega$ or $\dfrac{1}{2\pi f C} = 1.29\times10^4 \ \Omega \ \pm \ 35.7 \ \Omega$

This yields

$$C = \frac{1}{2\pi(100 \text{ Hz})\left(1.29\times10^4 \ \Omega \ \pm \ 35.7 \ \Omega\right)} = \boxed{123 \text{ nF or } 124 \text{ nF}}$$

(b) $\left(\Delta V_{\text{rms}}\right)_{coil} = I_{\text{rms}} Z_{coil} = I\sqrt{R^2 + X_L^2} = (4.00 \text{ A})\sqrt{(50.0 \ \Omega)^2 + \left(1.29\times10^4 \ \Omega\right)^2}$

$$= 5.15\times10^4 \text{ V} = \boxed{51.5 \text{ kV}}$$

Notice that this is a very large voltage!

21.27 $X_L = 2\pi f L = 2\pi(50.0 \text{ Hz})(0.185 \text{ H}) = 58.1 \ \Omega$

$$X_C = \frac{1}{2\pi f C} = \frac{1}{2\pi(50.0 \text{ Hz})\left(65.0\times10^{-6} \text{ F}\right)} = 49.0 \ \Omega$$

$$Z_{ad} = \sqrt{R^2 + \left(X_L - X_C\right)^2} = \sqrt{(40.0 \ \Omega)^2 + (58.1 \ \Omega - 49.0 \ \Omega)^2} = 41.0 \ \Omega$$

and $$I_{\text{rms}} = \frac{\Delta V_{\text{rms}}}{Z_{ad}} = \frac{\left(\Delta V_{\max}/\sqrt{2}\right)}{Z_{ad}} = \frac{150 \text{ V}}{(41.0 \ \Omega)\sqrt{2}} = 2.585 \text{ A}$$

(a) $Z_{ab} = R = 40.0 \ \Omega$, so $\left(\Delta V_{\text{rms}}\right)_{ab} = I_{\text{rms}} Z_{ab} = (2.585 \text{ A})(40.0 \ \Omega) = \boxed{103 \text{ V}}$

(b) $Z_{bc} = X_L = 58.1 \ \Omega$, and $\left(\Delta V_{\text{rms}}\right)_{bc} = I_{\text{rms}} Z_{bc} = (2.585 \text{ A})(58.1 \ \Omega) = \boxed{150 \text{ V}}$

(c) $Z_{cd} = X_C = 49.0 \ \Omega$, and $\left(\Delta V_{\text{rms}}\right)_{cd} = I_{\text{rms}} Z_{cd} = (2.585 \text{ A})(49.0 \ \Omega) = \boxed{127 \text{ V}}$

(d) $Z_{bd} = |X_L - X_C| = 9.15\ \Omega$, so $(\Delta V_{\rm rms})_{bd} = I_{\rm rms} Z_{bd} = (2.585\ \text{A})(9.15\ \Omega) = \boxed{23.6\ \text{V}}$

21.28 (a) $$X_C = \frac{1}{2\pi f C} = \frac{1}{2\pi(60.0\ \text{Hz})(30.0\times10^{-6}\ \text{F})} = 88.4\ \Omega$$

$$Z = \sqrt{R^2 + X_C^2} = \sqrt{(50.0\ \Omega)^2 + (88.4\ \Omega)^2} = 102\ \Omega$$

$$I_{\rm rms} = \frac{\Delta V_{\rm rms}}{Z} = \frac{100\ \text{V}}{102\ \Omega} = 0.984\ \text{A}$$

$$\phi = \tan^{-1}\left(\frac{0 - X_C}{R}\right) = \tan^{-1}\left(\frac{-88.4\ \Omega}{50.0\ \Omega}\right) = -60.5°$$

and $$\textit{power factor} = \cos\phi = \cos(-60.5°) = \boxed{0.492}$$

$$\mathcal{P}_{\rm av} = (\Delta V_{\rm rms}) I_{\rm rms} \cos\phi = (100\ \text{V})(0.984\ \text{A})(0.492) = \boxed{48.5\ \text{W}}$$

(b) $$X_L = 2\pi f L = 2\pi(60.0\ \text{Hz})(0.300\ \text{H}) = 113\ \Omega$$

$$Z = \sqrt{R^2 + X_L^2} = \sqrt{(50.0\ \Omega)^2 + (113\ \Omega)^2} = 124\ \Omega$$

$$I_{\rm rms} = \frac{\Delta V_{\rm rms}}{Z} = \frac{100\ \text{V}}{124\ \Omega} = 0.809\ \text{A}$$

$$\phi = \tan^{-1}\left(\frac{X_C - 0}{R}\right) = \tan^{-1}\left(\frac{113\ \Omega}{50.0\ \Omega}\right) = 66.1°$$

and $$\textit{power factor} = \cos\phi = \cos(66.1°) = \boxed{0.404}$$

$$\mathcal{P}_{\rm av} = (\Delta V_{\rm rms}) I_{\rm rms} \cos\phi = (100\ \text{V})(0.809\ \text{A})(0.404) = \boxed{32.7\ \text{W}}$$

21.29 (a) $$Z = \frac{\Delta V_{\rm rms}}{I_{\rm rms}} = \frac{104\ \text{V}}{0.500\ \text{A}} = \boxed{208\ \Omega}$$

(b) $\mathcal{P}_{\rm av} = I_{\rm rms}^2 R$ gives $R = \dfrac{\mathcal{P}_{\rm av}}{I_{\rm rms}^2} = \dfrac{10.0\ \text{W}}{(0.500\ \text{A})^2} = \boxed{40.0\ \Omega}$

(c) $Z=\sqrt{R^2+X_L^2}$, so $X_L=\sqrt{Z^2-R^2}=\sqrt{(208\ \Omega)^2-(40.0\ \Omega)^2}=204\ \Omega$

and $L=\dfrac{X_L}{2\pi f}=\dfrac{204\ \Omega}{2\pi(60.0\ \text{Hz})}=\boxed{0.541\ \text{H}}$

21.30 (a) $X_L=2\pi fL=2\pi(60.0\ \text{Hz})(0.100\ \text{H})=37.7\ \Omega$

$$X_C=\frac{1}{2\pi fC}=\frac{1}{2\pi(60.0\ \text{Hz})\left(200\times10^{-6}\ \text{F}\right)}=13.3\ \Omega$$

$$Z=\sqrt{R^2+(X_L-X_C)^2}=\sqrt{(20.0\ \Omega)^2+(37.7\ \Omega-13.3\ \Omega)^2}=31.6\ \Omega$$

$$\mathcal{P}_{\text{av}}=I_{\text{rms}}^2R=\left(\frac{I_{\text{max}}}{\sqrt{2}}\right)^2R=\frac{1}{2}\left(\frac{\Delta V_{\text{max}}}{Z}\right)^2R=\frac{1}{2}\left(\frac{100\ \text{V}}{31.6\ \Omega}\right)^2(20.0\ \Omega)=\boxed{100\ \text{W}}$$

and *power factor* $=\cos\phi=\dfrac{\mathcal{P}_{\text{av}}}{\Delta V_{\text{rms}}I_{\text{rms}}}=\dfrac{I_{\text{rms}}^2R}{\Delta V_{\text{rms}}I_{\text{rms}}}=\left(\dfrac{I_{\text{rms}}}{\Delta V_{\text{rms}}}\right)R=\dfrac{R}{Z}=\dfrac{20.0\ \Omega}{31.6\ \Omega}=\boxed{0.633}$

(b) The same calculations as shown in Part (a) above, with $f=50.0\ \text{Hz}$, give

$X_L=31.4\ \Omega$, $X_C=15.9\ \Omega$, $Z=25.3\ \Omega$, $\mathcal{P}_{\text{av}}=\boxed{156\ \text{W}}$ and *power factor* $=\boxed{0.790}$

21.31 (a) $\mathcal{P}_{\text{av}}=I_{\text{rms}}^2R=I_{\text{rms}}(I_{\text{rms}}R)=I_{\text{rms}}\left(\Delta V_{R,\,\text{rms}}\right)$, so $I_{\text{rms}}=\dfrac{\mathcal{P}_{\text{av}}}{\Delta V_{R,\,\text{rms}}}=\dfrac{14\ \text{W}}{50\ \text{V}}=0.28\ \text{A}$

Thus, $R=\dfrac{\Delta V_{R,\,\text{rms}}}{I_{\text{rms}}}=\dfrac{50\ \text{V}}{0.28\ \text{A}}=\boxed{1.8\times10^2\ \Omega}$

(b) $Z=\sqrt{R^2+X_L^2}$, which yields

$$X_L=\sqrt{Z^2-R^2}=\sqrt{\left(\frac{\Delta V_{\text{rms}}}{I_{\text{rms}}}\right)^2-R^2}=\sqrt{\left(\frac{90\ \text{V}}{0.28\ \text{A}}\right)^2-\left(1.8\times10^2\ \Omega\right)^2}=2.7\times10^2\ \Omega$$

and $L=\dfrac{X_L}{2\pi f}=\dfrac{2.7\times10^2\ \Omega}{2\pi(60\ \text{Hz})}=\boxed{0.71\ \text{H}}$

21.32 $X_L = 2\pi fL = 2\pi(600\text{ Hz})(6.0\times10^{-3}\text{ H}) = 23\ \Omega$

$$X_C = \frac{1}{2\pi fC} = \frac{1}{2\pi(600\text{ Hz})(25\times10^{-6}\text{ F})} = 11\ \Omega$$

$$Z = \sqrt{R^2 + (X_L - X_C)^2} = \sqrt{(25\ \Omega)^2 + (23\ \Omega - 11\ \Omega)^2} = 28\ \Omega$$

(a) $\Delta V_{R,\text{ rms}} = I_{\text{rms}}R = \left(\frac{\Delta V_{\text{rms}}}{Z}\right)R = \left(\frac{10\text{ V}}{28\ \Omega}\right)(25\ \Omega) = 9.0\text{ V}$

$$\Delta V_{L,\text{ rms}} = I_{\text{rms}}X_L = \left(\frac{\Delta V_{\text{rms}}}{Z}\right)X_L = \left(\frac{10\text{ V}}{28\ \Omega}\right)(23\ \Omega) = 8.2\text{ V}$$

$$\Delta V_{C,\text{ rms}} = I_{\text{rms}}X_C = \left(\frac{\Delta V_{\text{rms}}}{Z}\right)X_C = \left(\frac{10\text{ V}}{28\ \Omega}\right)(11\ \Omega) = 3.8\text{ V}$$

$\boxed{\text{No}}$, $\Delta V_{R,\text{ rms}} + \Delta V_{L,\text{ rms}} + \Delta V_{C,\text{ rms}} = 9.0\text{ V} + 8.2\text{ V} + 3.8\text{ V} = 21\text{ V} \neq 10\text{ V}$

However, observe that if we take phases into account and add these voltages vectorially, we find

$$\sqrt{(\Delta V_{R,\text{ rms}})^2 + (\Delta V_{L,\text{ rms}} - \Delta V_{C,\text{ rms}})^2} = \sqrt{(9.0\text{ V})^2 + (8.2\text{ V} - 3.8\text{ V})^2} = 10\text{ V} = \Delta V_{\text{rms}}$$

(b) The $\boxed{\text{power delivered to the resistor}}$ is the greatest. No power losses occur in an ideal capacitor or inductor.

(c) $\mathcal{P} = I_{\text{rms}}^2 R = \left(\frac{\Delta V_{\text{rms}}}{Z}\right)^2 R = \left(\frac{10\text{ V}}{28\ \Omega}\right)^2 (25\ \Omega) = \boxed{3.3\text{ W}}$

21.33 The resonance frequency of the circuit should match the broadcast frequency of the station.

$$f_0 = \frac{1}{2\pi\sqrt{LC}} \text{ gives } L = \frac{1}{4\pi^2 f_0^2 C},$$

or $$L = \frac{1}{4\pi^2(88.9\times10^6\text{ Hz})^2(1.40\times10^{-12}\text{ F})} = 2.29\times10^{-6}\text{ H} = \boxed{2.29\ \mu\text{H}}$$

21.34 (a) At resonance, $X_L = X_C$ so the impedance will be

$$Z = \sqrt{R^2 + \left(X_L - X_C\right)^2} = \sqrt{R^2 + 0} = R = \boxed{15\ \Omega}$$

(b) When $X_L = X_C$, we have $2\pi fL = \dfrac{1}{2\pi fC}$ which yields

$$f = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{(0.20\text{ H})\left(75\times10^{-6}\text{ F}\right)}} = \boxed{41\text{ Hz}}$$

(c) The current is a maximum $\boxed{\text{at resonance}}$ where the impedance has its minimum value of $Z = R$.

(d) At $f = 60\text{ Hz}$, $X_L = 2\pi(60\text{ Hz})(0.20\text{ H}) = 75\ \Omega$, $X_C = \dfrac{1}{2\pi(60\text{ Hz})\left(75\times10^{-6}\text{ F}\right)} = 35\ \Omega$,

and $Z = \sqrt{(15\ \Omega)^2 + (75\ \Omega - 35\ \Omega)^2} = 43\ \Omega$

Thus, $I_{\text{rms}} = \dfrac{\Delta V_{\text{rms}}}{Z} = \dfrac{\left(\Delta V_{\max}/\sqrt{2}\right)}{Z} = \dfrac{150\text{ V}}{\sqrt{2}(43\ \Omega)} = \boxed{2.5\text{ A}}$

21.35 $f_0 = \dfrac{1}{2\pi\sqrt{LC}}$, so $C = \dfrac{1}{4\pi^2 f_0^2 L}$

For $f_0 = (f_0)_{\min} = 500\text{ kHz} = 5.00\times10^5\text{ Hz}$

$$C = C_{\max} = \frac{1}{4\pi^2\left(5.00\times10^5\text{ Hz}\right)^2\left(2.0\times10^{-6}\text{ H}\right)} = 5.1\times10^{-8}\text{ F} = \boxed{51\text{ nF}}$$

For $f_0 = (f_0)_{\max} = 1600\text{ kHz} = 1.60\times10^6\text{ Hz}$

$$C = C_{\min} = \frac{1}{4\pi^2\left(1.60\times10^6\text{ Hz}\right)^2\left(2.0\times10^{-6}\text{ H}\right)} = 4.9\times10^{-9}\text{ F} = \boxed{4.9\text{ nF}}$$

21.36 The resonance frequency is $\omega_0 = 2\pi f_0 = \dfrac{1}{\sqrt{LC}}$

Also, $X_L = \omega L$ and $X_C = \dfrac{1}{\omega C}$

(a) At resonance, $X_C = X_L = \omega_0 L = \left(\dfrac{1}{\sqrt{LC}}\right)L = \sqrt{\dfrac{L}{C}} = \sqrt{\dfrac{3.00\text{ H}}{3.00\times10^{-6}\text{ F}}} = 1\,000\ \Omega$

Thus, $Z = \sqrt{R^2 + 0^2} = R$, $I_{\text{rms}} = \dfrac{\Delta V_{\text{rms}}}{Z} = \dfrac{120\text{ V}}{30.0\ \Omega} = 4.00\text{ A}$

and $\mathcal{P}_{\text{av}} = I_{\text{rms}}^2 R = (4.00\text{ A})^2(30.0\ \Omega) = \boxed{480\text{ W}}$

(b) At $\omega = \dfrac{1}{2}\omega_0$; $X_L = \dfrac{1}{2}\left(X_L\big|_{\omega_0}\right) = 500\ \Omega$, $X_C = 2\left(X_C\big|_{\omega_0}\right) = 2\,000\ \Omega$

$$Z = \sqrt{R^2 + (X_L - X_C)^2} = \sqrt{(30.0\ \Omega)^2 + (500\ \Omega - 2\,000\ \Omega)^2} = 1\,500\ \Omega$$

and $I_{\text{rms}} = \dfrac{120\text{ V}}{1\,500\ \Omega} = 0.080\,0\text{ A}$

so $\mathcal{P}_{\text{av}} = I_{\text{rms}}^2 R = (0.080\,0\text{ A})^2(30.0\ \Omega) = \boxed{0.192\text{ W}}$

(c) At $\omega = \dfrac{1}{4}\omega_0$; $X_L = \dfrac{1}{4}\left(X_L\big|_{\omega_0}\right) = 250\ \Omega$, $X_C = 4\left(X_C\big|_{\omega_0}\right) = 4\,000\ \Omega$

$Z = 3\,750\ \Omega$, and $I_{\text{rms}} = \dfrac{120\text{ V}}{3\,750\ \Omega} = 0.032\,0\text{ A}$

so $\mathcal{P}_{\text{av}} = I_{\text{rms}}^2 R = (0.032\,0\text{ A})^2(30.0\ \Omega) = 3.07\times10^{-2}\text{ W} = \boxed{30.7\text{ mW}}$

(d) At $\omega = 2\omega_0$; $X_L = 2\left(X_L\big|_{\omega_0}\right) = 2\,000\ \Omega$, $X_C = \dfrac{1}{2}\left(X_C\big|_{\omega_0}\right) = 500\ \Omega$

$Z = 1\,500\ \Omega$, and $I_{\text{rms}} = \dfrac{120\text{ V}}{1\,500\ \Omega} = 0.080\,0\text{ A}$

so $\mathcal{P}_{\text{av}} = I_{\text{rms}}^2 R = (0.080\,0\text{ A})^2(30.0\ \Omega) = \boxed{0.192\text{ W}}$

(e) At $\omega = 4\omega_0$; $X_L = 4\left(X_L\big|_{\omega_0}\right) = 4\,000\ \Omega$, $X_C = \frac{1}{4}\left(X_C\big|_{\omega_0}\right) = 250\ \Omega$

$$Z = 3\,750\ \Omega\text{, and } I_{\text{rms}} = \frac{120\ \text{V}}{3\,750\ \Omega} = 0.032\,0\ \text{A}$$

$$\text{so } \mathcal{P}_{\text{av}} = I_{\text{rms}}^2 R = (0.032\,0\ \text{A})^2(30.0\ \Omega) = 3.07\times10^{-2}\ \text{W} = \boxed{30.7\ \text{mW}}$$

The power delivered to the circuit is a maximum when the rms current is a maximum. This occurs when the frequency of the source is equal to the resonance frequency of the circuit.

21.37

$$\omega_0 = 2\pi f_0 = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{(10.0\times10^{-3}\ \text{H})(100\times10^{-6}\ \text{F})}} = 1\,000\ \text{rad/s}$$

Thus, $\omega = 2\omega_0 = 2\,000\ \text{rad/s}$

$$X_L = \omega L = (2\,000\ \text{rad/s})(10.0\times10^{-3}\ \text{H}) = 20.0\ \Omega$$

$$X_C = \frac{1}{\omega C} = \frac{1}{(2\,000\ \text{rad/s})(100\times10^{-6}\ \text{F})} = 5.00\ \Omega$$

$$Z = \sqrt{R^2 + (X_L - X_C)^2} = \sqrt{(10.0\ \Omega)^2 + (20.0\ \Omega - 5.00\ \Omega)^2} = 18.0\ \Omega$$

$$I_{\text{rms}} = \frac{\Delta V_{\text{rms}}}{Z} = \frac{50.0\ \text{V}}{18.0\ \Omega} = 2.77\ \text{A}$$

The average power is $\mathcal{P}_{\text{av}} = I_{\text{rms}}^2 R = (2.77\ \text{A})^2(10.0\ \Omega) = 76.9\ \text{W}$

and the energy converted in one period is

$$E = \mathcal{P}_{\text{av}}\cdot T = \mathcal{P}_{\text{av}}\cdot\left(\frac{2\pi}{\omega}\right) = \left(76.9\ \frac{\text{J}}{\text{s}}\right)\cdot\left(\frac{2\pi}{2\,000\ \text{rad/s}}\right) = \boxed{0.242\ \text{J}}$$

21.38 (a) $\Delta V_{2,\,\text{rms}} = \frac{N_2}{N_1}\left(\Delta V_{1,\,\text{rms}}\right)$

$$\text{so } N_2 = N_1\left(\frac{\Delta V_{2,\,\text{rms}}}{\Delta V_{1,\,\text{rms}}}\right) = (240\ \text{turns})\left(\frac{9.0\ \text{V}}{120\ \text{V}}\right) = \boxed{18\ \text{turns}}$$

(b) For an ideal transformer, $(\mathcal{P}_{\text{av}})_{input} = (\mathcal{P}_{\text{av}})_{ouput} = (\Delta V_{2,\,\text{rms}})I_{2,\,\text{rms}}$

Thus, $(\mathcal{P}_{\text{av}})_{input} = (9.0\text{ V})(0.400\text{ A}) = \boxed{3.6\text{ W}}$

21.39 The power input to the transformer is

$$\mathcal{P}_{input} = (\Delta V_{1,\,\text{rms}})I_{1,\,\text{rms}} = (3\,600\text{ V})(50\text{ A}) = 1.8\times10^{5}\text{ W}$$

For an ideal transformer, $(\mathcal{P}_{\text{av}})_{ouput} = (\Delta V_{2,\,\text{rms}})I_{2,\,\text{rms}} = (\mathcal{P}_{\text{av}})_{input}$ so the current in the long-distance power line is

$$I_{2,\,\text{rms}} = \frac{(\mathcal{P}_{\text{av}})_{input}}{(\Delta V_{2,\,\text{rms}})} = \frac{1.8\times10^{5}\text{ W}}{100\,000\text{ V}} = 1.8\text{ A}$$

The power dissipated as heat in the line is then

$$\mathcal{P}_{lost} = I^{2}_{2,\,\text{rms}}R_{line} = (1.8\text{ A})^{2}(100\ \Omega) = 3.2\times10^{2}\text{ W}$$

The percentage of the power delivered by the generator that is lost in the line is

$$\%\text{ Lost} = \frac{\mathcal{P}_{lost}}{\mathcal{P}_{input}}\times100\% = \left(\frac{3.2\times10^{2}\text{ W}}{1.8\times10^{5}\text{ W}}\right)\times100\% = \boxed{0.18\%}$$

21.40 (a) Since the transformer is to step the voltage *down* from 120 volts to 6.0 volts, the secondary must have $\boxed{\text{fewer turns}}$ than the primary.

(b) For an ideal transformer, $(\mathcal{P}_{\text{av}})_{input} = (\mathcal{P}_{\text{av}})_{ouput}$ or $(\Delta V_{1,\,\text{rms}})I_{1,\,\text{rms}} = (\Delta V_{2,\,\text{rms}})I_{2,\,\text{rms}}$ so the current in the primary will be

$$I_{1,\,\text{rms}} = \frac{(\Delta V_{2,\,\text{rms}})I_{2,\,\text{rms}}}{\Delta V_{1,\,\text{rms}}} = \frac{(6.0\text{ V})(500\text{ mA})}{120\text{ V}} = \boxed{25\text{ mA}}$$

(c) The ratio of the secondary to primary voltages is the same as the ratio of the number of turns on the secondary and primary coils, $\Delta V_2/\Delta V_1 = N_2/N_1$. Thus, the number of turns needed on the secondary coil of this step down transformer is

$$N_2 = N_1\left(\frac{\Delta V_2}{\Delta V_1}\right) = (400)\left(\frac{6.0\text{ V}}{120\text{ V}}\right) = \boxed{20\text{ turns}}$$

21.41 (a) At 90% efficiency, $(\mathcal{P}_{\text{av}})_{output} = 0.90(\mathcal{P}_{\text{av}})_{input}$

Thus, if $(\mathcal{P}_{\text{av}})_{output} = 1\,000 \text{ kW}$

the input power to the primary is $(\mathcal{P}_{\text{av}})_{input} = \dfrac{(\mathcal{P}_{\text{av}})_{output}}{0.90} = \dfrac{1\,000 \text{ kW}}{0.90} = \boxed{1.1\times 10^{3} \text{ kW}}$

(b) $I_{1,\text{rms}} = \dfrac{(\mathcal{P}_{\text{av}})_{input}}{\Delta V_{1,\text{rms}}} = \dfrac{1.1\times 10^{3} \text{ kW}}{\Delta V_{1,\text{rms}}} = \dfrac{1.1\times 10^{6} \text{ W}}{3\,600 \text{ V}} = \boxed{3.1\times 10^{2} \text{ A}}$

(c) $I_{2,\text{rms}} = \dfrac{(\mathcal{P}_{\text{av}})_{output}}{\Delta V_{2,\text{rms}}} = \dfrac{1\,000 \text{ kW}}{\Delta V_{1,\text{rms}}} = \dfrac{1.0\times 10^{6} \text{ W}}{120 \text{ V}} = \boxed{8.3\times 10^{3} \text{ A}}$

21.42 $R_{line} = \left(4.50\times 10^{-4} \ \Omega/\text{m}\right)\left(6.44\times 10^{5} \text{ m}\right) = 290 \ \Omega$

(a) The power transmitted is $(\mathcal{P}_{\text{av}})_{transmitted} = (\Delta V_{\text{rms}})I_{\text{rms}}$

so $I_{\text{rms}} = \dfrac{(\mathcal{P}_{\text{av}})_{transmitted}}{\Delta V_{\text{rms}}} = \dfrac{5.00\times 10^{6} \text{ W}}{500\times 10^{3} \text{ V}} = 10.0 \text{ A}$

Thus, $(\mathcal{P}_{\text{av}})_{loss} = I_{\text{rms}}^2 R_{line} = (10.0 \text{ A})^2 (290 \ \Omega) = 2.90\times 10^{4} \text{ W} = \boxed{29.0 \text{ kW}}$

(b) The power input to the line is

$$(\mathcal{P}_{\text{av}})_{input} = (\mathcal{P}_{\text{av}})_{transmitted} + (\mathcal{P}_{\text{av}})_{loss} = 5.00\times 10^{6} \text{ W} + 2.90\times 10^{4} \text{ W} = 5.03\times 10^{6} \text{ W}$$

and the fraction of input power lost during transmission is

$$fraction = \frac{(\mathcal{P}_{\text{av}})_{loss}}{(\mathcal{P}_{\text{av}})_{input}} = \frac{2.90\times 10^{4} \text{ W}}{5.03\times 10^{6} \text{ W}} = \boxed{0.005\,80 \ \text{ or } \ 0.580\%}$$

(c) It is impossible to deliver the needed power with an input voltage of 4.50 kV. The maximum line current with an input voltage of 4.50 kV occurs when the line is shorted out at the customer's end, and this current is

$$\left(I_{\text{rms}}\right)_{\text{max}} = \frac{\Delta V_{\text{rms}}}{R_{line}} = \frac{4\,500\text{ V}}{290\ \Omega} = 15.5\text{ A}$$

The maximum input power is then

$$\left(\mathcal{P}_{input}\right)_{\text{max}} = \left(\Delta V_{\text{rms}}\right)\left(I_{\text{rms}}\right)_{\text{max}}$$

$$= \left(4.50\times10^{3}\text{ V}\right)\left(15.5\text{ A}\right) = 6.98\times10^{4}\text{ W} = 6.98\text{ kW}$$

This is far short of meeting the customer's request, and all of this power is lost in the transmission line.

21.43 From $v = \lambda f$, the wavelength is

$$\lambda = \frac{v}{f} = \frac{3.00\times10^{8}\text{ m/s}}{75\text{ Hz}} = 4.00\times10^{6}\text{ m} = 4\,000\text{ km}$$

The required length of the antenna is then,

$L = \lambda/4 = \boxed{1\,000\text{ km}}$, or about 621 miles. Not very practical at all.

21.44 $$c = \frac{1}{\sqrt{\mu_0 \in_0}} = \frac{1}{\sqrt{\left(4\pi\times10^{-7}\text{ N}\cdot\text{s}^2/\text{C}^2\right)\left(8.854\times10^{-12}\text{ C}^2/\text{N}\cdot\text{m}^2\right)}}$$

or $c = \boxed{2.998\times10^{8}\text{ m/s}}$

21.45 (a) The frequency of an electromagnetic wave is $f = c/\lambda$, where c is the speed of light, and λ is the wavelength of the wave. The frequencies of the two light sources are then

Red: $$f_{red} = \frac{c}{\lambda_{red}} = \frac{3.00\times10^{8}\text{ m/s}}{660\times10^{-9}\text{ m}} = \boxed{4.55\times10^{14}\text{ Hz}}$$

and

Infrared: $$f_{IR} = \frac{c}{\lambda_{IR}} = \frac{3.00\times10^{8}\text{ m/s}}{940\times10^{-9}\text{ m}} = \boxed{3.19\times10^{14}\text{ Hz}}$$

(b) The intensity of an electromagnetic wave is proportional to the square of its amplitude. If 67% of the incident intensity of the red light is absorbed, then the intensity of the emerging wave is $(100\% - 67\%) = 33\%$ of the incident intensity, or $I_f = 0.33 I_i$. Hence, we must have

$$\frac{E_{\max,\,f}}{E_{\max,\,i}} = \sqrt{\frac{I_f}{I_i}} = \sqrt{0.33} = \boxed{0.57}$$

21.46 If I_0 is the incident intensity of a light beam, and I is the intensity of the beam after passing through length L of a fluid having concentration C of absorbing molecules, the Beer-Lambert law states that $\log_{10}(I/I_0) = -\varepsilon CL$ where ε is a constant.

For 660-nm light, the absorbing molecules are oxygenated hemoglobin. Thus, if 33% of this wavelength light is transmitted through blood, the concentration of oxygenated hemoglobin in the blood is

$$C_{HBO2} = \frac{-\log_{10}(0.33)}{\varepsilon L} \qquad [1]$$

The absorbing molecules for 940-nm light are deoxygenated hemoglobin, so if 76% of this light is transmitted through the blood, the concentration of these molecules in the blood is

$$C_{HB} = \frac{-\log_{10}(0.76)}{\varepsilon L} \qquad [2]$$

Dividing equation [2] by equation [1] gives the ratio of deoxygenated hemoglobin to oxygenated hemoglobin in the blood as

$$\frac{C_{HB}}{C_{HBO2}} = \frac{\log_{10}(0.76)}{\log_{10}(0.33)} = 0.25 \quad \text{or} \quad C_{HB} = 0.25 C_{HBO2}$$

Since all the hemoglobin in the blood is either oxygenated or deoxygenated, it is necessary that $C_{HB} + C_{HBO2} = 1.00$, and we now have $0.25 C_{HBO2} + C_{HBO2} = 1.0$. The fraction of hemoglobin that is oxygenated in this blood is then

$$C_{HBO2} = \frac{1.0}{1.0 + 0.25} = 0.80 \quad \text{or} \quad \boxed{80\%}$$

Someone with only 80% oxygenated hemoglobin in the blood is probably in serious trouble needing supplemental oxygen immediately.

21.47 The distance between adjacent antinodes in a standing wave is $\lambda/2$

Thus, $\lambda = 2(6.00 \text{ cm}) = 12.0 \text{ cm} = 0.120 \text{ m}$, and

$$c = \lambda f = (0.120 \text{ m})(2.45\times10^{9} \text{ Hz}) = \boxed{2.94\times10^{8} \text{ m/s}}$$

21.48 At Earth's location, the wave fronts of the solar radiation are spheres whose radius is the Sun-Earth distance. Thus, from $Intensity = \dfrac{\mathcal{P}_{\text{av}}}{A} = \dfrac{\mathcal{P}_{\text{av}}}{4\pi r^2}$, the total power is

$$\mathcal{P}_{\text{av}} = (Intensity)(4\pi r^2) = \left(1\,340 \ \frac{\text{W}}{\text{m}^2}\right)\left[4\pi\left(1.49\times10^{11} \text{ m}\right)^2\right] = \boxed{3.74\times10^{26} \text{ W}}$$

21.49 From $Intensity = \dfrac{E_{\max}B_{\max}}{2\mu_0}$ and $\dfrac{E_{\max}}{B_{\max}} = c$, we find $Intensity = \dfrac{cB_{\max}^2}{2\mu_0}$

Thus,

$$B_{\max} = \sqrt{\frac{2\mu_0}{c}(Intensity)} = \sqrt{\frac{2\left(4\pi\times10^{-7} \text{ T}\cdot\text{m/A}\right)}{3.00\times10^{8} \text{ m/s}}\left(1\,340 \text{ W/m}^2\right)} = \boxed{3.35\times10^{-6} \text{ T}}$$

and $$E_{\max} = B_{\max}c = \left(3.35\times10^{-6} \text{ T}\right)\left(3.00\times10^{8} \text{ m/s}\right) = \boxed{1.01\times10^{3} \text{ V/m}}$$

21.50 $$\lambda = \frac{c}{f} = \frac{3.00\times10^{8} \text{ m/s}}{27.33\times10^{6} \text{ Hz}} = \boxed{11.0 \text{ m}}$$

21.51 (a) For the AM band,

$$\lambda_{\min} = \frac{c}{f_{\max}} = \frac{3.00\times10^{8} \text{ m/s}}{1\,600\times10^{3} \text{ Hz}} = \boxed{188 \text{ m}}$$

$$\lambda_{\max} = \frac{c}{f_{\min}} = \frac{3.00\times10^{8} \text{ m/s}}{540\times10^{3} \text{ Hz}} = \boxed{556 \text{ m}}$$

(b) For the FM band,

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

$$\lambda_{\max} = \frac{c}{f_{\min}} = \frac{3.00 \times 10^8 \text{ m/s}}{88 \times 10^6 \text{ Hz}} = \boxed{3.4 \text{ m}}$$

21.52 The transit time for the radio wave is

$$t_R = \frac{d_R}{c} = \frac{100 \times 10^3 \text{ m}}{3.00 \times 10^8 \text{ m/s}} = 3.33 \times 10^{-4} \text{ s} = 0.333 \text{ ms}$$

and that for the sound wave is

$$t_s = \frac{d_s}{v_{sound}} = \frac{3.0 \text{ m}}{343 \text{ m/s}} = 8.7 \times 10^{-3} \text{ s} = 8.7 \text{ ms}$$

Thus, $\boxed{\text{the radio listeners hear the news 8.4 ms before the studio audience}}$ because radio waves travel so much faster than sound waves.

21.53 If an object of mass *m* is attached to a spring of spring constant *k*, the natural frequency of vibration of that system is $f = \sqrt{k/m}/2\pi$. Thus, the resonance frequency of the C=O double bond will be

$$f = \frac{1}{2\pi}\sqrt{\frac{k}{m_{\substack{oxygen\\atom}}}} = \frac{1}{2\pi}\sqrt{\frac{2\,800 \text{ N/m}}{2.66 \times 10^{-26} \text{ kg}}} = \boxed{5.2 \times 10^{13} \text{ Hz}}$$

and the light with this frequency has wavelength

$$\lambda = \frac{c}{f} = \frac{3.00 \times 10^8 \text{ m/s}}{5.2 \times 10^{13} \text{ Hz}} = 5.8 \times 10^{-6} \text{ m} = \boxed{5.8 \ \mu\text{m}}$$

The infrared region of the electromagnetic spectrum ranges from $\lambda_{\max} \approx 1 \text{ mm}$ down to $\lambda_{\min} = 700 \text{ nm} = 0.7 \ \mu\text{m}$. Thus, the $\boxed{\text{required wavelength falls within the infrared region}}$.

21.54 Since the space station and the ship are moving toward one another, the frequency after being Doppler shifted is $f_O = f_S(1+u/c)$, so the change in frequency is

$$\Delta f = f_O - f_S = f_S\left(\frac{u}{c}\right) = \left(6.0\times10^{14}\ \text{Hz}\right)\left(\frac{1.8\times10^{5}\ \text{m/s}}{3.0\times10^{8}\ \text{m/s}}\right) = \boxed{3.6\times10^{11}\ \text{Hz}}$$

and the frequency observed on the spaceship is

$$f_O = f_S + \Delta f = 6.0\times10^{14}\ \text{Hz} + 3.6\times10^{11}\ \text{Hz} = \boxed{6.003\,6\times10^{14}\ \text{Hz}}$$

21.55 Since you and the car ahead of you are moving away from each other (getting farther apart) at a rate of $u = 120\ \text{km/h} - 80\ \text{km/h} = 40\ \text{km/h}$, the Doppler shifted frequency you will detect is $f_O = f_S(1-u/c)$, and the change in frequency is

$$\Delta f = f_O - f_S = -f_S\left(\frac{u}{c}\right) = -\left(4.3\times10^{14}\ \text{Hz}\right)\left(\frac{40\ \text{km/h}}{3.0\times10^{8}\ \text{m/s}}\right)\left(\frac{0.278\ \text{m/s}}{1\ \text{km/h}}\right) = \boxed{-1.6\times10^{7}\ \text{Hz}}$$

The frequency you will detect will be

$$f_O = f_S + \Delta f = 4.3\times10^{14}\ \text{Hz} - 1.6\times10^{7}\ \text{Hz} = \boxed{4.299\,999\,84\times10^{14}\ \text{Hz}}$$

21.56 The driver was driving toward the warning lights, so the correct form of the Doppler shift equation is $f_O = f_S(1+u/c)$. The frequency emitted by the yellow warning light is

$$f_S = \frac{c}{\lambda_S} = \frac{3.00\times10^{8}\ \text{m/s}}{580\times10^{-9}\ \text{m}} = 5.17\times10^{14}\ \text{Hz}$$

and the frequency the driver claims that she observed is

$$f_O = \frac{c}{\lambda_O} = \frac{3.00\times10^{8}\ \text{m/s}}{560\times10^{-9}\ \text{m}} = 5.36\times10^{14}\ \text{Hz}$$

The speed with which she would have to approach the light for the Doppler effect to yield this claimed shift is

$$u = c\left(\frac{f_O}{f_S} - 1\right) = \left(3.00\times10^{8}\ \text{m/s}\right)\left(\frac{5.36\times10^{14}\ \text{Hz}}{5.17\times10^{14}\ \text{Hz}} - 1\right) = \boxed{1.1\times10^{7}\ \text{m/s}}$$

21.57 $$R = \frac{(\Delta V)_{\text{DC}}}{I_{\text{DC}}} = \frac{12.0 \text{ V}}{0.630 \text{ A}} = 19.0\ \Omega$$

$$Z = \sqrt{R^2 + (2\pi f L)^2} = \frac{\Delta V_{\text{rms}}}{I_{\text{rms}}} = \frac{24.0 \text{ V}}{0.570 \text{ A}} = 42.1\ \Omega$$

Thus, $$L = \frac{\sqrt{Z^2 - R^2}}{2\pi f} = \frac{\sqrt{(42.1\ \Omega)^2 - (19.0\ \Omega)^2}}{2\pi(60.0 \text{ Hz})} = 9.96 \times 10^{-2} \text{ H} = \boxed{99.6 \text{ mH}}$$

21.58 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 $(1.7 \text{ m})(0.3 \text{ m})\cos 30° = 0.4 \text{ m}^2$.

The intensity the radiation at Earth's surface is $I_{\text{surface}} = 0.6 I_{\text{incoming}}$ and only 50% of this is absorbed. Since $I = \frac{\mathcal{P}_{\text{av}}}{A} = \frac{(\Delta E/\Delta t)}{A}$, the absorbed energy is

$$\Delta E = (0.5 I_{\text{surface}}) A(\Delta t) = \left[0.5\left(0.6 I_{\text{incoming}}\right)\right] A(\Delta t)$$

$$= (0.5)(0.6)\left(1\,340 \text{ W/m}^2\right)\left(0.4 \text{ m}^2\right)(3\,600 \text{ s}) = 6 \times 10^5 \text{ J } \boxed{\sim 10^6 \text{ J}}$$

21.59 $$Z = \sqrt{R^2 + (X_C)^2} = \sqrt{R^2 + (2\pi f C)^{-2}}$$

$$= \sqrt{(200\ \Omega)^2 + \left[2\pi(60 \text{ Hz})\left(5.0 \times 10^{-6} \text{ F}\right)\right]^{-2}} = 5.7 \times 10^2\ \Omega$$

Thus, $$\mathcal{P}_{\text{av}} = I_{\text{rms}}^2 R = \left(\frac{\Delta V_{\text{rms}}}{Z}\right)^2 R = \left(\frac{120 \text{ V}}{5.7 \times 10^2\ \Omega}\right)^2 (200\ \Omega) = 8.9 \text{ W} = 8.9 \times 10^{-3} \text{ kW}$$

and $$cost = \Delta E \cdot (rate) = \mathcal{P}_{\text{av}} \cdot \Delta t \cdot (rate)$$

$$= \left(8.9 \times 10^{-3} \text{ kW}\right)(24 \text{ h})(8.0 \text{ cents/kWh}) = \boxed{1.7 \text{ cents}}$$

21.60 $X_L = \omega L$, so $\omega = X_L/L$

Then, $X_C = \dfrac{1}{\omega C} = \dfrac{1}{C(X_L/L)}$ which gives

$$L = (X_L \cdot X_C)C = [(12\ \Omega)(8.0\ \Omega)]C \text{ or } L = (96\ \Omega^2)C \qquad (1)$$

From $\omega_0 = 2\pi f_0 = \dfrac{1}{\sqrt{LC}}$, we obtain $LC = \dfrac{1}{(2\pi f_0)^2}$

Substituting from Equation (1), this becomes $(96\ \Omega^2)C^2 = \dfrac{1}{(2\pi f_0)^2}$

or $$C = \frac{1}{(2\pi f_0)\sqrt{96\ \Omega^2}} = \frac{1}{[2\pi(2\,000/\pi\ \text{Hz})]\sqrt{96\ \Omega^2}} = 2.6\times10^{-5}\ \text{F} = \boxed{26\ \mu\text{F}}$$

Then, from Equation (1),

$$L = (96\ \Omega^2)(2.6\times10^{-5}\ \text{F}) = 2.5\times10^{-3}\ \text{H} = \boxed{2.5\ \text{mH}}$$

21.61 (a) The box cannot contain a capacitor since a steady DC current cannot flow in a series circuit containing a capacitor. Since the AC and DC currents are different, even when a 3.0 V potential difference is used in both cases, the box must contain a reactive element. The conclusion is that the box must contain a $\boxed{\text{resistor and inductor}}$ connected in series.

(b) $$R = \frac{\Delta V_{\text{DC}}}{I_{\text{DC}}} = \frac{3.00\ \text{V}}{0.300\ \text{A}} = 10\ \Omega$$

$$Z = \frac{\Delta V_{\text{rms}}}{I_{\text{rms}}} = \frac{3.00\ \text{V}}{0.200\ \text{A}} = 15\ \Omega$$

Since $Z = \sqrt{R^2 + X_L^2} = \sqrt{R^2 + (2\pi f L)^2}$, we find

$$L = \frac{\sqrt{Z^2 - R^2}}{2\pi f} = \frac{\sqrt{(15\ \Omega)^2 - (10\ \Omega)^2}}{2\pi(60\ \text{Hz})} = \boxed{30\ \text{mH}}$$

21.62 (a) The required frequency is $f = \frac{c}{\lambda} = \frac{3.00\times10^{8}\ \text{m/s}}{3.00\times10^{-2}\ \text{m}} = 1.0\times10^{10}\ \text{Hz}$. Therefore, the resonance frequency of the circuit is $f_0 = \frac{1}{2\pi\sqrt{LC}} = 1.0\times10^{10}\ \text{Hz}$, giving

$$C = \frac{1}{(2\pi f_0)^2 L} = \frac{1}{\left(2\pi\times10^{10}\ \text{Hz}\right)^2\left(400\times10^{-12}\ \text{H}\right)} = 6.3\times10^{-13}\ \text{F} = \boxed{0.63\ \text{pF}}$$

(b) $C = \frac{\epsilon_0\, A}{d} = \frac{\epsilon_0\, \ell^2}{d}$, so

$$\ell = \sqrt{\frac{C\cdot d}{\epsilon_0}} = \sqrt{\frac{\left(6.3\times10^{-13}\ \text{F}\right)\left(1.0\times10^{-3}\ \text{m}\right)}{8.85\times10^{-12}\ \text{C}^2/\text{N}\cdot\text{m}}} = 8.5\times10^{-3}\ \text{m} = \boxed{8.5\ \text{mm}}$$

(c) $X_C = X_L = (2\pi f_0)L = 2\pi\left(1.0\times10^{10}\ \text{Hz}\right)\left(400\times10^{-12}\ \text{H}\right) = \boxed{25\ \Omega}$

21.63 (a) $\frac{E_{\text{max}}}{B_{\text{max}}} = c$, so

$$B_{\text{max}} = \frac{E_{\text{max}}}{c} = \frac{0.20\times10^{-6}\ \text{V/m}}{3.00\times10^{8}\ \text{m/s}} = \boxed{6.7\times10^{-16}\ \text{T}}$$

(b) $Intensity = \frac{E_{\text{max}}B_{\text{max}}}{2\mu_0}$

$$= \frac{\left(0.20\times10^{-6}\ \text{V/m}\right)\left(6.7\times10^{-16}\ \text{T}\right)}{2\left(4\pi\times10^{-7}\ \text{T}\cdot\text{m/A}\right)} = \boxed{5.3\times10^{-17}\ \text{W/m}^2}$$

(c) $\mathcal{P}_{\text{av}} = (Intensity)\cdot A = (Intensity)\left[\frac{\pi d^2}{4}\right]$

$$= \left(5.3\times10^{-17}\ \text{W/m}^2\right)\left[\frac{\pi(20.0\ \text{m})^2}{4}\right] = \boxed{1.7\times10^{-14}\ \text{W}}$$

21.64 (a) $Z = \frac{\Delta V_{\text{rms}}}{I_{\text{rms}}} = \frac{12\ \text{V}}{2.0\ \text{A}} = \boxed{6.0\ \Omega}$

(b) $$R = \frac{\Delta V_{\rm DC}}{I_{\rm DC}} = \frac{12\ \text{V}}{3.0\ \text{A}} = 4.0\ \Omega$$

From $Z = \sqrt{R^2 + X_L^2} = \sqrt{R^2 + (2\pi f L)^2}$, we find

$$L = \frac{\sqrt{Z^2 - R^2}}{2\pi f} = \frac{\sqrt{(6.0\ \Omega)^2 - (4.0\ \Omega)^2}}{2\pi(60\ \text{Hz})} = 1.2\times10^{-2}\ \text{H} = \boxed{12\ \text{mH}}$$

21.65 (a) The radiation pressure on the perfectly reflecting sail is

$$p = \frac{2(\mathit{Intensity})}{c} = \frac{2(1\,340\ \text{W/m}^2)}{3.00\times10^8\ \text{m/s}} = 8.93\times10^{-6}\ \text{N/m}^2$$

so the total force on the sail is

$$F = p\cdot A = (8.93\times10^{-6}\ \text{N/m}^2)(6.00\times10^4\ \text{m}^2) = \boxed{0.536\ \text{N}}$$

(b) $$a = \frac{F}{m} = \frac{0.536\ \text{N}}{6\,000\ \text{kg}} = \boxed{8.93\times10^{-5}\ \text{m/s}^2}$$

(c) From $\Delta x = v_0 t + \frac{1}{2}at^2$, with $v_0 = 0$, the time is

$$t = \sqrt{\frac{2(\Delta x)}{a}} = \sqrt{\frac{2(3.84\times10^8\ \text{m})}{8.93\times10^{-5}\ \text{m/s}^2}} = (2.93\times10^6\ \text{s})\left(\frac{1\ \text{d}}{8.64\times10^4\ \text{s}}\right) = \boxed{33.9\ \text{d}}$$

21.66 We know that $\dfrac{N_1}{N_2} = \dfrac{\Delta V_{1,\,\rm rms}}{\Delta V_{2,\,\rm rms}} = \dfrac{(I_{1,\,\rm rms}Z_1)}{(I_{2,\,\rm rms}Z_2)} = \left(\dfrac{I_{1,\,\rm rms}}{I_{2,\,\rm rms}}\right)\dfrac{Z_1}{Z_2}$

Also, for an ideal transformer,

$$(\Delta V_{1,\,\rm rms})I_{1,\,\rm rms} = (\Delta V_{2,\,\rm rms})I_{2,\,\rm rms} \text{ which gives } \frac{I_{1,\,\rm rms}}{I_{2,\,\rm rms}} = \frac{\Delta V_{2,\,\rm rms}}{\Delta V_{1,\,\rm rms}}$$

Therefore, $\dfrac{N_1}{N_2} = \left(\dfrac{\Delta V_{2,\,\rm rms}}{\Delta V_{1,\,\rm rms}}\right)\dfrac{Z_1}{Z_2}$, or $\dfrac{N_1}{N_2}\left(\dfrac{\Delta V_{1,\,\rm rms}}{\Delta V_{2,\,\rm rms}}\right) = \dfrac{Z_1}{Z_2}$

This gives $\dfrac{N_1}{N_2}\left(\dfrac{N_1}{N_2}\right) = \dfrac{Z_1}{Z_2}$, or $\dfrac{N_1}{N_2} = \sqrt{\dfrac{Z_1}{Z_2}} = \sqrt{\dfrac{8\,000\ \Omega}{8.0\ \Omega}} = \boxed{32}$

21.67 Consider a cylindrical volume with

$$V = 1.00\ \text{Liter} = 1.00\times10^{-3}\ \text{m}^3$$

and cross-sectional area $A = 1.00\ \text{m}^2$

The length of this one liter cylinder is

$$d = \frac{V}{A} = \frac{1.00\times10^{-3}\ \text{m}^3}{1.00\ \text{m}^2} = 1.00\times10^{-3}\ \text{m}$$

Imagine this cylinder placed at the top of Earth's atmosphere, with its length perpendicular to the incident wave fronts. Then, all the energy in the one liter volume of sunlight will strike the atmosphere in the time required for sunlight to travel the length of the cylinder. This time is

$$\Delta t = \frac{d}{c} = \frac{1.00\times10^{-3}\ \text{m}}{3.00\times10^{8}\ \text{m/s}} = 3.33\times10^{-12}\ \text{s}$$

The energy passing through the $1.00\ \text{m}^2$ area of the end of the cylinder in this time is

$$\Delta E = \mathcal{P}_{\text{av}}\cdot\Delta t = \left[(\mathit{Intensity})\cdot A\right]\cdot\Delta t$$

$$= \left(1\,340\ \text{W/m}^2\right)\left(1.00\ \text{m}^2\right)\left(3.33\times10^{-12}\ \text{s}\right) = \boxed{4.47\times10^{-9}\ \text{J}}$$

21.68 The capacitance of a parallel-plate capacitor is $C = \epsilon_0 A/d$, and its reactance in an AC circuit is $X_C = 1/2\pi fC$. Observe that reducing the plate separation to one-half of its original value will double the capacitance and reduce the capacitive reactance to one-half the original value.

The impedance of an *RLC* series circuit in which $X_L = R$ is $Z = \sqrt{R^2 + (R - X_C)^2}$. When the applied voltage is ΔV, the current in the circuit is $I = \Delta V/Z = \Delta V\big/\sqrt{R^2 + (R - X_C)^2}$. If now the plate separation, and hence the capacitive reactance, is cut to one-half the original value, the new impedance is $Z' = \sqrt{R^2 + (R - X_C/2)^2}$ and the new current will be $I' = \Delta V\big/Z' = \Delta V\big/\sqrt{R^2 + (R - X_C/2)^2}$.

If it is observed that $I' = 2I$, then we must have

$$\frac{\Delta V}{\sqrt{R^2 + (R - X_C/2)^2}} = \frac{2\Delta V}{\sqrt{R^2 + (R - X_C)^2}} \quad \text{or} \quad R^2 + (R - X_C)^2 = 4\left[R^2 + (R - X_C/2)^2\right]$$

Expanding the last result yields

$$R^2 + R^2 - 2RX_C + X_C^2 = 4R^2 + 4R^2 - 4RX_C + X_C^2$$

which reduces to $0 = 6R^2 - 2RX_C$ and yields $\boxed{X_C = 3R}$