Chapter 21

Alternating Current Circuits and Electromagnetic Waves

ANSWERS TO MULTIPLE CHOICE QUESTIONS

1. In an electromagnetic wave, the electric field $\vec{\mathbf{E}}$, the magnetic field $\vec{\mathbf{B}}$, and the direction of propagation of the wave are always mutually perpendicular to each other. Thus, with $\vec{\mathbf{B}}$ (in the $-x$-direction) and the direction of propagation ($+y$-direction) both in the xy-plane, $\vec{\mathbf{E}}$ must be parallel to the z-axis, meaning that either (c) or (d) must be the correct answer. To choose between these possible answers, recall the right-hand rule for electromagnetic waves (see Section 21.11 in the textbook). Hold your right hand, with the fingers extended, so the thumb is in the direction of propagation ($+y$) and your palm is facing the direction of $\vec{\mathbf{B}}$ ($-x$-direction). Then the orientation of the extended fingers is the direction of the electric field $\vec{\mathbf{E}}$. You should find this to be the negative z-direction, so the correct choice is (d).

2. When the frequency doubles, the rms current $I_{rms} = \Delta V_{L,rms}/X_L = \Delta V_{L,rms}/2\pi fL$ is cut in half. Thus, the new current is $I_{rms} = 3.0\text{ A}/2 = 1.5\text{ A}$, and (e) is the correct answer.

3. At the resonance frequency, $X_L = X_C$ and the impedance is $Z = \sqrt{R^2 + (X_L - X_C)^2} = R$. Thus, the rms current is $I_{rms} = \Delta V_{rms}/Z = (120\text{ V})/(20\ \Omega) = 6.0\text{ A}$, and (b) is the correct choice.

4. $\Delta V_{L,rms} = I_{rms}X_L = I_{rms}(2\pi fL) = (2.0\text{ A})2\pi(60.0\text{ Hz})[(1.0/2\pi)\text{H}] = 120\text{ V}$, and the correct answer is choice (c).

ANSWERS TO EVEN NUMBERED CONCEPTUAL QUESTIONS

10. 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.

PROBLEM SOLUTIONS

21.1 For an AC circuit containing only resistance (the filament of the lightbulb), the power dissipated is $P = I_{rms}^2 R = (\Delta V_{rms}/R)^2 R = \Delta V_{rms}^2/R = (\Delta V_{max}/\sqrt{2})^2/R$.

(a) $$R = \frac{\Delta V_{rms}^2}{P} = \frac{(170\text{ V}/\sqrt{2})^2}{75.0\text{ W}} = \boxed{193\ \Omega}$$

(b) $R = \dfrac{\Delta V_{rms}^2}{P} = \dfrac{\left(170\ \text{V}/\sqrt{2}\right)^2}{100.0\ \text{W}} = \boxed{145\ \Omega}$

21.2 (a) $\Delta V_{R,\max} = \sqrt{2}\left(\Delta V_{R,\text{rms}}\right) = \sqrt{2}\left(1.20\times10^2\ \text{V}\right) = \boxed{1.70\times10^2\ \text{V}}$

(b) $P_{av} = I_{rms}^2 R = \dfrac{\Delta V_{rms}^2}{R} \Rightarrow R = \dfrac{\Delta V_{rms}^2}{P_{av}} = \dfrac{\left(1.20\times10^2\ \text{V}\right)^2}{60.0\ \text{W}} = \boxed{2.40\times10^2\ \Omega}$

(c) Because $R = \dfrac{\Delta V_{rms}^2}{P_{av}}$ (see above), if the bulbs are designed to operate at the same voltage,

$\boxed{\text{the 100 W will have the lower resistance}}$.

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

(a) For bulbs 1 and 2: $I_{1,\text{rms}} = I_{2,\text{rms}} = \dfrac{150\ \text{W}}{120\ \text{V}} = \boxed{1.25\ \text{A}}$

For bulb 3: $I_{3,\text{rms}} = \dfrac{100\ \text{W}}{120\ \text{V}} = \boxed{0.833\ \text{A}}$

(b) $R_1 = R_2 = \dfrac{120\ \text{V}}{1.25\ \text{A}} = \boxed{96.0\ \Omega}$ and $R_3 = \dfrac{120\ \text{V}}{0.833\ \text{A}} = \boxed{144\ \Omega}$

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

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

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

21.13 $X_L = 2\pi(60.0\ \text{Hz})L = 54.0\ \Omega \Rightarrow 2\pi L = \dfrac{54.0\ \Omega}{60.0\ \text{s}^{-1}} = 0.900\ \Omega\cdot\text{s}$

Then, when $\Delta V_{rms} = 100\ \text{V}$ and $f = 50.0\ \text{Hz}$, the maximum current will be

$$I_{\max} = \frac{\Delta V_{\max}}{X_L} = \frac{\sqrt{2}\left(\Delta V_{rms}\right)}{(2\pi L)f} = \frac{\sqrt{2}(100\ \text{V})}{(0.900\ \Omega\cdot\text{s})(50.0\ \text{Hz})} = \boxed{3.14\ \text{A}}$$

21.14 (a) $X_L = 2\pi f L = 2\pi(80.0\ \text{Hz})\left(25.0\times10^{-3}\ \text{H}\right) = \boxed{12.6\ \Omega}$

(b) $I_{rms} = \dfrac{\Delta V_{L,\text{rms}}}{X_L} = \dfrac{78.0\ \text{V}}{12.6\ \Omega} = \boxed{6.19\ \text{A}}$

(c) $I_{\max} = \sqrt{2}\,I_{rms} = \sqrt{2}(6.19\ \text{A}) = \boxed{8.75\ \text{A}}$

21.37 The resonance frequency of a series *RLC* circuit is $f_0 = 1/\left(2\pi\sqrt{LC}\right)$. Thus, if $L = 1.40\ \mu\text{H}$ and the desired resonance frequency is $f_0 = 99.7$ MHz, the needed capacitance is

$$C = \frac{1}{4\pi^2 f_0^2 L} = \frac{1}{4\pi^2\left(99.7\times10^6\ \text{Hz}\right)^2\left(1.40\times10^{-6}\ \text{H}\right)} = 1.82\times10^{-12}\ \text{F} = \boxed{1.82\ \text{pF}}$$

21.38 The resonance frequency of a series *RLC* circuit is $f_0 = 1/\left(2\pi\sqrt{LC}\right)$. Thus, the ratio of the resonance frequencies when the same inductance is used with two different capacitances in the circuit is

$$\frac{f_{0,2}}{f_{0,1}} = \left(\frac{1}{2\pi\sqrt{LC_2}}\right)\left(\frac{2\pi\sqrt{LC_1}}{1}\right) = \sqrt{\frac{C_1}{C_2}}$$

If $f_{0,1} = 2.84$ kHz when $C_1 = 6.50\ \mu\text{F}$, the resonance frequency when the capacitance is $C_2 = 9.80\ \mu\text{F}$ will be

$$f_{0,2} = f_{0,1}\sqrt{\frac{C_1}{C_2}} = (2.84\ \text{kHz})\sqrt{\frac{6.50\ \mu\text{F}}{9.80\ \mu\text{F}}} = \boxed{2.31\ \text{kHz}}$$

21.59 (a) $$\lambda = \frac{c}{f} = \frac{3.00\times10^8\ \text{m/s}}{5.00\times10^{19}\ \text{Hz}} = 6.00\times10^{-12}\ \text{m} = \boxed{6.00\ \text{pm}}$$

(b) $$\lambda = \frac{c}{f} = \frac{3.00\times10^8\ \text{m/s}}{4.00\times10^9\ \text{Hz}} = 7.50\times10^{-2}\ \text{m} = \boxed{7.50\ \text{cm}}$$