Chapter 20

ANSWERS TO MULTIPLE CHOICE QUESTIONS

1. The flux through a flat coil in a uniform magnetic field is a maximum when the plane of the coil is perpendicular to the direction of the field. Thus, with the field parallel to the *y*-axis, the flux is a maximum when the plane of the coil is parallel to the *xz*-plane, and (c) is the correct choice.

2. Choose the positive *z*-direction to be the reference direction ($\theta = 0°$) for the normal to the plane of the coil. Then, the change in flux through the coil is

$$\Delta\Phi_B = \left(B_f \cos\theta_f - B_i \cos\theta_i\right)A = \left[(3.0\text{ T})\cos 0° - (1.0\text{ T})\cos 180°\right](0.50\text{ m})^2 = 1.0\text{ Wb}$$

and the magnitude of the induced emf is

$$|\varepsilon| = N\frac{|\Delta\Phi_B|}{\Delta t} = (10)\left(\frac{1.0\text{ Wb}}{2.0\text{ s}}\right) = 5.0\text{ V}$$

The correct answer is choice (b).

4. The angular velocity of the rotating coil is $\omega = 10.0\ \text{rev/s} = 20\pi\ \text{rad/s}$ and the maximum emf induced in the coil is

$$\varepsilon_{\max} = NBA\omega = (100)(0.050\,0\text{ T})(0.100\text{ m}^2)(20\pi\ \text{rad/s}) = 31.4\text{ V}$$

showing the correct choice to be (a).

6. As the bar slides to the right along the rails, the magnetic flux through the conducting path formed by the bar, rails, and the resistive element at the left end is directed out of the page and increasing in magnitude. Thus, the induced current must generate a flux directed into the page through the area enclosed by the current path. This means the induced current must be in the clockwise direction and choice (b) is correct. Also, as the induced current flows, the rod will experience a magnetic force that tends to impede the motion of the rod. Therefore, an external force must be exerted on the bar to keep it moving at constant speed, and choice (d) is also correct.

7. The amplitude of the induced emf in the coil of a generator is directly proportional to the angular velocity of the coil $(\varepsilon_{\max} = NBA\omega)$. Therefore, when the rate of rotation is doubled, the amplitude of the induced emf is also doubled, and the correct choice is (b).

ANSWERS TO EVEN NUMBERED CONCEPTUAL QUESTIONS

2. Consider the copper tube to be a large set of rings stacked one on top of the other. As the magnet falls toward or falls away from each ring, a current is induced in the ring. Thus, there is a current in the copper tube around its circumference.

PROBLEM SOLUTIONS

20.1 The angle between the direction of the constant field and the normal to the plane of the loop is $\theta = 0°$, so

$$\Phi_B = BA\cos\theta = (0.50\text{ T})\left[\left(8.0\times10^{-2}\text{ m}\right)\left(12\times10^{-2}\text{ m}\right)\right]\cos 0° = \boxed{4.8\times10^{-3}\text{ T}\cdot\text{m}^2}$$

20.8 $$|\varepsilon| = \frac{|\Delta\Phi_B|}{\Delta t} = \frac{(\Delta B)A\cos\theta}{\Delta t} = \frac{(1.5\text{ T} - 0)\left[\pi\left(1.6\times10^{-3}\text{ m}\right)^2\right]\cos 0°}{120\times10^{-3}\text{ s}} = 1.0\times10^{-4}\text{ V} = \boxed{0.10\text{ mV}}$$

20.33 Note the similarity between the situation in this problem and a generator. In a generator, one normally has a loop rotating in a constant magnetic field so the flux through the loop varies sinusoidally in time. In this problem, we have a stationary loop in an oscillating magnetic field, and the flux through the loop varies sinusoidally in time. In both cases, a sinusoidal emf $\mathcal{E} = \mathcal{E}_{max} \sin \omega t$, where $\mathcal{E}_{max} = NBA\omega$, is induced in the loop.

The loop in this case consists of a single band $(N = 1)$ around the perimeter of a red blood cell with diameter $d = 8.0 \times 10^{-6}$ m. The angular frequency of the oscillating flux through the area of this loop is $\omega = 2\pi f = 2\pi(60 \text{ Hz}) = 120\pi$ rad/s. The maximum induced emf is then

$$\mathcal{E}_{max} = NBA\omega = B\left(\frac{\pi d^2}{4}\right)\omega = \frac{(1.0\times 10^{-3} \text{ T})\pi(8.0\times 10^{-6} \text{ m})^2(120\pi \text{ s}^{-1})}{4} = \boxed{1.9\times 10^{-11} \text{ V}}$$

20.45 (a) $I_{max} = \mathcal{E}/R$, so $\mathcal{E} = I_{max}R = (8.0 \text{ A})(0.30\ \Omega) = \boxed{2.4 \text{ V}}$.

(b) The time constant is $\tau = L/R$, giving

$$L = \tau R = (0.25 \text{ s})(0.30\ \Omega) = 7.5\times 10^{-2} \text{ H} = \boxed{75 \text{ mH}}$$

(c) The current as a function of time is $I = I_{max}\left(1 - e^{-t/\tau}\right)$, so at $t = \tau$,

$$I = I_{max}\left(1 - e^{-1}\right) = 0.632 I_{max} = 0.632(8.0 \text{ A}) = \boxed{5.1 \text{ A}}$$

(d) At $t = \tau$, $I = 5.1$ A, and the voltage drop across the resistor is

$$\Delta V_R = -IR = -(5.1 \text{ A})(0.30\ \Omega) = \boxed{-1.5 \text{ V}}$$

(e) Applying Kirchhoff's loop rule to the circuit shown in Figure P20.43 gives $\mathcal{E} + \Delta V_R + \Delta V_L = 0$. Thus, at $t = \tau$, we have

$$\Delta V_L = -(\mathcal{E} + \Delta V_R) = -(2.4 \text{ V} - 1.5 \text{ V}) = \boxed{-0.90 \text{ V}}$$

20.46 The current in the *RL* circuit at time *t* is $I = \frac{\mathcal{E}}{R}\left(1 - e^{-t/\tau}\right)$. The potential difference across the resistor is $\Delta V_R = RI = \mathcal{E}\left(1 - e^{-t/\tau}\right)$, and from Kirchhoff's loop rule, the potential difference across the inductor is

$$\Delta V_L = \mathcal{E} - \Delta V_R = \mathcal{E}\left[1 - \left(1 - e^{-t/\tau}\right)\right] = \mathcal{E}e^{-t/\tau}$$

(a) At $t = 0$, $\Delta V_R = \mathcal{E}\left(1 - e^{-0}\right) = \mathcal{E}(1 - 1) = \boxed{0}$.

(b) At $t = \tau$, $\Delta V_R = \mathcal{E}\left(1 - e^{-1}\right) = (6.0 \text{ V})(1 - 0.368) = \boxed{3.8 \text{ V}}$.

(c) At $t = 0$, $\Delta V_L = \mathcal{E}e^{-0} = \mathcal{E} = \boxed{6.0 \text{ V}}$.

(d) At $t = \tau$, $\Delta V_L = \mathcal{E}e^{-1} = (6.0 \text{ V})(0.368) = \boxed{2.2 \text{ V}}$.

20.53 The flux due to the current in loop 1 passes from left to right through the area enclosed by loop 2. As loop 1 moves closer to loop 2, the magnitude of this flux through loop 2 is increasing. The induced current in loop 2 generates a magnetic field directed toward the left through the area it encloses in order to oppose the increasing flux from loop 1. This means that the induced current in loop 2 must flow $\boxed{\text{counterclockwise}}$ as viewed from the left end of the rod.