Objective Questions 1-11; Problems: 9, 13, 14, 17, 20, 23, 25, 28, 30, 36, 55

1. Figure OQ31.1 is a graph of the magnetic flux through a certain coil of wire as a function of time during an interval while the radius of the coil is increased, the coil is rotated through 1.5 revolutions, and the external source of the magnetic field is turned off, in that order. Rank the emf induced in the coil at the instants marked A through E from the largest positive value to the largest-magnitude negative value. In your ranking, note any cases of equality and also any instants when the emf is zero.

*OQ31.1* The ranking is $E > A > B = D = 0 > C$. The emf is given by the negative of the time derivative of the magnetic flux. We pick out the steepest downward slope at instant E as marking the moment of largest emf. Next comes A. At B and at D the graph line is horizontal so the emf is zero. At C the emf has its greatest negative value.

2. A circular loop of wire with a radius of 4.0 cm is in a uniform magnetic field of magnitude 0.060 T. The plane of the loop is perpendicular to the direction of the magnetic field. In a time interval of 0.50 s, the magnetic field changes to the opposite direction with a magnitude of 0.040 T. What is the magnitude of the average emf induced in the loop? (a) 0.20 V (b) 0.025 V (c) 5.0 mV (d) 1.0 mV (e) 0.20 mV

*OQ31.2* Answer (a). Treating the original flux as positive (i.e., choosing the normal to have the same direction as the original field), the flux changes from $\Phi_{Bl} = B_i A \cos \theta_i = B_i A \cos 0^\circ = B_i A$ to $\Phi_{Bf} = B_f A \cos \theta_f = B_f A \cos 180^\circ = -B_f A$.

$$\varepsilon = -\frac{\Delta \Phi_B}{\Delta t} = -\frac{\left( -B_f A \right) - \left( B_i A \right)}{\Delta t} = \frac{2 \left( B_f + B_i \right) A}{\Delta t}$$

$$= 2 \left[ \frac{(0.060 \text{ T}) + (0.040 \text{ T})}{0.50 \text{ s}} \right] \left[ \pi \left( 0.040 \text{ m} \right)^2 \right] = 2.0 \times 10^{-3} = 2.0 \text{ mV}$$
3. A rectangular conducting loop is placed near a long wire carrying a current \( I \) as shown in Figure Q31.3. If \( I \) decreases in time, what can be said of the current induced in the loop? (a) The direction of the current depends on the size of the loop. (b) The current is clockwise. (c) The current is counterclockwise. (d) The current is zero. (e) Nothing can be said about the current in the loop without more information.

**Q31.3**  
Answer (b). With the current in long wire flowing in the direction shown in Figure Q31.3, the magnetic flux through the rectangular loop is directed into the page. If this current is decreasing in time, the change in the flux is directed opposite to the flux itself (or out of the page). The induced current will then flow clockwise around the loop, producing a flux directed into the page through the loop and opposing the change in flux due to the decreasing current in the long wire.

4. A flat coil of wire is placed in a uniform magnetic field that is in the y direction. (i) The magnetic flux through the coil is maximum if the plane of the coil is where? More than one answer may be correct. (a) in the xy plane (b) in the yz plane (c) in any orientation, because it is a constant (ii) For what orientation is the flux zero? Choose from the same possibilities as in part (i).

**Q31.4**  
(i) Answer (c). (ii) Answers (a) and (b). The magnetic flux is \( \Phi_B = BA \cos \theta \). Therefore the flux is a maximum when \( \vec{B} \) is perpendicular to the loop of wire and zero when there is no component of magnetic field perpendicular to the loop. The flux is zero when the loop is turned so that the field lies in the plane of its area.

5. A square, flat loop of wire is pulled at constant velocity through a region of uniform magnetic field directed perpendicular to the plane of the loop as shown in Figure Q31.5. Which of the following statements are correct? More than one statement may be correct. (a) Current is induced in the loop in the clockwise direction. (b) Current is induced in the loop in the counterclockwise direction. (c) No current is induced in the loop. (d) Charge separation occurs in the loop, with the top edge positive. (e) Charge separation occurs in the loop, with the top edge negative.

**Q31.5**  
Answers (c) and (d). The magnetic flux through the coil is constant in time, so the induced emf is zero, but positive test charges in the leading and trailing sides of the square experience a \( \vec{F} = q (\vec{v} \times \vec{B}) \) force that is in direction (velocity to the right) \( \times \) (field perpendicularly into the page away from you) \( = \) (force toward the top of the square). The charges migrate upward to give positive charge to the top of the square until there is a downward electric field large enough to prevent more charge separation.

**Q31.6**  
Answers (b) and (d). By the magnetic force law \( \vec{F} = q (\vec{v} \times \vec{B}) \); the positive charges in the moving bar will feel a magnetic force in direction (velocity to the right) \( \times \) (field perpendicularly out of the page) \( = \) (force downward toward the bottom end of the bar). These charges will move downward and therefore clockwise in the circuit. The current induced in the bar experiences a force in the magnetic field that tends to slow the bar: (current downward) \( \times \) (field perpendicularly out of the page) \( = \) (force to the left); therefore, an external force is required to keep the bar moving at constant speed to the right.
7. A bar magnet is held in a vertical orientation above a loop of wire that lies in the horizontal plane as shown in Figure OQ31.7. The south end of the magnet is toward the loop. After the magnet is dropped, what is true of the induced current in the loop as viewed from above? (a) It is clockwise as the magnet falls toward the loop. (b) It is counterclockwise as the magnet falls toward the loop. (c) It is clockwise after the magnet has moved through the loop and moves away from it. (d) It is always clockwise. (e) It is first counterclockwise as the magnet approaches the loop and then clockwise after it has passed through the loop.

**OQ31.7**  Answer (a). As the bar magnet approaches the loop from above, with its south end downward as shown in Figure OQ31.7, the magnetic flux through the area enclosed by the loop is directed upward and increasing in magnitude. To oppose this increasing upward flux, the induced current in the loop will flow clockwise, as seen from above, producing a flux directed downward through the area enclosed by the loop. After the bar magnet has passed through the plane of the loop, and is departing with its north end upward, a decreasing flux is directed upward through the loop. To oppose this decreasing upward flux, the induced current in the loop flows counterclockwise as seen from above, producing flux directed upward through the area enclosed by the loop. From this analysis, we see that (a) is the only true statement among the listed choices.

8. What happens to the amplitude of the induced emf when the rate of rotation of a generator coil is doubled? (a) It becomes four times larger. (b) It becomes two times larger. (c) It is unchanged. (d) It becomes one-half as large. (e) It becomes one-fourth as large.

**OQ31.8**  Answer (b). The maximum induced emf in a generator is proportional to the rate of rotation. The rate of change of flux of the external magnetic field through the turns of the coil is doubled, so the maximum induced emf is doubled.

9. Two coils are placed near each other as shown in Figure OQ31.9. The coil on the left is connected to a battery and a switch, and the coil on the right is connected to a resistor. What is the direction of the current in the resistor (i) at an instant immediately after the switch is thrown closed, (ii) after the switch has been closed for several seconds, and (iii) at an instant after the switch has then been thrown open? Choose each answer from the possibilities (a) left, (b) right, or (c) the current is zero.

**OQ31.9**  (i) Answer (b). The battery makes counterclockwise current in the primary coil, so its magnetic field is to the right and increasing just after the switch is closed. The secondary coil will oppose the change with a leftward field, which comes from an induced clockwise current that goes to the right in the resistor. The upper pair of hands in the diagram represent this effect.

(ii) Answer (c). At steady state the primary magnetic field is unchanging, so no emf is induced in the secondary.

(iii) Answer (a). The primary’s field is to the right and decreasing as the switch is opened. The secondary coil opposes this decrease by making its own field to the right, carrying counterclockwise current to the left in the resistor. The lower pair of hands diagrammed represent this chain of events.
10. A circuit consists of a conducting movable bar and a lightbulb connected to two conducting rails as shown in Figure Q31.10. An external magnetic field is directed perpendicular to the plane of the circuit. Which of the following actions will make the bulb light up? More than one statement may be correct. (a) The bar is moved to the left. (b) The bar is moved to the right. (c) The magnitude of the magnetic field is increased. (d) The magnitude of the magnetic field is decreased. (e) The bar is lifted off the rails.

*Q31.10 Answers (a), (b), (c), and (d). With the magnetic field perpendicular to the plane of the page in Figure Q31.10, the flux through the closed loop to the left of the bar is given by \( \Phi_B = BA \), where \( B \) is the magnitude of the field and \( A \) is the area enclosed by the loop. Any action which produces a change in this product, \( BA \), will induce a current in the loop and cause the bulb to light. Such actions include increasing or decreasing the magnitude of the field (\( B \)), and moving the bar to the right or left and changing the enclosed area \( A \). Thus, the bulb will light during all of the actions in choices (a), (b), (c), and (d).

11. Two rectangular loops of wire lie in the same plane as shown in Figure Q31.11. If the current \( I \) in the outer loop is counterclockwise and increases with time, what is true of the current induced in the inner loop? More than one statement may be correct. (a) It is zero. (b) It is clockwise. (c) It is counterclockwise. (d) Its magnitude depends on the dimensions of the loops. (e) Its direction depends on the dimensions of the loops.

*Q31.11 Answers (b) and (d). A current flowing counterclockwise in the outer loop of Figure Q31.11 produces a magnetic flux through the inner loop that is directed out of the page. If this current is increasing in time, the change in the flux is in the same direction as the flux itself (or out of the page). The induced current in the inner loop will then flow clockwise around the loop, producing a flux through the loop directed into the page, opposing the change in flux due to the increasing current in the outer loop. The flux through the inner loop is given by \( \Phi_B = BA \), where \( B \) is the magnitude of the field and \( A \) is the area enclosed by the loop. The magnitude of the flux, and thus the magnitude of the rate of change of the flux, depends on the size of the area \( A \).
9. An aluminum ring of radius 5.00 cm and resistance $3.00 \times 10^{-4} \Omega$ is placed on top of a long air-core solenoid with 1 000 turns per meter and radius 3.00 cm, as shown in Figure P31.7. Over the area of the end of the solenoid, assume that the axial component of the field produced by the solenoid is half as strong as at the center of the solenoid. Assume the solenoid produces negligible field outside its cross-sectional area. The current in the solenoid is increasing at a rate of 270 A/s. (a) What is the induced current in the ring? At the center of the ring, what are (b) the magnitude and (c) the direction of the magnetic field produced by the induced current in the ring?

\[ E = \frac{d(BA)}{dt} = \frac{1}{2} \frac{d}{dt} (\mu_0 n I) A = \frac{1}{2} \mu_0 n \frac{d}{dt} (\pi r^2) = \frac{1}{2} \mu_0 n \pi r^2 \frac{dI}{dt} \]

\[ I_{\text{ring}} = \frac{E}{R} = \frac{\frac{1}{2} (4\pi \times 10^{-7} \text{ T} \cdot \text{m}/\text{A}) (1000) \pi (0.0300 \text{ m})^2}{3.00 \times 10^{-4} \Omega} \]

\[ = 1.60 \text{ A}, \text{ counterclockwise as viewed from the left end.} \]

\[ B_{\text{ring}} = \frac{\mu_0 I}{2r} = \frac{(4\pi \times 10^{-7} \text{ T} \cdot \text{m}/\text{A}) (1.60 \text{ A})}{2 (0.0500 \text{ m})} = 2.01 \times 10^{-5} \text{ T} = 20.1 \mu\text{T} \]

(c) The solenoid’s field points to the right through the ring, and is increasing, so to oppose the increasing field, \( B_{\text{ring}} \) points to the left.

**P31.13**

The initial magnetic field inside the solenoid is

\[ B = \mu_0 n I = \left(4\pi \times 10^{-7} \text{ T} \cdot \text{m}/\text{A}\right) \left(\frac{100}{0.200 \text{ m}}\right) (3.00 \text{ A}) = 1.88 \times 10^{-3} \text{ T} \]

(a) \[ \Phi_B = BA \cos \theta = \left(1.88 \times 10^{-3} \text{ T}\right) \left(1.00 \times 10^{-2} \text{ m}\right)^2 \cos 0^\circ \]

\[ = 1.88 \times 10^{-7} \text{ T} \cdot \text{m}^2 \]

(b) When the current is zero, the flux through the loop is \( \Phi_B = 0 \) and the average induced emf has been

\[ |\Delta \Phi_B| = \frac{\Delta \Phi_B}{\Delta t} = \frac{0 - 1.88 \times 10^{-7} \text{ T} \cdot \text{m}^2}{3.00 \text{ s}} = 6.28 \times 10^{-8} \text{ V} \]
14. A long solenoid has 400 turns per meter and carries a current given by \( I = (30.0 \text{ A})(1 - e^{-1.60t}) \). Inside the solenoid and coaxial with it is a coil that has a radius of 6.00 cm and consists of a total of 250 turns of fine wire (Fig. P31.13). What emf is induced in the coil by the changing current?

\[
\begin{align*}
\Phi_B &= \int B \, dA = \mu_0 n (30.0)(1 - e^{-1.60t}) \int dA \\
\Phi_B &= \mu_0 n (30.0)(1 - e^{-1.60t}) \pi R^2 \\
\varepsilon &= -N \frac{d\Phi_B}{dt} = -N \mu_0 n (30.0) \pi R^2 (1.60) e^{-1.60t} \\
\varepsilon &= - (250)(4\pi \times 10^{-7})(400)(30.0) \left[ \pi (0.0600)^2 \right] (1.60) e^{-1.60t} = \left( 6.82 \times 10^{-2} \right) e^{-1.60t} \\
\varepsilon &= 68.2 e^{-1.60t}, \text{ where } t \text{ is in seconds and } \varepsilon \text{ is in mV.}
\end{align*}
\]

17. A toroid having a rectangular cross section \((a = 2.00 \text{ cm} \times b = 3.00 \text{ cm})\) and inner radius \(R = 4.00 \text{ cm}\) consists of 500 turns of wire that carries a sinusoidal current \( I = I_{\text{max}} \sin \omega t \), with \( I_{\text{max}} = 50.0 \text{ A} \) and a frequency \( f = \frac{\omega}{2\pi} = 60.0 \text{ Hz} \). A coil that consists of 20 turns of wire links with the toroid, as in Figure P31.17. Determine the emf induced in the coil as a function of time.

\[
\begin{align*}
B &= \frac{\mu_0 N I}{2\pi r} = \frac{500 \mu_0 I}{2\pi r} \\
\Phi_B &= \int B \, dA = \frac{500 \mu_0 I}{2\pi} \sin \omega \int \frac{a \, dx}{r} \\
\Phi_B &= \frac{500 \mu_0 I}{2\pi} \sin \omega \ln \left( \frac{b+R}{R} \right) \\
\varepsilon &= N \frac{d\Phi_B}{dt} = 20 \left( \frac{500 \mu_0 I_{\text{max}}}{2\pi} \right) \omega a \ln \left( \frac{b+R}{R} \right) \cos \omega t \\
\varepsilon &= \frac{10^4}{2\pi} \left( 4\pi \times 10^{-7} \text{ N/A}^2 \right) (50.0 \text{ A}) (377 \text{ rad/s}) (0.020 \text{ cm}) \ln \left( (3.00 + 4.00) \text{ cm} \right) \cos \omega t \\
\varepsilon &= \left( 0.422 \text{ V} \right) \cos \omega t
\end{align*}
\]

P31.14

\[ B = \mu_0 n I = \mu_0 n (30.0)(1 - e^{-1.60t}) \]

\[ \Phi_B = \int B \, dA = \mu_0 n (30.0)(1 - e^{-1.60t}) \int dA \]

\[ \Phi_B = \mu_0 n (30.0)(1 - e^{-1.60t}) \pi R^2 \]

\[ \varepsilon = -N \frac{d\Phi_B}{dt} = -N \mu_0 n (30.0) \pi R^2 (1.60) e^{-1.60t} \]

\[ \varepsilon = - (250)(4\pi \times 10^{-7})(400)(30.0) \left[ \pi (0.0600)^2 \right] (1.60) e^{-1.60t} = \left( 6.82 \times 10^{-2} \right) e^{-1.60t} \]

\[ \varepsilon = 68.2 e^{-1.60t}, \text{ where } t \text{ is in seconds and } \varepsilon \text{ is in mV.} \]

P31.17

In a toroid, all the flux is confined to the inside of the toroid.

\[
\begin{align*}
B &= \frac{\mu_0 N I}{2\pi r} = \frac{500 \mu_0 I}{2\pi r} \\
\Phi_B &= \int B \, dA = \frac{500 \mu_0 I}{2\pi} \sin \omega \int \frac{a \, dx}{r} \\
\Phi_B &= \frac{500 \mu_0 I}{2\pi} \sin \omega \ln \left( \frac{b+R}{R} \right) \\
\varepsilon &= N \frac{d\Phi_B}{dt} = 20 \left( \frac{500 \mu_0 I_{\text{max}}}{2\pi} \right) \omega a \ln \left( \frac{b+R}{R} \right) \cos \omega t \\
\varepsilon &= \frac{10^4}{2\pi} \left( 4\pi \times 10^{-7} \text{ N/A}^2 \right) (50.0 \text{ A}) (377 \text{ rad/s}) (0.020 \text{ cm}) \ln \left( (3.00 + 4.00) \text{ cm} \right) \cos \omega t \\
\varepsilon &= \left( 0.422 \text{ V} \right) \cos \omega t
\end{align*}
\]
20. Use Lenz’s law to answer the following questions concerning the direction of induced currents. (a) What is the direction of the induced current in resistor $R$ in Figure P31.28a when the bar magnet is moved to the left? (b) What is the direction of the current induced in the resistor $R$ immediately after the switch $S$ in Figure P31.28b is closed? (c) What is the direction of the induced current in $R$ when the current $I$ in Figure P31.28c decreases rapidly to zero? (d) A copper bar is moved to the right while its axis is maintained in a direction perpendicular to a magnetic field, as shown in Figure P31.28d. If the top of the bar becomes positive relative to the bottom, what is the direction of the magnetic field?

P31.20  
(a) $\mathbf{B}_{ext} = B_{0} \hat{\mathbf{i}}$ and $B_{ext}$ decreases; therefore, the induced field is $\mathbf{B}_{0} = B_{0} \hat{\mathbf{i}}$ (to the right) and the current in the resistor is directed to the right.

(b) $\mathbf{B}_{ext} = B_{0}(-\hat{\mathbf{i}})$ increases; therefore, the induced field $\mathbf{B}_{0} = B_{0}(+\hat{\mathbf{i}})$ is to the right, and the current in the resistor is directed to the right.

(c) $\mathbf{B}_{ext} = B_{0}(-\hat{\mathbf{k}})$ into the paper and $B_{ext}$ decreases; therefore, the induced field is $\mathbf{B}_{0} = B_{0}(-\hat{\mathbf{k}})$ into the paper, and the current in the resistor is directed to the right.

(d) By the magnetic force law, $\mathbf{F}_{B} = \mathbf{q} \times \mathbf{B}$. Therefore, a positive charge will move to the top of the bar if $\mathbf{B}$ is into the paper.

23. Figure P31.20 shows a top view of a bar that can slide without friction. The resistor is 6.00 $\Omega$ and a 2.50-T magnetic field is directed perpendicularly downward, into the paper. Let $\ell = 1.20$ m. (a) Calculate the applied force required to move the bar to the right at a constant speed of 2.00 m/s. (b) At what rate is energy delivered to the resistor?

P31.23  
(a) $|\mathbf{F}_{B}| = I|\ell \times \mathbf{B}| = IB$

When $I = \frac{E}{R}$ and $E = B\ell v$

we get $\mathbf{F}_{B} = \frac{B\ell v}{R} (\ell B) = \frac{B^{2} \ell^{2} v}{R} = \frac{(2.50)^{2}(1.20)^{2}(2.00)}{6.00} = 3.00$ N .

The applied force is 3.00 N to the right.

(b) $P = \frac{I^{2} R}{6.00} = 6.00$ W or $P = Fv = 6.00$ W
The motional emf induced in a conductor is proportional to the component of the magnetic field perpendicular to the conductor and to its velocity. The total field is perpendicular to the conductor, but not to its velocity. As shown in the left figure, the component of the field perpendicular to the velocity is \( B_\perp = B \cos \theta \). The motion of the bar down the rails produces an induced emf \( \mathcal{E} = B_\perp l \mathbf{v} = B l \mathbf{v} \cos \theta \) that pushes charge into the page. The induced emf produces a current \( I = \mathcal{E} / R = B l \mathbf{v} \mathbf{v} \cos \theta / R \), where we assume that significant resistance is present only in the resistor. Because current in the bar travels into the page, and the field is downward, a magnetic force acts on the bar to the left: its magnitude is \( F = l B \mathbf{v} \sin 90.0^\circ = l B \mathbf{v} = B^2 l^2 \mathbf{v} \cos \theta / R \).

![ANS FIG. P31.25(a)](image)

In the free-body diagram, it is convenient to use a coordinate system with axes vertical and horizontal. The force relationships are

\[
\sum F_x = -F + n \sin \theta = 0 \quad \rightarrow \quad n \sin \theta = F = B^2 l^2 \mathbf{v} \cos \theta / R
\]

\[
\sum F_y = -mg + n \cos \theta = 0 \quad \rightarrow \quad n \cos \theta = mg
\]

Dividing the first by the second equation, we get

\[
\frac{n \sin \theta}{n \cos \theta} = \frac{B^2 l^2 \mathbf{v} \cos \theta / R}{mg} \quad \rightarrow \quad \mathbf{v} = \frac{mg \sin \theta}{B^2 l^2 \cos^2 \theta}
\]

For the values given, we find that

\[
\mathbf{v} = \frac{(0.200 \text{ kg})(9.80 \text{ m/s}^2)(1.00 \text{ \Omega}) \sin 25.0^\circ}{(0.500 \text{ T})^2 (1.20 \text{ m})^2 \cos^2 25.0^\circ} = 2.80 \text{ m/s}
\]
P31.28
(a) The motional emf induced in the bar must be \( \varepsilon = IR \), where \( I \) is the current in this series circuit. Since \( \varepsilon = B/\ell \), the speed of the moving bar must be

\[
v = \frac{\varepsilon}{B/\ell} = \frac{IR}{B/\ell} = \frac{(8.50 \times 10^{-3} \text{ A})(9.00 \Omega)}{(0.300 \text{ T})(0.350 \text{ m})} = 0.729 \text{ m/s}
\]

(b) The flux through the closed loop formed by the rails, the bar, and the resistor is directed into the page and is increasing in magnitude. To oppose this change in flux, the current must flow in a manner so as to produce flux out of the page through the area enclosed by the loop. This means the current will flow counterclockwise.

(c) The rate at which energy is delivered to the resistor is

\[
P = I^2R = \left( 8.50 \times 10^{-3} \text{ A} \right)^2 (9.00 \Omega) = 6.50 \times 10^{-4} \text{ W} = 0.650 \text{ mW}
\]

(d) Work is being done by the external force, which is transformed into internal energy in the resistor.

P31.36
(a) Use Equation 31.11, where \( B \) is the horizontal component of the magnetic field because the coil rotates about a vertical axis:

\[
\varepsilon_{\text{max}} = N B_{\text{horizontal}} A \omega = 100 (2.00 \times 10^{-5} \text{ T})(0.200 \text{ m})^2 \left[ \frac{1500 \text{ rev}}{\text{min}} \left( \frac{2\pi \text{ rad}}{1 \text{ rev}} \right) \left( \frac{1 \text{ min}}{60 \text{ s}} \right) \right]
\]

\[
= 1.26 \times 10^{-2} \text{ V} = 12.6 \text{ mV}
\]

(b) Maximum emf occurs when the magnetic flux through the coil is changing the fastest. This occurs at the moment when the flux is zero, which is when the plane of the coil is parallel to the magnetic field.
30. A rectangular coil with resistance $R$ has $N$ turns, each of length $\ell$ and width $w$ as shown in Figure P31.29. The coil moves into a uniform magnetic field $B$ with constant velocity $v$. What are the magnitude and direction of the total magnetic force on the coil (a) as it enters the magnetic field, (b) as it moves within the field, and (c) as it leaves the field?

**P31.30**

(a) The force on the side of the coil entering the field (consisting of $N$ wires) is

$$F = N (ILB) = N (IwB)$$

The induced emf in the coil is

$$|\varepsilon| = N \frac{d\Phi_B}{dt} = N \frac{d(BwL)}{dt} = NBvw$$

so the current is $I = \frac{|\varepsilon|}{R} = \frac{NBvw}{R}$ counterclockwise.

The force on the leading side of the coil is then:

$$F = N \left( \frac{NBvw}{R} \right) wB = \frac{N^2 B^2 w^2 v}{R} \text{ to the left}$$

(b) Once the coil is entirely inside the field,

$$\Phi_B = NBA = \text{constant}$$

so $\varepsilon = 0$, $I = 0$, and $F = 0$

(c) As the coil starts to leave the field, the flux decreases at the rate $Bwv$, so the magnitude of the current is the same as in part (a), but now the current is clockwise. Thus, the force exerted on the trailing side of the coil is:

$$F = \frac{N^2 B^2 w^2 v}{R} \text{ to the left again}$$
55. A conducting rod of length \( \ell = 35.0 \text{ cm} \) is free to slide on two parallel conducting bars as shown in Figure P31.50. Two resistors \( R_1 = 2.00 \, \Omega \) and \( R_2 = 5.00 \, \Omega \) are connected across the ends of the bars to form a loop. A constant magnetic field \( B = 2.50 \, \text{T} \) is directed perpendicularly into the page. An external agent pulls the rod to the left with a constant speed of \( v = 8.00 \, \text{m/s} \). Find (a) the currents in both resistors, (b) the total power delivered to the resistance of the circuit, and (c) the magnitude of the applied force that is needed to move the rod with this constant velocity.

P31.55 The emf induced between the ends of the moving bar is \( \varepsilon = B\ell v = (2.50 \, \text{T})(0.350 \, \text{m})(8.00 \, \text{m/s}) = 7.20 \, \text{V} \).

The left-hand loop contains decreasing flux away from you, so the induced current in it will be clockwise, to produce its own field directed away from you. Let \( I_1 \) represent the current flowing upward through the 2.00-\( \Omega \) resistor. The right-hand loop will carry counterclockwise current. Let \( I_3 \) be the upward current in the 5.00-\( \Omega \) resistor.

(a) Kirchhoff's loop rule then gives: \( +7.20 \, \text{V} - I_1 (2.00 \, \Omega) = 0 \) \( I_1 = \boxed{3.50 \, \text{A}} \)

and

\( +7.20 \, \text{V} - I_3 (5.00 \, \Omega) = 0 \) \( I_3 = \boxed{1.40 \, \text{A}} \).

(b) The total power dissipated in the resistors of the circuit is

\[ P = \varepsilon I_1 + \varepsilon I_3 = \varepsilon (I_1 + I_3) = (7.20 \, \text{V})(3.50 \, \text{A} + 1.40 \, \text{A}) = \boxed{34.3 \, \text{W}}. \]

(c) Method 1: The current in the sliding conductor is downward with value \( I_2 = 3.50 \, \text{A} + 1.40 \, \text{A} = 4.90 \, \text{A} \). The magnetic field exerts a force of \( F = \vec{I}_2 \vec{B} = (4.90 \, \text{A})(0.350 \, \text{m})(2.50 \, \text{T}) = 4.29 \, \text{N} \) directed toward the right on this conductor. An outside agent must then exert a force of \( \boxed{4.29 \, \text{N}} \) to the left to keep the bar moving.

Method 2: The agent moving the bar must supply the power according to \( P = \vec{F} \cdot \vec{v} = F v \cos 0^\circ \). The force required is then:

\[ F = \frac{P}{v} = \frac{34.3 \, \text{W}}{8.00 \, \text{m/s}} = \boxed{4.29 \, \text{N}}. \]