19.47 The magnetic field inside a long solenoid is $B = \mu_0 nI = \mu_0 \left(\frac{N}{L}\right) I$. Thus, the required current is

$$I = \frac{BL}{\mu_0 N} = \frac{\left(1.00\times10^{-4}\ \text{T}\right)\left(0.400\ \text{m}\right)}{\left(4\pi\times10^{-7}\ \text{T}\cdot\text{m/A}\right)\left(1\,000\right)} = 3.18\times10^{-2}\ \text{A} = \boxed{31.8\ \text{mA}}$$

20.3 The magnetic flux through the loop is given by $\Phi_B = BA\cos\theta$ where B is the magnitude of the magnetic field, A is the area enclosed by the loop, and θ is the angle the magnetic field makes with the normal to the plane of the loop. Thus,

$$\Phi_B = BA\cos\theta = \left(0.300\ \text{T}\right)\left(2.00\ \text{m}\right)^2\cos 50.0^\circ = \boxed{7.71\times10^{-1}\ \text{T}\cdot\text{m}^2}$$

20.6 The magnetic field generated by the current in the solenoid is

$$B = \mu_0 nI = \left(4\pi\times10^{-7}\ \text{T}\cdot\text{m/A}\right)\left(\frac{250}{0.200\ \text{m}}\right)\left(15.0\ \text{A}\right) = 2.36\times10^{-2}\ \text{T}$$

and the flux through each turn on the solenoid is

$$\Phi_B = BA\cos\theta$$

$$= \left(2.36\times10^{-2}\ \text{T}\right)\left[\frac{\pi\left(4.00\times10^{-2}\ \text{m}\right)^2}{4}\right]\cos 0^\circ = \boxed{2.96\times10^{-5}\ \text{T}\cdot\text{m}^2}$$

20.11 The magnitude of the induced emf is $|\mathcal{E}| = \frac{|\Delta\Phi_B|}{\Delta t} = \frac{|\Delta(B\cos\theta)|A}{\Delta t}$

If the normal to the plane of the loop is considered to point in the original direction of the magnetic field, then $\theta_i = 0^\circ$ and $\theta_f = 180^\circ$. Thus, we find

$$|\mathcal{E}| = \frac{\left|\left(0.20\ \text{T}\right)\cos 180^\circ - \left(0.30\ \text{T}\right)\cos 0^\circ\right|\pi\left(0.30\ \text{m}\right)^2}{1.5\ \text{s}} = 9.4\times10^{-2}\ \text{V} = \boxed{94\ \text{mV}}$$

20.16 The magnitude of the average emf is

$$|\boldsymbol{\varepsilon}| = \frac{N(\Delta\Phi_B)}{\Delta t} = \frac{NBA[\Delta(\cos\theta)]}{\Delta t}$$

$$= \frac{200(1.1\ \text{T})(100\times10^{-4}\ \text{m}^2)(\cos 0° - \cos 180°)}{0.10\ \text{s}} = 44\ \text{V}$$

Therefore, the average induced current is $I = \frac{|\boldsymbol{\varepsilon}|}{R} = \frac{44\ \text{V}}{5.0\ \Omega} = \boxed{8.8\ \text{A}}$

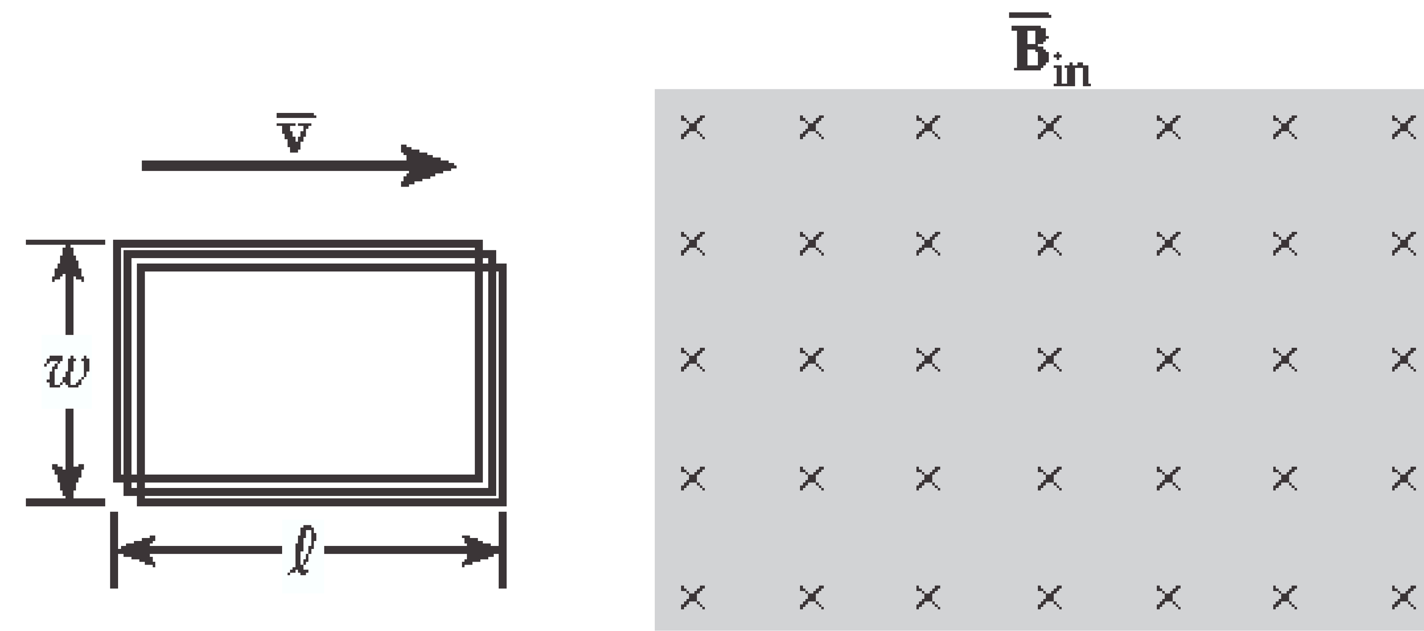
20.18 From $\varepsilon = B\ell v$, the required speed is

$$v = \frac{\varepsilon}{B\ell} = \frac{IR}{B\ell} = \frac{(0.500\ \text{A})(6.00\ \Omega)}{(2.50\ \text{T})(1.20\ \text{m})} = \boxed{1.00\ \text{m/s}}$$

20.23 (a) To oppose the motion of the magnet, the magnetic field generated by the induced current should be directed to the right along the axis of the coil. The current must then be $\boxed{\text{left to right}}$ through the resistor.

(b) The magnetic field produced by the current should be directed to the left along the axis of the coil, so the current must be $\boxed{\text{right to left}}$ through the resistor.

20.25 (a) After the right end of the coil has entered the field, but the left end has not, the flux through the area enclosed by the coil is directed into the page and is increasing in magnitude. This increasing flux induces an emf of magnitude



$$|\mathcal{E}| = \frac{\Delta\Phi_B}{\Delta t} = \frac{NB(\Delta A)}{\Delta t} = NBwv$$

in the loop. Note that in the above equation, ΔA is the area enclosed by the coil that enters the field in time Δt. This emf produces a counterclockwise current in the loop to oppose the increasing inward flux. The magnitude of this current is $I = \mathcal{E}/R = NBwv/R$. The right end of the loop is now a conductor, of length Nw, carrying a current toward the top of the page through a field directed into the page. The field exerts a magnetic force of magnitude

$$F = BI(Nw) = B\left(\frac{NBwv}{R}\right)(Nw) = \boxed{\frac{N^2B^2w^2v}{R}} \text{ directed } \boxed{\text{toward the left}}$$

on this conductor, and hence, on the loop.

(b) When the loop is entirely within the magnetic field, the flux through the area enclosed by the loop is constant. Hence, there is no induced emf or current in the loop, and the field exerts $\boxed{\text{zero}}$ force on the loop.

(c) After the right end of the loop emerges from the field, and before the left end emerges, the flux through the loop is directed into the page and decreasing. This decreasing flux induces an emf of magnitude $|\mathcal{E}| = NBwv$ in the loop, which produces an induced current directed clockwise around the loop so as to oppose the decreasing flux. The current has magnitude $I = \mathcal{E}/R = NBwv/R$. This current flowing upward, through conductors of total length Nw, in the left end of the loop, experiences a magnetic force given by

$$F = BI(Nw) = B\left(\frac{NBwv}{R}\right)(Nw) = \boxed{\frac{N^2B^2w^2v}{R}} \text{ directed } \boxed{\text{toward the left}}$$

20.28 When the switch is closed, the current from the battery produces a magnetic field directed toward the right along the axis of both coils.

(a) As the battery current is growing in magnitude, the induced current in the rightmost coil opposes the increasing rightward directed field by generating a field toward to the left along the axis. Thus, the induced current must be $\boxed{\text{left to right}}$ through the resistor.

(b) Once the battery current, and the field it produces, have stabilized, the flux through the rightmost coil is constant and there is $\boxed{\text{no induced current}}$.

(c) As the switch is opened, the battery current and the field it produces rapidly decrease in magnitude. To oppose this decrease in the rightward directed field, the induced current must produce a field toward the right along the axis, so the induced current is $\boxed{\text{right to left}}$ through the resistor.

20.34 (a) Using $\mathcal{E}_{\max} = NBA\omega$,

$$\mathcal{E}_{\max} = 1\,000(0.20\text{ T})(0.10\text{ m}^2)\left[\left(60\ \frac{\text{rev}}{\text{s}}\right)\left(\frac{2\pi\text{ rad}}{1\text{ rev}}\right)\right] = 7.5\times10^3 = \boxed{7.5\text{ kV}}$$

(b) $\mathcal{E}_{\max}$ occurs when the flux through the loop is changing the most rapidly. This is when the plane of the loop is $\boxed{\text{parallel to the magnetic field}}$.

20.57 (a) To move the bar at uniform speed, the magnitude of the applied force must equal that of the magnetic force retarding the motion of the bar. Therefore, $F_{app} = BI\ell$. The magnitude of the induced current is

$$I = \frac{|\mathcal{E}|}{R} = \frac{(\Delta\Phi_B/\Delta t)}{R} = \frac{B(\Delta A/\Delta t)}{R} = \frac{B\ell v}{R}$$

so the field strength is $B = \dfrac{IR}{\ell v}$, giving $F_{app} = I^2R/v$

Thus, the current is

$$I = \sqrt{\frac{F_{app}\cdot v}{R}} = \sqrt{\frac{(1.00\text{ N})(2.00\text{ m/s})}{8.00\ \Omega}} = \boxed{0.500\text{ A}}$$

(b) $\mathcal{P} = I^2R = (0.500\text{ A})^2(8.00\ \Omega) = \boxed{2.00\text{ W}}$

(c) $\mathcal{P}_{input} = F_{app}\cdot v = (1.00\text{ N})(2.00\text{ m/s}) = \boxed{2.00\text{ W}}$

20.37 $|\boldsymbol{\mathcal{E}}_{av}| = L\left|\frac{\Delta I}{\Delta t}\right| = \left(3.00\times10^{-3}\ \text{H}\right)\left(\frac{1.50\ \text{A}-0.20\ \text{A}}{0.20\ \text{s}}\right) = 2.0\times10^{-2}\ \text{V} = \boxed{20\ \text{mV}}$

20.43 The maximum current in a RL circuit $I_{max} = \boldsymbol{\mathcal{E}}/R$, so the resistance is

$$R = \frac{\boldsymbol{\mathcal{E}}}{I_{max}} = \frac{6.0\ \text{V}}{0.300\ \text{A}} = 20\ \Omega$$

The inductive time constant is $\tau = L/R$, so

$$L = \tau\cdot R = \left(600\times10^{-6}\ \text{s}\right)\left(20\ \Omega\right) = 1.2\times10^{-2}\ \text{H} = \boxed{12\ \text{mH}}$$

20.46 (a) $\tau = \frac{L}{R} = \frac{8.00\ \text{mH}}{4.00\ \Omega} = \boxed{2.00\ \text{ms}}$

(b) $I = \frac{\boldsymbol{\mathcal{E}}}{R}\left(1-e^{-t/\tau}\right) = \left(\frac{6.00\ \text{V}}{4.00\ \Omega}\right)\left(1-e^{-250\times10^{-6}\ \text{s}/2.00\times10^{-3}\ \text{s}}\right) = \boxed{0.176\ \text{A}}$

(c) $I_{max} = \frac{\boldsymbol{\mathcal{E}}}{R} = \frac{6.00\ \text{V}}{4.00\ \Omega} = \boxed{1.50\ \text{A}}$

(d) $I = I_{max}\left(1-e^{-t/\tau}\right)$ yields $e^{-t/\tau} = 1 - I/I_{max}$,

and $t = -\tau\ln\left(1-I/I_{max}\right) = -\left(2.00\ \text{ms}\right)\ln\left(1-0.800\right) = \boxed{3.22\ \text{ms}}$

20.48 (a) The inductance of a solenoid is given by $L = \mu_0 N^2 A/\ell$, where N is the number of turns on the solenoid, A is its cross-sectional area, and ℓ is its length. For the given solenoid,

$$L = \frac{\mu_0 N^2\left(\pi r^2\right)}{\ell} = \frac{\left(4\pi\times10^{-7}\ \text{T}\cdot\text{m/A}\right)\left(300\right)^2\pi\left(5.00\times10^{-2}\ \text{m}\right)^2}{0.200\ \text{m}} = \boxed{4.44\times10^{-3}\ \text{H}}$$

(b) When the solenoid described above carries a current of $I = 0.500\ \text{A}$, the stored energy is

$$PE_L = \frac{1}{2}LI^2 = \frac{1}{2}\left(4.44\times10^{-3}\ \text{H}\right)\left(0.500\ \text{A}\right)^2 = \boxed{5.55\times10^{-4}\ \text{J}}$$