P23.1 $|\mathcal{E}| = \left|\dfrac{\Delta\Phi_B}{\Delta t}\right| = \dfrac{\Delta(\vec{\mathbf{B}}\cdot\vec{\mathbf{A}})}{\Delta t} = \dfrac{(2.50\text{ T} - 0.500\text{ T})(8.00\times10^{-4}\text{ m}^2)}{1.00\text{ s}}\left(\dfrac{1\text{ N}\cdot\text{s}}{1\text{ T}\cdot\text{C}\cdot\text{m}}\right)\left(\dfrac{1\text{ V}\cdot\text{C}}{1\text{ N}\cdot\text{m}}\right)$

$|\mathcal{E}| = 1.60\text{ mV}$ and $I_{\text{loop}} = \dfrac{\mathcal{E}}{R} = \dfrac{1.60\text{ mV}}{2.00\ \Omega} = \boxed{0.800\text{ mA}}$

P23.2 $\mathcal{E} = -N\dfrac{\Delta BA\cos\theta}{\Delta t} = -NB\pi r^2\left(\dfrac{\cos\theta_f - \cos\theta_i}{\Delta t}\right) = -25.0(50.0\times10^{-6}\text{ T})\left[\pi(0.500\text{ m})^2\right]\left(\dfrac{\cos180° - \cos0°}{0.200\text{ s}}\right)$

$\mathcal{E} = \boxed{+9.82\text{ mV}}$

P23.3 Noting unit conversions from $\vec{\mathbf{F}} = q\vec{\mathbf{v}}\times\vec{\mathbf{B}}$ and $U = qV$, the induced voltage is

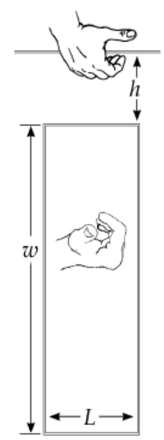
$\mathcal{E} = -N\dfrac{d(\vec{\mathbf{B}}\cdot\vec{\mathbf{A}})}{dt} = -N\left(\dfrac{0 - B_iA\cos\theta}{\Delta t}\right) = \dfrac{+200(1.60\text{ T})(0.200\text{ m}^2)\cos0°}{20.0\times10^{-3}\text{ s}}\left(\dfrac{1\text{ N}\cdot\text{s}}{1\text{ T}\cdot\text{C}\cdot\text{m}}\right)\left(\dfrac{1\text{ V}\cdot\text{C}}{\text{N}\cdot\text{m}}\right) = 3\,200\text{ V}$

$I = \dfrac{\mathcal{E}}{R} = \dfrac{3\,200\text{ V}}{20.0\ \Omega} = \boxed{160\text{ A}}$

P23.5 (a) $d\Phi_B = \vec{\mathbf{B}}\cdot d\vec{\mathbf{A}} = \dfrac{\mu_0 I}{2\pi x}L\,dx:\ \Phi_B = \displaystyle\int_h^{h+w}\dfrac{\mu_0 IL}{2\pi}\dfrac{dx}{x} = \boxed{\dfrac{\mu_0 IL}{2\pi}\ln\left(\dfrac{h+w}{h}\right)}$

(b) $\mathcal{E} = -\dfrac{d\Phi_B}{dt} = -\dfrac{d}{dt}\left[\dfrac{\mu_0 IL}{2\pi}\ln\left(\dfrac{h+w}{h}\right)\right] = -\left[\dfrac{\mu_0 L}{2\pi}\ln\left(\dfrac{h+w}{h}\right)\right]\dfrac{dI}{dt}$

$\mathcal{E} = -\dfrac{(4\pi\times10^{-7}\text{ T}\cdot\text{m/A})(1.00\text{ m})}{2\pi}\ln\left(\dfrac{1.00+10.0}{1.00}\right)(10.0\text{ A/s}) = \boxed{-4.80\ \mu\text{V}}$



The long wire produces magnetic flux into the page through the rectangle, shown by the first hand in the figure to the right.

As the magnetic flux increases, the rectangle produces its own magnetic field out of the page, which it does by carrying $\boxed{\text{counterclockwise}}$ current (second hand in the figure).

P23.7 $|\mathcal{E}| = \left|\dfrac{\Delta\Phi_B}{\Delta t}\right| = N\left(\dfrac{dB}{dt}\right)A = N(0.010\,0 + 0.080\,0t)A$

At $t = 5.00$ s, $|\mathcal{E}| = 30.0(0.410\text{ T/s})\left[\pi(0.040\,0\text{ m})^2\right] = \boxed{61.8\text{ mV}}$

***P23.10** The upper loop has area $\pi(0.05\text{ m})^2 = 7.85\times10^{-3}\text{ m}^2$. The induced emf in it is

$$\mathcal{E} = -N\frac{d}{dt}BA\cos\theta = -1A\cos 0°\frac{dB}{dt} = -7.85\times10^{-3}\text{ m}^2(2\text{ T/s}) = -1.57\times10^{-2}\text{ V}.$$

The minus sign indicates that it tends to produce counterclockwise current, to make its own magnetic field out of the page. Similarly, the induced emf in the lower loop is

$$\mathcal{E} = -NA\cos\theta\frac{dB}{dt} = -\pi(0.09\text{ m})^2 2\text{ T/s} = -5.09\times10^{-2}\text{ V} = +5.09\times10^{-2}\text{ V}$$ to produce

$\boxed{\text{counterclockwise current in the lower loop, which becomes clockwise current in the upper loop}}$.

The net emf for current in this sense around the figure 8 is

$5.09\times10^{-2}\text{ V} - 1.57\times10^{-2}\text{ V} = 3.52\times10^{-2}\text{ V}$.

It pushes current in this sense through series resistance $[2\pi(0.05\text{ m}) + 2\pi(0.09\text{ m})]3\ \Omega/\text{m} = 2.64\ \Omega$.

The current is $I = \frac{\mathcal{E}}{R} = \frac{3.52\times10^{-2}\text{ V}}{2.64\ \Omega} = \boxed{13.3\text{ mA}}$.

P23.12 $I = \frac{\mathcal{E}}{R} = \frac{B\ell v}{R}$

$\boxed{v = 1.00\text{ m/s}}$

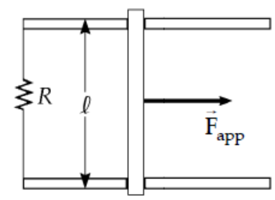


FIG. P23.12

P23.13 (a) $\left|\vec{F}_B\right| = I\left|\vec{\ell}\times\vec{B}\right| = I\ell B$

When $I = \frac{\mathcal{E}}{R}$

and $\mathcal{E} = B\ell v$

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

The applied force is $\boxed{3.00\text{ N to the right}}$.

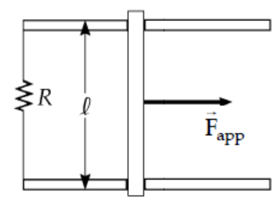


FIG. P23.13

(b) $\mathcal{P} = I^2R = \frac{B^2\ell^2v^2}{R} = 6.00\text{ W}$ or $\mathcal{P} = Fv = \boxed{6.00\text{ W}}$

P23.20 (a) $\vec{B}_{ext} = B_{ext}\hat{i}$ and B_{ext} decreases; therefore, the induced field is $\vec{B}_0 = B_0\hat{i}$ (to the right) and the current in the resistor is directed $\boxed{\text{to the right}}$.

(b) $\vec{B}_{ext} = B_{ext}(-\hat{i})$ increases; therefore, the induced field $\vec{B}_0 = B_0(+\hat{i})$ is to the right, and the current in the resistor is directed $\boxed{\text{to the right}}$.

(c) $\vec{B}_{ext} = B_{ext}(-\hat{k})$ into the paper and B_{ext} decreases; therefore, the induced field is $\vec{B}_0 = B_0(-\hat{k})$ into the paper, and the current in the resistor is directed $\boxed{\text{to the right}}$.

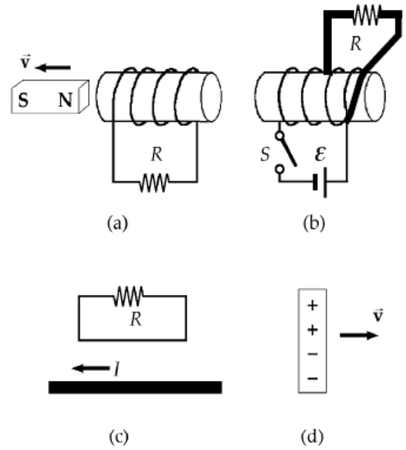


FIG. P23.20

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

P23.22 (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

$$|\mathcal{E}| = N\frac{d\Phi_B}{dt} = N\frac{d(Bwx)}{dt} = NBwv.$$

so the current is $I = \frac{|\mathcal{E}|}{R} = \frac{NBwv}{R}$ counterclockwise.

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

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

(b) Once the coil is entirely inside the field, $\Phi_B = NBA = \text{constant}$,

so $\mathcal{E} = 0$, $I = 0$, and $F = \boxed{0}$.

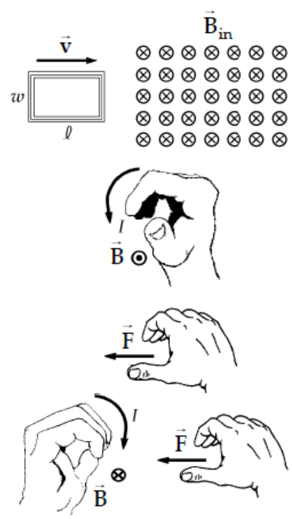


FIG. P23.22

(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:

$$F = \boxed{\frac{N^2B^2w^2v}{R} \text{ to the left again}}.$$

P23.27 $$|\mathcal{E}| = L\frac{\Delta I}{\Delta t} = \left(3.00\times10^{-3}\text{ H}\right)\left(\frac{1.50\text{ A} - 0.200\text{ A}}{0.200\text{ s}}\right) = 1.95\times10^{-2}\text{ V} = \boxed{19.5\text{ mV}}$$

P23.28 Treating the telephone cord as a solenoid, we have:

$$L = \frac{\mu_0 N^2 A}{\ell} = \frac{(4\pi \times 10^{-7}\ \text{T}\cdot\text{m/A})(70.0)^2 \pi (6.50 \times 10^{-3}\ \text{m})^2}{0.600\ \text{m}} = \boxed{1.36\ \mu\text{H}}.$$

P23.30 From $|\mathcal{E}| = L\left(\frac{\Delta I}{\Delta t}\right)$, we have $L = \frac{\mathcal{E}}{(\Delta I/\Delta t)} = \frac{24.0 \times 10^{-3}\ \text{V}}{10.0\ \text{A/s}} = 2.40 \times 10^{-3}\ \text{H}$.

From $L = \frac{N\Phi_B}{I}$, we have $\Phi_B = \frac{LI}{N} = \frac{(2.40 \times 10^{-3}\ \text{H})(4.00\ \text{A})}{500} = \boxed{19.2\ \mu\text{T}\cdot\text{m}^2}$.

P23.32 $L = \frac{N\Phi_B}{I} = \frac{NBA}{I} \approx \frac{NA}{I} \cdot \frac{\mu_0 NI}{2\pi R} = \boxed{\frac{\mu_0 N^2 A}{2\pi R}}$

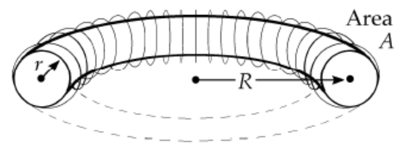


FIG. P23.32

P23.33 (a) At time t, $I(t) = \frac{\mathcal{E}(1 - e^{-t/\tau})}{R}$

where $\tau = \frac{L}{R} = 0.200\ \text{s}$.

After a long time, $I_{max} = \frac{\mathcal{E}(1 - e^{-\infty})}{R} = \frac{\mathcal{E}}{R}$.

At $I(t) = 0.500 I_{max}$ $(0.500)\frac{\mathcal{E}}{R} = \frac{\mathcal{E}(1 - e^{-t/0.200\ \text{s}})}{R}$

so $0.500 = 1 - e^{-t/0.200\ \text{s}}$.

Isolating the constants on the right, $\ln(e^{-t/0.200\ \text{s}}) = \ln(0.500)$

and solving for t, $-\frac{t}{0.200\ \text{s}} = -0.693$

or $t = \boxed{0.139\ \text{s}}$.

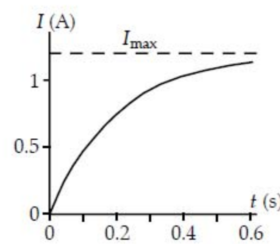


FIG. P23.33

(b) Similarly, to reach 90% of I_{max}, $0.900 = 1 - e^{-t/\tau}$

and $t = -\tau \ln(1 - 0.900)$.

Thus, $t = -(0.200\ \text{s})\ln(0.100) = \boxed{0.461\ \text{s}}$.

P23.34 Taking $\tau = \dfrac{L}{R}$, $\quad I = I_0 e^{-t/\tau}$: $\quad \dfrac{dI}{dt} = I_0 e^{-t/\tau}\left(-\dfrac{1}{\tau}\right)$

$IR + L\dfrac{dI}{dt} = 0$ will be true if $\quad I_0 R e^{-t/\tau} + L\left(I_0 e^{-t/\tau}\right)\left(-\dfrac{1}{\tau}\right) = 0$.

Because $\tau = \dfrac{L}{R}$, we have agreement with $0 = 0$.

P23.35 (a) $\tau = \dfrac{L}{R} = 2.00 \times 10^{-3}\ \text{s} = \boxed{2.00\ \text{ms}}$

(b) $I = I_{\max}\left(1 - e^{-t/\tau}\right) = \left(\dfrac{6.00\ \text{V}}{4.00\ \Omega}\right)\left(1 - e^{-0.250/2.00}\right) = \boxed{0.176\ \text{A}}$

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

(d) $0.800 = 1 - e^{-t/2.00\ \text{ms}} \rightarrow t = -(2.00\ \text{ms})\ln(0.200) = \boxed{3.22\ \text{ms}}$

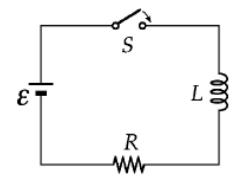


FIG. P23.35

P23.36 (a) $\Delta V_R = IR = (8.00\ \Omega)(2.00\ \text{A}) = 16.0\ \text{V}$

and $\quad \Delta V_L = \mathcal{E} - \Delta V_R = 36.0\ \text{V} - 16.0\ \text{V} = 20.0\ \text{V}$.

Therefore, $\quad \dfrac{\Delta V_R}{\Delta V_L} = \dfrac{16.0\ \text{V}}{20.0\ \text{V}} = \boxed{0.800}$.

(b) $\Delta V_R = IR = (4.50\ \text{A})(8.00\ \Omega) = 36.0\ \text{V}$

$\Delta V_L = \mathcal{E} - \Delta V_R = \boxed{0}$

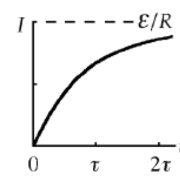


FIG. P23.36

P23.38 $I = I_{\max}\left(1 - e^{-t/\tau}\right)$: $\quad 0.980 = 1 - e^{-3.00\times 10^{-3}/\tau}$

$0.020\,0 = e^{-3.00\times 10^{-3}/\tau}$

$\tau = -\dfrac{3.00\times 10^{-3}}{\ln(0.020\,0)} = 7.67 \times 10^{-4}\ \text{s}$

$\tau = \dfrac{L}{R}$, so $\quad L = \tau R = \left(7.67 \times 10^{-4}\right)(10.0) = \boxed{7.67\ \text{mH}}$

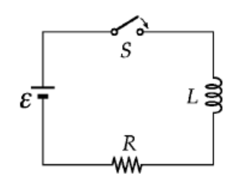


FIG. P23.38

P23.41 $\tau = \dfrac{L}{R} = \dfrac{0.140}{4.90} = 28.6\ \text{ms}$

$I_{\max} = \dfrac{\mathcal{E}}{R} = \dfrac{6.00\ \text{V}}{4.90\ \Omega} = 1.22\ \text{A}$

(a) $I = I_{\max}\left(1 - e^{-t/\tau}\right)$ so $\quad 0.220 = 1.22\left(1 - e^{-t/\tau}\right)$

$e^{-t/\tau} = 0.820$: $\quad t = -\tau \ln(0.820) = \boxed{5.66\ \text{ms}}$

(b) $I = I_{\max}\left(1 - e^{-10.0/0.028\,6}\right) = (1.22\ \text{A})\left(1 - e^{-350}\right) = \boxed{1.22\ \text{A}}$

(c) $I = I_{\max} e^{-t/\tau}$ and $\quad 0.160 = 1.22 e^{-t/\tau}$

so $\quad t = -\tau \ln(0.131) = \boxed{58.1\ \text{ms}}$.

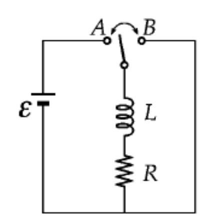


FIG. P23.41

P23.42 (a) The magnetic energy density is given by

$$u=\frac{B^2}{2\mu_0}=\frac{(4.50\text{ T})^2}{2\left(1.26\times10^{-6}\text{ T}\cdot\text{m/A}\right)}=\boxed{8.06\times10^6\text{ J/m}^3}.$$

(b) The magnetic energy stored in the field equals u times the volume of the solenoid (the volume in which B is non-zero).

$$U=uV=\left(8.06\times10^6\text{ J/m}^3\right)\left[(0.260\text{ m})\pi(0.031\,0\text{ m})^2\right]=\boxed{6.32\text{ kJ}}$$

P23.43 $L=\mu_0\dfrac{N^2A}{\ell}=\mu_0\dfrac{(68.0)^2\left[\pi\left(0.600\times10^{-2}\right)^2\right]}{0.080\,0}=8.21\ \mu\text{H}$

$$U=\frac{1}{2}LI^2=\frac{1}{2}\left(8.21\times10^{-6}\text{ H}\right)(0.770\text{ A})^2=\boxed{2.44\ \mu\text{J}}$$

P23.44 (a) $U=\dfrac{1}{2}LI^2=\dfrac{1}{2}(4.00\text{ H})(0.500\text{ A})^2$ $\quad U=\boxed{0.500\text{ J}}$

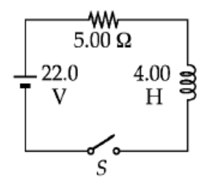


FIG. P23.44

(b) When the current is 1.00 A,

Kirchhoff's loop rule reads $\quad +22.0\text{ V}-(1.00\text{ A})(5.00\ \Omega)-\Delta V_L=0$.

Then $\quad \Delta V_L=17.0\text{ V}$.

The power being stored in the inductor is

$$I\Delta V_L=(1.00\text{ A})(17.0\text{ V})=\boxed{17.0\text{ W}}.$$

(c) $\mathcal{P}=I\Delta V=(0.500\text{ A})(22.0\text{ V})$ $\quad \mathcal{P}=\boxed{11.0\text{ W}}$

P23.55 We are given $\quad \Phi_B=\left(6.00t^3-18.0t^2\right)\text{ T}\cdot\text{m}^2$

and $\quad \mathcal{E}=-\dfrac{d\Phi_B}{dt}=-18.0t^2+36.0t$.

Maximum $\mathcal{E}$ occurs when $\quad \dfrac{d\mathcal{E}}{dt}=-36.0t+36.0=0$

which gives $\quad t=1.00\text{ s}$.

Therefore, the maximum current (at $t=1.00$ s) is $\quad I=\dfrac{\mathcal{E}}{R}=\dfrac{(-18.0+36.0)\text{ V}}{3.00\ \Omega}=\boxed{6.00\text{ A}}$.