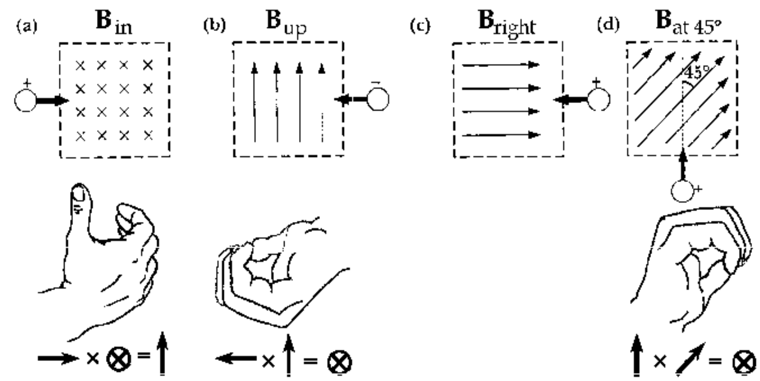
22.1 (a) up

(b) out of the page, since the charge is negative.

(c) no deflection

(d) into the page



22.2 (a) $F_B = qvB\sin\theta = \left(1.60\times10^{-19}\ \text{C}\right)\left(3.00\times10^{6}\ \text{m/s}\right)\left(3.00\times10^{-1}\ \text{T}\right)\sin 37.0°$

$F_B = \boxed{8.67\times10^{-14}\ \text{N}}$

(b) $a = \dfrac{F}{m} = \dfrac{8.67\times10^{-14}\ \text{N}}{1.67\times10^{-27}\ \text{kg}} = \boxed{5.19\times10^{13}\ \text{m/s}^2}$

***22.5** $\mathbf{F}_B = q\mathbf{v}\times\mathbf{B}$

$$\mathbf{v}\times\mathbf{B} = \begin{vmatrix} \mathbf{i} & \mathbf{j} & \mathbf{k} \\ +2 & -4 & +1 \\ +1 & +2 & -3 \end{vmatrix} = (12-2)\mathbf{i} + (1+6)\mathbf{j} + (4+4)\mathbf{k} = 10\mathbf{i} + 7\mathbf{j} + 8\mathbf{k}$$

$$|\mathbf{v}\times\mathbf{B}| = \sqrt{10^2+7^2+8^2} = 14.6\ \text{T}\cdot\text{m/s}$$

$$|\mathbf{F}_B| = q|\mathbf{v}\times\mathbf{B}| = \left(1.60\times10^{-19}\ \text{C}\right)(14.6\ \text{T}\cdot\text{m/s}) = \boxed{2.34\times10^{-18}\ \text{N}}$$

***22.6** (a) We begin with $qvB = \dfrac{mv^2}{R}$

or $qRB = mv$

But $L = mvR = qR^2B$

Therefore, $R = \sqrt{\dfrac{L}{qB}} = \sqrt{\dfrac{4.00 \times 10^{-25}\ \text{J}\cdot\text{s}}{\left(1.60 \times 10^{-19}\ \text{C}\right)\left(1.00 \times 10^{-3}\ \text{T}\right)}} = 0.0500\ \text{m} = \boxed{5.00\ \text{cm}}$

(b) Thus, $v = \dfrac{L}{mR} = \dfrac{4.00 \times 10^{-25}\ \text{J}\cdot\text{s}}{\left(9.11 \times 10^{-31}\ \text{kg}\right)(0.0500\ \text{m})} = \boxed{8.78 \times 10^6\ \text{m/s}}$

***22.8** $F_B = F_e$

so $qvB = qE$

where $v = \sqrt{2K/m}$ and K is kinetic energy of the electron.

$$E = vB = \sqrt{\frac{2K}{m}}B = \sqrt{\frac{2(750)\left(1.60 \times 10^{-19}\right)}{9.11 \times 10^{-31}}}(0.0150) = \boxed{244\ \text{kV/m}}$$

***22.10** Note that the "cyclotron frequency" is an angular speed. The motion of the proton is described by $\Sigma F = ma$:

$$|q|vB\sin 90° = \frac{mv^2}{r}$$

$$|q|B = m\frac{v}{r} = m\omega$$

(a) $\omega = \frac{|q|B}{m} = \frac{\left(1.60\times10^{-19}\text{ C}\right)\left(0.8\text{ N}\cdot\text{s/C}\cdot\text{m}\right)}{\left(1.67\times10^{-27}\text{ kg}\right)}\left(\frac{\text{kg}\cdot\text{m}}{\text{N}\cdot\text{s}^2}\right) = \boxed{7.66\times10^{7}\text{ rad/s}}$

(b) $v = \omega r = \left(7.66\times10^{7}\text{ rad/s}\right)\left(0.350\text{ m}\right)\left(\frac{1}{1\text{ rad}}\right) = \boxed{2.68\times10^{7}\text{ m/s}}$

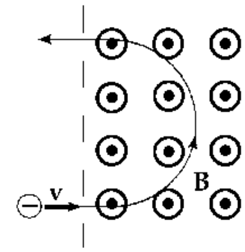
(c) $K = \frac{1}{2}mv^2 = \frac{1}{2}\left(1.67\times10^{-27}\text{ kg}\right)\left(2.68\times10^{7}\text{ m/s}\right)^2\left(\frac{1\text{ eV}}{1.6\times10^{-19}\text{ J}}\right) = \boxed{3.76\times10^{6}\text{ eV}}$

(d) The proton gains 600 eV twice during each revolution, so the number of revolutions is

$$\frac{3.76\times10^{6}\text{ eV}}{2(600\text{ eV})} = \boxed{3.13\times10^{3}\text{ revolutions}}$$

(e) $\theta = \omega t$ $\qquad t = \frac{\theta}{\omega} = \frac{3.13\times10^{3}\text{ rev}}{7.66\times10^{7}\text{ rad/s}}\left(\frac{2\pi\text{ rad}}{1\text{ rev}}\right) = \boxed{2.57\times10^{-4}\text{ s}}$

22.49 The boundary between a region of strong magnetic field and a region of zero field cannot be perfectly sharp, but we ignore the thickness of the transition zone. In the field the electron moves on an arc of a circle:



$\Sigma F = ma$:

$$|q|vB\sin 90° = \frac{mv^2}{r}$$

$$\frac{v}{r} = \omega = \frac{|q|B}{m} = \frac{(1.60\times10^{-19}\text{ C})(10^{-3}\text{ N}\cdot\text{s/C}\cdot\text{m})}{(9.11\times10^{-31}\text{ kg})}$$

$$= 1.76\times10^{8}\text{ rad/s}$$

The time for one half revolution is,

from $\Delta\theta = \omega\Delta t$

$$\Delta t = \frac{\Delta\theta}{\omega} = \frac{\pi\text{ rad}}{1.76\times10^{8}\text{ rad/s}} = \boxed{1.79\times10^{-8}\text{ s}}$$

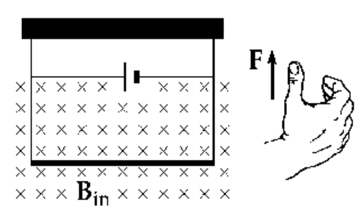
(b) The maximum depth of penetration is the radius of the path.

Then $v = \omega r = (1.76\times10^{8}\text{ s}^{-1})(0.02\text{ m}) = 3.51\times10^{6}\text{ m/s}$

and $K = \frac{1}{2}mv^2 = \frac{1}{2}(9.11\times10^{-31}\text{ kg})(3.51\times10^{6}\text{ m/s})^2 = 5.62\times10^{-18}\text{ J} = \frac{5.62\times10^{-18}\text{ J}\cdot\text{e}}{1.60\times10^{-19}\text{ C}} = \boxed{35.1\text{ eV}}$

22.13 $\mathbf{F}_B = I\boldsymbol{\ell}\times\mathbf{B} = (2.40\text{ A})(0.750\text{ m})\mathbf{i}\times(1.60\text{ T})\mathbf{k} = \boxed{(-2.88\,\mathbf{j})\text{ N}}$

***22.14** $\frac{|\mathbf{F}_B|}{\ell} = \frac{mg}{\ell} = \frac{I|\boldsymbol{\ell}\times\mathbf{B}|}{\ell}$

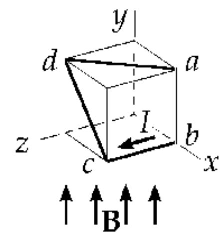


$$I = \frac{mg}{B\ell} = \frac{(0.0400\text{ kg/m})(9.80\text{ m/s}^2)}{3.60\text{ T}} = \boxed{0.109\text{ A}}$$

The direction of I in the bar is $\boxed{\text{to the right}}$.

22.16 For each segment, $I = 5.00\text{ A}$ and $\mathbf{B} = 0.0200\text{ N/A}\cdot\text{m }\mathbf{j}$

Segment	$\boldsymbol{\ell}$	$\mathbf{F}_B = I(\boldsymbol{\ell}\times\mathbf{B})$
ab	$-0.400\text{ m }\mathbf{j}$	$\boxed{0}$
bc	$0.400\text{ m }\mathbf{k}$	$\boxed{(40.0\text{ mN})(-\mathbf{i})}$
cd	$-0.400\text{ m }\mathbf{i} + 0.400\text{ m }\mathbf{j}$	$\boxed{(40.0\text{ mN})(-\mathbf{k})}$
da	$0.400\text{ m }\mathbf{i} - 0.400\text{ m }\mathbf{k}$	$\boxed{(40.0\text{ mN})(\mathbf{k}+\mathbf{i})}$



***22.18** (a) $2\pi r = 2.00\text{ m}$

so $r = 0.318\text{ m}$

$$\mu = IA = \left(17.0\times10^{-3}\text{ A}\right)\left[\pi(0.318)^2\text{ m}^2\right] = \boxed{5.41\text{ mA}\cdot\text{m}^2}$$

(b) $\tau = \mu \times \mathbf{B}$

so $$\tau = \left(5.41\times10^{-3}\text{ A}\cdot\text{m}^2\right)(0.800\text{ T}) = \boxed{4.33\text{ mN}\cdot\text{m}}$$

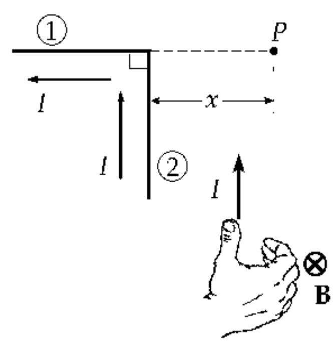
***22.23** $$B = \frac{\mu_0 I}{2\pi r} = \frac{\left(4\pi\times10^{-7}\right)(1.00\text{ A})}{2\pi(1.00\text{ m})} = \boxed{2.00\times10^{-7}\text{ T}}$$

***22.24** We can think of the total magnetic field as the superposition of the field due to the long straight wire (having magnitude $\mu_0 I/2\pi R$ and directed into the page) and the field due to the circular loop (having magnitude $\mu_0 I/2R$ and directed into the page). The resultant magnetic field is:

$$\boxed{\mathbf{B} = \left(1+\frac{1}{\pi}\right)\frac{\mu_0 I}{2R}\quad\text{(directed into the page)}}$$

22.25 For leg 1, $d\mathbf{s}\times\hat{\mathbf{r}} = 0$, so there is no contribution to the field from this segment. For leg 2, the wire is only semi-infinite; thus,

$$B = \frac{1}{2}\left(\frac{\mu_0 I}{2\pi x}\right) = \boxed{\frac{\mu_0 I}{4\pi x}\quad\text{into the paper}}$$



***22.27** Label the wires 1, 2, and 3 as shown in Figure (a) and let the magnetic field created by the currents in these wires be $\mathbf{B}_1$, $\mathbf{B}_2$, and $\mathbf{B}_3$ respectively.

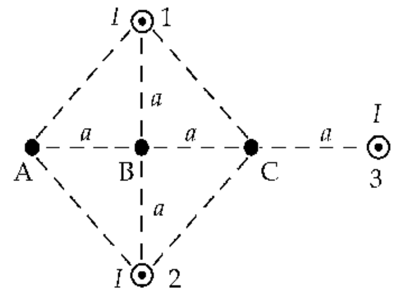


Figure (a)

(a) At Point A:

$$B_1 = B_2 = \frac{\mu_0 I}{2\pi\left(a\sqrt{2}\right)}$$

and $$B_3 = \frac{\mu_0 I}{2\pi(3a)}$$

The directions of these fields are shown in Figure (b). Observe that the horizontal components of $\mathbf{B}_1$ and $\mathbf{B}_2$ cancel while their vertical components both add to $\mathbf{B}_3$.

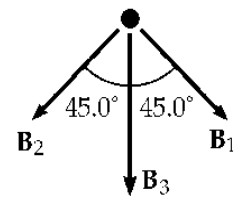


Figure (b)

Therefore, the net field at point A is:

$$B_A = B_1 \cos 45.0° + B_2 \cos 45.0° + B_3 = \frac{\mu_0 I}{2\pi a}\left[\frac{2}{\sqrt{2}}\cos 45.0° + \frac{1}{3}\right]$$

$$B_A = \frac{\left(4\pi \times 10^{-7}\ \mathrm{T\cdot m/A}\right)(2.00\ \mathrm{A})}{2\pi\left(1.00 \times 10^{-2}\ \mathrm{m}\right)}\left[\frac{2}{\sqrt{2}}\cos 45° + \frac{1}{3}\right]$$

$B_A =$ 53.3 μT toward the bottom of the page

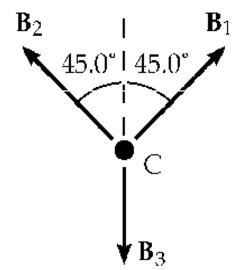


Figure (c)

(b) At point B: $\mathbf{B}_1$ and $\mathbf{B}_2$ cancel,

leaving $$B_B = B_3 = \frac{\mu_0 I}{2\pi(2a)}$$

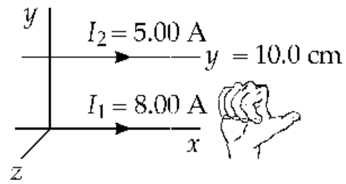
$$B_B = \frac{\left(4\pi \times 10^{-7}\ \mathrm{T\cdot m/A}\right)(2.00\ \mathrm{A})}{2\pi(2)\left(1.00 \times 10^{-2}\ \mathrm{m}\right)} =$$ 20.0 μT toward the bottom of the page

(c) At point C: $$B_1 = B_2 = \frac{\mu_0 I}{2\pi\left(a\sqrt{2}\right)}$$

and $B_3 = \dfrac{\mu_0 I}{2\pi a}$ with the directions shown in Figure (c). Again, the horizontal components of $\mathbf{B}_1$ and $\mathbf{B}_2$ cancel. The vertical components both oppose $\mathbf{B}_3$ giving

$$B_C = 2\left[\frac{\mu_0 I}{2\pi\left(a\sqrt{2}\right)}\cos 45.0°\right] - \frac{\mu_0 I}{2\pi a} = \frac{\mu_0 I}{2\pi a}\left[\frac{2}{\sqrt{2}}\cos 45.0° - 1\right] = \boxed{0}$$

22.30 Let both wires carry current in the x direction, the first at $y = 0$ and the second at $y = 10.0$ cm.



(a) $\mathbf{B} = \dfrac{\mu_0 I}{2\pi r}\mathbf{k} = \dfrac{(4\pi \times 10^{-7}\ \text{T}\cdot\text{m/A})(5.00\ \text{A})}{2\pi(0.100\ \text{m})}\mathbf{k}$

$\mathbf{B} = \boxed{1.00 \times 10^{-5}\ \text{T out of the page}}$

(b) $\mathbf{F}_B = I_2 \boldsymbol{\ell} \times \mathbf{B} = (8.00\ \text{A})\left[(1.00\ \text{m})\mathbf{i} \times \left(1.00 \times 10^{-5}\ \text{T}\right)\mathbf{k}\right] = \left(8.00 \times 10^{-5}\ \text{N}\right)(-\mathbf{j})$

$\boxed{\mathbf{F}_B = 8.00 \times 10^{-5}\ \text{N toward the first wire}}$

(c) $\mathbf{B} = \dfrac{\mu_0 I}{2\pi r}(-\mathbf{k}) = \dfrac{(4\pi \times 10^{-7}\ \text{T}\cdot\text{m/A})(8.00\ \text{A})}{2\pi(0.100\ \text{m})}(-\mathbf{k}) = \left(1.60 \times 10^{-5}\ \text{T}\right)(-\mathbf{k})$

$\mathbf{B} = \boxed{1.60 \times 10^{-5}\ \text{T into the page}}$

(d) $\mathbf{F}_B = I_1 \boldsymbol{\ell} \times \mathbf{B} = (5.00\ \text{A})\left[(1.00\ \text{m})\mathbf{i} \times \left(1.60 \times 10^{-5}\ \text{T}\right)(-\mathbf{k})\right] = \left(8.00 \times 10^{-5}\ \text{N}\right)(+\mathbf{j})$

$\mathbf{F}_B = \boxed{8.00 \times 10^{-5}\ \text{N towards the second wire}}$

***22.35** From Ampere's law, the magnetic field at point a is given by $B_a = \mu_0 I_a / 2\pi r_a$, where I_a is the net current through the area of the circle of radius r_a. In this case, $I_a = 1.00$ A out of the page (the current in the inner conductor), so

$$B_a = \frac{(4\pi \times 10^{-7}\ \text{T}\cdot\text{m/A})(1.00\ \text{A})}{2\pi\left(1.00 \times 10^{-3}\ \text{m}\right)} = \boxed{200\ \mu\text{T toward top of page}}$$

Similarly at point b: $B_b = \dfrac{\mu_0 I_b}{2\pi r_b}$, where I_b is the net current through the area of the circle having radius r_b.

Taking out of the page as positive, $I_b = 1.00\ \text{A} - 3.00\ \text{A} = -2.00\ \text{A}$, or $I_b = 2.00$ A into the page. Therefore,

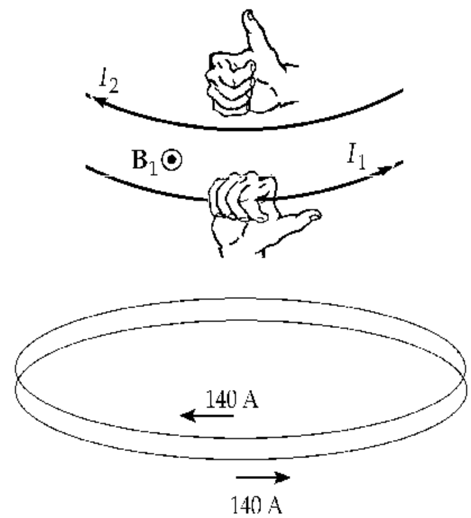
$$B_b = \frac{(4\pi \times 10^{-7}\ \text{T}\cdot\text{m/A})(2.00\ \text{A})}{2\pi\left(3.00 \times 10^{-3}\ \text{m}\right)} = \boxed{133\ \mu\text{T toward bottom of page}}$$

22.40 The resistance of the wire is $R_e = \frac{\rho \ell}{\pi r^2}$, so it carries current $I = \frac{\mathcal{E}}{R_e} = \frac{\mathcal{E} \pi r^2}{\rho \ell}$

If there is a single layer of windings, the number of turns per length is the reciprocal of the wire diameter: $n = 1/2r$.

So, $$B = n\mu_0 I = \frac{\mu_0 \mathcal{E} \pi r^2}{\rho \ell (2r)} = \frac{\mu_0 \mathcal{E} \pi r}{2\rho \ell} = \frac{(4\pi \times 10^{-7} \text{ T}\cdot\text{m/A})(20.0 \text{ V})\pi(2.00\times 10^{-3} \text{ m})}{2(1.70\times 10^{-8}\ \Omega\cdot\text{m})(10.0 \text{ m})} = \boxed{464 \text{ mT}}$$

22.58 Model the two wires as straight parallel wires (!)



(a) $F_B = \frac{\mu_0 I^2 \ell}{2\pi a}$ (Equation 22.27)

$$F_B = \frac{(4\pi \times 10^{-7})(140)^2 (2\pi)(0.100)}{2\pi(1.00\times 10^{-3})} = \boxed{2.46 \text{ N}} \text{ upward}$$

(b) $$a_{\text{loop}} = \frac{2.46 \text{ N} - m_{\text{loop}} g}{m_{\text{loop}}} = \boxed{107 \text{ m/s}^2} \text{ upward}$$