Chapter 19
Magnetism

Problem Solutions

19.1 The direction in parts (a) through (d) is found by use of the right hand rule. You must remember that the electron is negatively charged and thus experiences a force in the direction exactly opposite that predicted by the right hand rule for a positively charged particle.

(a) $\boxed{\text{horizontal and due east}}$ (b) $\boxed{\text{horizontal and 30° N of E}}$

(c) $\boxed{\text{horizontal and due east}}$ (d) $\boxed{\text{zero force}}$, $F = qvB\sin\theta = qvB\sin(180°) = 0$

19.3 Since the particle is positively charged, use the right hand rule. In this case, start with the fingers of the right hand in the direction of $\mathbf{v}$ and the thumb pointing in the direction of $\mathbf{F}$. As you start closing the hand, the fingers point in the direction of $\mathbf{B}$ after they have moved 90°. The results are

(a) $\boxed{\text{into the page}}$ (b) $\boxed{\text{toward the right}}$ (c) $\boxed{\text{toward bottom of page}}$

19.8 The speed attained by the electron is found from $\frac{1}{2}mv^2 = |q|(\Delta V)$, or

$$v = \sqrt{\frac{2e(\Delta V)}{m}} = \sqrt{\frac{2(1.60\times 10^{-19}\text{ C})(2\,400\text{ V})}{9.11\times 10^{-31}\text{ kg}}} = 2.90\times 10^{7}\text{ m/s}$$

(a) Maximum force occurs when the electron enters the region perpendicular to the field.

$$F_{\max} = |q|vB\sin 90°$$

$$= (1.60\times 10^{-19}\text{ C})(2.90\times 10^{7}\text{ m/s})(1.70\text{ T}) = \boxed{7.90\times 10^{-12}\text{ N}}$$

(b) Minimum force occurs when the electron enters the region parallel to the field.

$$F_{\min} = |q| vB \sin 0° = \boxed{0}$$

19.9 $B = \dfrac{F}{qv} = \dfrac{ma}{qv} = \dfrac{(1.67 \times 10^{-27} \text{ kg})(2.0 \times 10^{13} \text{ m/s}^2)}{(1.60 \times 10^{-19} \text{ C})(1.0 \times 10^{7} \text{ m/s})} = \boxed{0.021 \text{ T}}$

The right hand rule shows that $\mathbf{B}$ must be in $\boxed{\text{the } -y \text{ direction}}$ to yield a force in the $+x$ direction when $\mathbf{v}$ is in the $+z$ direction.

19.11 From $F = BIL\sin\theta$, the magnetic field is

$$B = \frac{F/L}{I\sin\theta} = \frac{0.12 \text{ N/m}}{(15 \text{ A})\sin 90°} = \boxed{8.0 \times 10^{-3} \text{ T}}$$

The direction of $\mathbf{B}$ must be $\boxed{\text{the } +z \text{ direction}}$ to have $\mathbf{F}$ in the $-y$ direction when $\mathbf{I}$ is in the $+x$ direction.

19.15 $F = BIL\sin\theta = (0.300 \text{ T})(10.0 \text{ A})(5.00 \text{ m})\sin(30.0°) = \boxed{7.50 \text{ N}}$

19.19 For the wire to move upward at constant speed, the net force acting on it must be zero. Thus, $BIL\sin\theta = mg$ and for minimum field $\theta = 90°$. The minimum field is

$$B = \frac{mg}{IL} = \frac{(0.015 \text{ kg})(9.80 \text{ m/s}^2)}{(5.0 \text{ A})(0.15 \text{ m})} = \boxed{0.20 \text{ T}}$$

For the magnetic force to be directed upward when the current is toward the left, **B** must be directed $\boxed{\text{out of the page}}$.

19.22 The magnitude of the torque is $\tau = NBIA\sin\theta$, where θ is the angle between the field and the perpendicular to the plane of the loop. The circumference of the loop is $2\pi r = 2.00 \text{ m}$, so the radius is $r = \dfrac{1.00 \text{ m}}{\pi}$ and the area is $A = \pi r^2 = \dfrac{1}{\pi} \text{ m}^2$.

Thus, $\tau = (1)(0.800 \text{ T})(17.0 \times 10^{-3} \text{ A})\left(\dfrac{1}{\pi} \text{ m}^2\right)\sin 90.0° = \boxed{4.33 \times 10^{-3} \text{ N} \cdot \text{m}}$

19.24 Note that the angle between the field and the perpendicular to the plane of the loop is $\theta = 90.0° - 30.0° = 60.0°$. Then, the magnitude of the torque is

$$\tau = NBIA\sin\theta = 100(0.80\text{ T})(1.2\text{ A})\left[(0.40\text{ m})(0.30\text{ m})\right]\sin 60.0° = \boxed{10\text{ N}\cdot\text{m}}$$

With current in the $-y$ direction, the outside edge of the loop will experience a force directed out of the page ($+z$ direction) according to the right hand rule. Thus, the loop will rotate $\boxed{\text{clockwise as viewed from above}}$.

19.27 The magnitude of the force a proton experiences as it moves perpendicularly to a magnetic field is

$$F = qvB\sin\theta = (+e)vB\sin(90.0°) = evB$$

This force is always directed perpendicular to the velocity of the proton and will supply the centripetal acceleration as the proton follows a circular path. Thus,

$$evB = m\frac{v^2}{r} \qquad \text{or} \qquad v = \frac{erB}{m}$$

and the time required for the proton to complete one revolution is

$$T = \frac{2\pi r}{v} = \frac{2\pi r}{erB/m} = \frac{2\pi m}{eB}$$

If it is observed that $T = 1.00\ \mu\text{s}$, the magnitude of the magnetic field is

$$B = \frac{2\pi m}{eT} = \frac{2\pi\left(1.67\times10^{-27}\text{ kg}\right)}{\left(1.60\times10^{-19}\text{ C}\right)\left(1.00\times10^{-6}\text{ s}\right)} = \boxed{6.56\times10^{-2}\text{ T}}$$

19.29 For the particle to pass through with no deflection, the net force acting on it must be zero. Thus, the magnetic force and the electric force must be in opposite directions and have equal magnitudes. This gives

$F_m = F_e$, or $qvB = qE$ which reduces to $\boxed{v = E/B}$

19.34 Imagine grasping the conductor with the right hand so the fingers curl around the conductor in the direction of the magnetic field. The thumb then points along the conductor in the direction of the current. The results are

(a) $\boxed{\text{toward the left}}$ (b) $\boxed{\text{out of page}}$ (c) $\boxed{\text{lower left to upper right}}$

19.37 From $B = \mu_0 I / 2\pi r$, the required distance is

$$r = \frac{\mu_0 I}{2\pi B} = \frac{\left(4\pi \times 10^{-7}\ \text{T}\cdot\text{m/A}\right)\left(20\ \text{A}\right)}{2\pi\left(1.7\times 10^{-3}\ \text{T}\right)} = 2.4\times 10^{-3}\ \text{m} = \boxed{2.4\ \text{mm}}$$

19.38 Assume that the wire on the right is wire 1 and that on the left is wire 2. Also, choose the positive direction for the magnetic field to be out of the page and negative into the page.

(a) At the point half way between the two wires,

$$B_{net} = -B_1 - B_2 = -\left[\frac{\mu_0 I_1}{2\pi r_1} + \frac{\mu_0 I_2}{2\pi r_2}\right] = -\frac{\mu_0}{2\pi r}\left(I_1 + I_2\right)$$

$$= -\frac{\left(4\pi \times 10^{-7}\ \text{T}\cdot\text{m/A}\right)}{2\pi\left(5.00\times 10^{2}\ \text{m}\right)}\left(10.0\ \text{A}\right) = -4.00\times 10^{-5}\ \text{T}$$

or $\quad B_{net} = \boxed{40.0\ \mu\text{T into the page}}$

(b) At point P_1, $\quad B_{net} = +B_1 - B_2 = \dfrac{\mu_0}{2\pi}\left[\dfrac{I_1}{r_1} - \dfrac{I_2}{r_2}\right]$

$$B_{net} = \frac{\left(4\pi \times 10^{-7}\ \text{T}\cdot\text{m/A}\right)}{2\pi}\left[\frac{5.00\ \text{A}}{0.100\ \text{m}} - \frac{5.00\ \text{A}}{0.200\ \text{m}}\right] = \boxed{5.00\ \mu\text{T out of page}}$$

(c) At point P_2, $\quad B_{net} = -B_1 + B_2 = \dfrac{\mu_0}{2\pi}\left[-\dfrac{I_1}{r_1} + \dfrac{I_2}{r_2}\right]$

$$B_{net} = \frac{\left(4\pi \times 10^{-7}\ \text{T}\cdot\text{m/A}\right)}{2\pi}\left[-\frac{5.00\ \text{A}}{0.300\ \text{m}} + \frac{5.00\ \text{A}}{0.200\ \text{m}}\right]$$

$$= \boxed{1.67\ \mu\text{T out of page}}$$

19.41 Call the wire along the x axis wire 1 and the other wire 2. Also, choose the positive direction for the magnetic fields at point P to be out of the page.

At point P, $B_{net} = +B_1 - B_2 = \dfrac{\mu_0 I_1}{2\pi r_1} - \dfrac{\mu_0 I_2}{2\pi r_2} = \dfrac{\mu_0}{2\pi}\left(\dfrac{I_1}{r_1} - \dfrac{I_2}{r_2}\right)$

or $$B_{net} = \frac{\left(4\pi \times 10^{-7}\ \mathrm{T \cdot m/A}\right)}{2\pi}\left(\frac{7.00\ \mathrm{A}}{3.00\ \mathrm{m}} - \frac{6.00\ \mathrm{A}}{4.00\ \mathrm{m}}\right) = +1.67 \times 10^{-7}\ \mathrm{T}$$

$$B_{net} = \boxed{0.167\ \mu\mathrm{T}\ \text{ out of the page}}$$

19.44 (a) $$\frac{F}{L} = \frac{\mu_0 I_1 I_2}{2\pi d} = \frac{\left(4\pi \times 10^{-7}\ \mathrm{T \cdot m/A}\right)\left(10.0\ \mathrm{A}\right)^2}{2\pi\left(0.100\ \mathrm{m}\right)}$$

$$= \boxed{2.00 \times 10^{-4}\ \mathrm{N/m}\ \ (\text{attraction})}$$

(b) The magnitude remains the same as calculated in (a), but the wires are repelled. Thus, $\dfrac{F}{L} = \boxed{2.00 \times 10^{-4}\ \mathrm{N/m}\ \ (\text{repulsion})}$

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

$$I = \frac{BL}{\mu_0 N} = \frac{\left(1.00 \times 10^{-4}\ \mathrm{T}\right)\left(0.400\ \mathrm{m}\right)}{\left(4\pi \times 10^{-7}\ \mathrm{T \cdot m/A}\right)\left(1\,000\right)} = 3.18 \times 10^{-2}\ \mathrm{A} = \boxed{31.8\ \mathrm{mA}}$$

19.49 The magnetic field inside the solenoid is

$$B = \mu_0 n I_1 = \left(4\pi \times 10^{-7}\ \mathrm{T \cdot m/A}\right)\left[\left(30\ \frac{\text{turns}}{\text{cm}}\right)\left(\frac{100\ \text{cm}}{1\ \text{m}}\right)\right]\left(15.0\ \mathrm{A}\right) = 5.65 \times 10^{-2}\ \mathrm{T}$$

Therefore, the magnitude of the magnetic force on any one of the sides of the square loop is

$$F = BI_2 L \sin 90.0^\circ = \left(5.65 \times 10^{-2}\ \mathrm{T}\right)\left(0.200\ \mathrm{A}\right)\left(2.00 \times 10^{-2}\ \mathrm{m}\right) = \boxed{2.26 \times 10^{-4}\ \mathrm{N}}$$

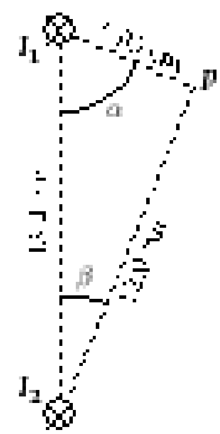
The forces acting on the sides of the loop lie in the plane of the loop, are perpendicular to the sides, and are directed $\boxed{\text{away from the interior}}$ of the loop. Thus, they tend to stretch the loop but do not tend to rotate it. The torque acting on the loop is $\boxed{\tau = 0}$

19.57 (a) Since the magnetic field is directed from N to S (that is, from left to right within the artery), positive ions with velocity in the direction of the blood flow experience a magnetic deflection toward electrode *A*. Negative ions will experience a force deflecting them toward electrode *B*. This separation of charges creates an electric field directed from *A* toward *B*. At equilibrium, the electric force caused by this field must balance the magnetic force, so

$$qvB = qE = q(\Delta V/d)$$

or $$v = \frac{\Delta V}{Bd} = \frac{160\times 10^{-6}\ \text{V}}{(0.040\,0\ \text{T})(3.00\times 10^{-3}\ \text{m})} = \boxed{1.33\ \text{m/s}}$$

(b) The magnetic field is directed from N to S. If the charge carriers are negative moving in the direction of $\mathbf{v}$, the magnetic force is directed toward point B. Negative charges build up at point *B*, making the potential at *A* higher than that at *B*. If the charge carriers are positive moving in the direction of $\mathbf{v}$, the magnetic force is directed toward *A*, so positive charges build up at *A*. This also makes the potential at *A* higher than that at *B*. Therefore the sign of the potential difference $\boxed{\text{does not depend on the charge of the ions}}$.



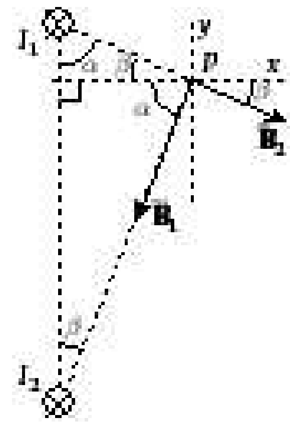
19.61 First, observe that $(5.00\ \text{cm})^2 + (12.0\ \text{cm})^2 = (13.0\ \text{cm})^2$. Thus, the triangle shown in dashed lines is a right triangle giving

$$\alpha = \sin^{-1}\left(\frac{12.0\ \text{cm}}{13.0\ \text{cm}}\right) = 67.4°\text{, and } \beta = 90.0° - \alpha = 22.6°$$

At point *P*, the field due to wire 1 is

$$B_1 = \frac{\mu_0 I_1}{2\pi r_1} = \frac{(4\pi\times 10^{-7}\ \text{T}\cdot\text{m/A})(3.00\ \text{A})}{2\pi(5.00\times 10^{-2}\ \text{m})} = 12.0\ \mu\text{T}$$

and it is directed from P toward wire 2, or to the left and at 67.4° below the horizontal. The field due to wire 2 has magnitude



$$B_2 = \frac{\mu_0 I_2}{2\pi r_2} = \frac{\left(4\pi \times 10^{-7}\ \mathrm{T\cdot m/A}\right)\left(3.00\ \mathrm{A}\right)}{2\pi\left(12.00 \times 10^{-2}\ \mathrm{m}\right)} = 5.00\ \mu\mathrm{T}$$

and at P is directed away from wire 1 or to the right and at 22.6° below the horizontal.

Thus, $B_{1x} = -B_1 \cos 67.4° = -4.62\ \mu\mathrm{T}$ $\quad B_{1y} = -B_1 \sin 67.4° = -11.1\ \mu\mathrm{T}$

$$B_{2x} = B_2 \cos 22.6° = +4.62\ \mu\mathrm{T} \quad B_{2y} = -B_2 \sin 22.6° = -1.92\ \mu\mathrm{T}$$

and $B_x = B_{1x} + B_{2x} = 0$, while $B_y = B_{1y} + B_{2y} = -13.0\ \mu\mathrm{T}$.

The resultant field at P is

$$\mathbf{B} = \boxed{13.0\ \mu\mathrm{T}\ \text{directed toward the bottom of the page}}$$