Chapter 22

Magnetism

Answers to Even-numbered Conceptual Questions

2. Yes. If an electric field exists in this region of space, and no magnetic field is present, the electric field will exert a force on the electron and cause it to accelerate.

4. The magnetic field in the continental United States points primarily toward the north. Therefore, an electron moving toward the east experiences a downward magnetic force. Of course, the magnetic force on a positively-charged proton moving toward the east is upward.

6. In this case, the magnetic force on the electron points to the east.

8. In each case, the force acting on the particle must point toward the center of curvature of its path. Therefore, particles 1 and 2 have negative charges; particle 3 has a positive charge.

10. We want the magnetic force on the proton to be toward the center of the Earth, so that it provides some of the necessary centripetal force. It follows that the proton must move in a westward direction.

12. In a uniform electric field, the force on a charged particle is always in the same direction, leading to parabolic trajectories. In a uniform magnetic field, the force of a charged particle is always at right angles to the motion, resulting in circular or helical trajectories. Perhaps even more important, a charged particle experiences a force due to an electric field whether it is moving or at rest; in a magnetic field, the particle must be moving to experience a force.

14. The electric field must point in the positive x direction, regardless of the sign of the particle's charge.

16. A current-carrying wire in a uniform magnetic field can experience zero force only if the wire points in the same or opposite direction as the magnetic field. In such a case, the angle θ in Equation 22-4 will be either 0° or 180°, in which case $F = ILB \sin \theta = 0$.

18. The force between wires carrying currents in the same direction is attractive, and inversely proportional to the distance between the wires. Similarly, the force between wires with oppositely directed currents is repulsive. It follows from simple geometry, then, that the net force acting on wire 2 is directed toward wire 4.

20. If we apply the right-hand rule to wires 2 and 4, we see that they produce magnetic fields at the center of the square that point toward wire 3. On the other hand, the magnetic fields produced by wires 1 and 3 at the center of the square cancel one another. It follows that the total magnetic field at the center of the square points toward wire 3.

22. If the current loop is to attract the magnet, it must produce a magnetic field with its north pole pointing to the right; that is, pointing toward the south pole of the bar magnet. For this to be the case, the current in the wire must point out of the page, which means, in turn, that terminal A must be the positive terminal.

Solutions to Problems

1. $F = ma = evB$

$$a = \frac{evB}{m} = \frac{(1.6\times10^{-19}\text{ C})\left(9.5\ \frac{\text{m}}{\text{s}}\right)(1.2\text{ T})}{1.673\times10^{-27}\text{ kg}} = \boxed{1.1\times10^{9}\ \text{m/s}^2}$$

2. $$v = \frac{F}{eB} = \frac{8.9\times10^{-15}\text{ N}}{(1.6\times10^{-19}\text{ C})(0.12\text{ T})} = \boxed{4.6\times10^{5}\ \text{m/s}}$$

3. $F = qvB\sin 0° = \boxed{0}$

4. $$a = \frac{evB}{m} = \frac{(1.60\times10^{-19}\text{ C})\left(355\ \frac{\text{m}}{\text{s}}\right)(4.05\times10^{-5}\text{ T})}{1.673\times10^{-27}\text{ kg}} = \boxed{1.38\times10^{6}\ \text{m/s}^2}$$

5. $F = qvB\sin\theta$

$$\theta = \sin^{-1}\frac{F}{qvB}$$

(a) $$\theta = \sin^{-1}\frac{4.8\times10^{-6}\text{ N}}{(0.32\times10^{-6}\text{ C})\left(16\ \frac{\text{m}}{\text{s}}\right)(0.95\text{ T})} = \boxed{81°}$$

(b) $$\theta = \sin^{-1}\frac{3.0\times10^{-6}\text{ N}}{(0.32\times10^{-6}\text{ C})\left(16\ \frac{\text{m}}{\text{s}}\right)(0.95\text{ T})} = \boxed{38°}$$

(c) $$\theta = \sin^{-1}\frac{1.0\times10^{-7}\text{ N}}{(0.32\times10^{-6}\text{ C})\left(16\ \frac{\text{m}}{\text{s}}\right)(0.95\text{ T})} = \boxed{1.2°}$$

6. $F_1 = qv_1B\sin 90°$

$$B = \frac{F_1}{qv_1}$$

$$F_2 = qv_2\left(\frac{F_1}{qv_1}\right)\sin\theta_2 = \frac{v_2}{v_1}F_1\sin\theta_2 = \frac{6.8\ \frac{\text{m}}{\text{s}}}{23\ \frac{\text{m}}{\text{s}}}\left(2.2\times10^{-4}\text{ N}\right)\sin 25° = \boxed{2.7\times10^{-5}\text{ N}}$$

7. $F = F_x\sin 45° = (6.2\times10^{-16}\text{ N})\sin 45° = \boxed{4.4\times10^{-16}\text{ N}}$

8. Since the electron experiences zero magnetic force when traveling along the x-axis, $\vec{\mathbf{B}}$ is directed along the x-axis. Using the RHR in conjunction with the fact that the charge of an electron is negative, we see that $\vec{\mathbf{B}}$ points in the

$\boxed{\text{negative } x\text{-direction}}$.

$$B = \frac{F}{ev} = \frac{2.0\times10^{-13}\text{ N}}{(1.6\times10^{-19}\text{ C})\left(9.1\times10^{5}\ \frac{\text{m}}{\text{s}}\right)} = \boxed{1.4\text{ T}}$$

9. (a) Since the magnetic force is directly proportional to both the charge and the speed of the particles, and since the particles experience the same force, $\boxed{\text{particle 2}}$ must have a greater speed because particle 1 has the greater charge.

(b) $F_1 = 4qv_1B\sin\theta = F_2 = qv_2B\sin\theta$

$$\frac{v_1}{v_2} = \boxed{\frac{1}{4}}$$

10. $\vec{\mathbf{F}}_E = qE\hat{\mathbf{x}} = (6.60\times10^{-6}\text{ C})\left(1250\ \frac{\text{N}}{\text{C}}\right)\hat{\mathbf{x}} = (8.25\times10^{-3}\text{ N})\hat{\mathbf{x}}$

Since $F_{\text{net}} < F_E$, the force due to the magnetic field opposes the force due to the electric field. So, $\vec{\mathbf{F}}_B = -F_B\hat{\mathbf{x}},$ where $F_B > 0.$ According to the RHR, $\vec{\mathbf{v}}$ is in the $\boxed{\text{negative } y\text{-direction}}$.

$$F_{\text{net}} = qE - qvB$$
$$qvB = qE - F_{\text{net}}$$
$$v = \frac{1}{B}\left(E - \frac{F_{\text{net}}}{q}\right) = \frac{1}{1.02\text{ T}}\left(1250\ \frac{\text{N}}{\text{C}} - \frac{6.23\times10^{-3}\text{ N}}{6.60\times10^{-6}\text{ C}}\right) = \boxed{300\text{ m/s}}$$

11. (a) $\vec{\mathbf{F}}_E = e\vec{\mathbf{E}} = F_E\hat{\mathbf{x}}$

$$\vec{\mathbf{E}} = \frac{F_E}{e}\hat{\mathbf{x}} = \frac{8.0\times10^{-13}\text{ N}}{1.6\times10^{-19}\text{ C}}\hat{\mathbf{x}} = \boxed{(5.0\times10^{6}\text{ N/C})\hat{\mathbf{x}}}$$

(b) $\vec{\mathbf{F}}_B = -F_B\hat{\mathbf{x}}$ and $\vec{\mathbf{v}} = v\hat{\mathbf{y}}$, so $\vec{\mathbf{B}} = -B\hat{\mathbf{z}}$.

$$F_E - F_B = F$$
$$F_B = F_E - F = evB$$
$$\vec{\mathbf{B}} = -\frac{F_E - F}{ev}\hat{\mathbf{z}} = -\frac{8.0\times10^{-13}\text{ N} - 7.5\times10^{-13}\text{ N}}{(1.6\times10^{-19}\text{ C})\left(1.5\times10^{6}\ \frac{\text{m}}{\text{s}}\right)}\hat{\mathbf{z}} = \boxed{(-0.2\text{ T})\hat{\mathbf{z}}}$$

12. $$r = \frac{mv}{eB} = \frac{(9.11\times10^{-31}\text{ kg})\left(6.27\times10^{5}\ \frac{\text{m}}{\text{s}}\right)}{(1.6\times10^{-19}\text{ C})(0.55\text{ T})} = \boxed{6.5\times10^{-6}\text{ m}}$$

13. $$r = \frac{mv}{eB} = \frac{(1.673\times10^{-27}\text{ kg})\left(6.27\times10^{5}\ \frac{\text{m}}{\text{s}}\right)}{(1.6\times10^{-19}\text{ C})(0.55\text{ T})} = \boxed{1.2\text{ cm}}$$

14. $$v = \frac{E}{B} = \frac{450\ \frac{\text{N}}{\text{C}}}{0.12\text{ T}} = \boxed{3.8\text{ km/s}}$$

15. According to the RHR, the force due to the magnetic field is in the positive y-direction. Since the force due to the electric field must oppose the magnetic force, $\vec{\mathbf{E}}$ must point in the negative y-direction.

$$\vec{\mathbf{E}} = vB(-\hat{\mathbf{y}}) = \left(4.5\times10^3\ \frac{\text{m}}{\text{s}}\right)(0.96\ \text{T})(-\hat{\mathbf{y}}) = \boxed{(-4.3\times10^3\ \text{N/C})\hat{\mathbf{y}}}$$

16. (a) $$v = \frac{E}{B} = \frac{V}{dB} = \left(\frac{195\times10^{-6}\ \text{V}}{(2.75\times10^{-3}\ \text{m})(0.065\ \text{T})}\right) = \boxed{1.1\ \text{m/s}}$$

(b) According to the RHR, the direction of the magnetic force experienced by a positively charged ion is down. The electric force opposes the magnetic force, so the electric field points up. If the ion is negatively charged, the direction of the magnetic force is up. In this case, the electric field still points up, but the force points down. So, the answer does not depend on the sign of the ions. Since the electric field points in the direction of decreasing potential, the bottom electrode is at the higher potential.

17. $$\frac{1}{2}mv^2 = eV$$

$$v = \sqrt{\frac{2eV}{m}}$$

$$B = \frac{mv}{er} = \frac{m}{er}\sqrt{\frac{2eV}{m}} = \frac{1}{r}\sqrt{\frac{2mV}{e}} = \frac{1}{0.17\ \text{m}}\sqrt{\frac{2(9.11\times10^{-31}\ \text{kg})(410\ \text{V})}{1.60\times10^{-19}\ \text{C}}} = \boxed{0.40\ \text{mT}}$$

18. (a) $$v = \frac{qrB}{m} = \frac{(12.5\times10^{-6}\ \text{C})(26.8\ \text{m})(1.01\ \text{T})}{2.80\times10^{-5}\ \text{kg}} = \boxed{12.1\ \text{m/s}}$$

(b) $$t = \frac{2\pi r}{v} = \frac{2\pi m}{qB} = \frac{2\pi(2.80\times10^{-5}\ \text{kg})}{(12.5\times10^{-6}\ \text{C})(1.01\ \text{T})} = \boxed{13.9\ \text{s}}$$

19. (a) According to the RHR, a positively charged particle would experience a force to the left. Since the particle is experiencing a force to the right, it must be negatively charged.

(b) $$m = \frac{erB}{v} = \frac{(1.60\times10^{-19}\ \text{C})(0.520\ \text{m})(0.180\ \text{T})}{\left(1.67\times10^{-27}\ \frac{\text{kg}}{\text{u}}\right)\left(6.0\times10^6\ \frac{\text{m}}{\text{s}}\right)} = \boxed{1.5\ \text{u}}$$

20. $$K = \frac{1}{2}mv^2$$

$$v = \sqrt{\frac{2K}{m}}$$

$$r = \frac{mv}{eB} = \frac{m}{eB}\sqrt{\frac{2K}{m}} = \frac{\sqrt{2mK}}{eB} = \frac{\sqrt{2(1.673\times10^{-27}\ \text{kg})(4.9\times10^{-16}\ \text{J})}}{(1.6\times10^{-19}\ \text{C})(0.26\ \text{T})} = \boxed{3.1\ \text{cm}}$$

21. (a) $$t = \frac{T}{2} = \frac{1}{2}\left(\frac{2\pi r}{v}\right) = \frac{\pi r}{v} = \frac{\pi}{v}\left(\frac{mv}{qB}\right) = \frac{\pi m}{qB}$$

$$t = \frac{\pi(2m_\text{p} + 2m_\text{n})}{2eB} = \frac{\pi(1.673\times10^{-27}\ \text{kg} + 1.675\times10^{-27}\ \text{kg})}{(1.60\times10^{-19}\ \text{C})(0.155\ \text{T})} = \boxed{4.24\times10^{-7}\ \text{s}}$$

(b) The time does not depend upon the speed of the particle, so the answer to part (a) will $\boxed{\text{stay the same}}$.

(c) $t = \boxed{4.24 \times 10^{-7}\ \text{s}}$

22. **(a)** Since $r = p/(eB)$ for both particles, and since p and B are the same for both particles, the ratio of radii is $\boxed{1}$.

(b)
$$\frac{1}{2}m_\text{p}v_\text{p}^2 = \frac{1}{2}m_\text{e}v_\text{e}^2$$
$$\frac{v_\text{p}}{v_\text{e}} = \sqrt{\frac{m_\text{e}}{m_\text{p}}}$$
$$r = \frac{mv}{eB} = \frac{\frac{1}{2}mv^2}{\frac{1}{2}evB} = \frac{2K}{evB}$$
$$K_\text{e} = \frac{1}{2}ev_\text{e}Br_\text{e}$$
$$K_\text{p} = \frac{1}{2}ev_\text{p}Br_\text{p}$$
$$K_\text{e} = K_\text{p}$$
$$\frac{1}{2}ev_\text{e}Br_\text{e} = \frac{1}{2}ev_\text{p}Br_\text{p}$$
$$v_\text{e}r_\text{e} = v_\text{p}r_\text{p}$$
$$\frac{r_\text{e}}{r_\text{p}} = \frac{v_\text{p}}{v_\text{e}} = \sqrt{\frac{m_\text{e}}{m_\text{p}}} = \sqrt{\frac{9.11\times10^{-31}\text{ kg}}{1.673\times10^{-27}\text{ kg}}} = \boxed{0.0233}$$

23. $F = ILB\sin 90° = (0.675\text{ A})(2.55\text{ m})(0.720\text{ T}) = \boxed{1.24\text{ N}}$

24. $F = ILB\sin\theta = (2.8\text{ A})(2.25\text{ m})(0.88\text{ T})\sin 36.0° = \boxed{3.3\text{ N}}$

25.
$$\sin\theta = \frac{F}{ILB}$$
$$\theta = \sin^{-1}\frac{F}{ILB} = \sin^{-1}\frac{1.6\text{ N}}{(3.0\text{ A})(1.2\text{ m})(0.50\text{ T})} = \boxed{63°}$$

26.
$$F = ILB\sin\theta$$
$$F_\text{top} = F_\text{bottom} = ILB(0) = \boxed{0}$$
$$F_\text{left} = F_\text{right} = ILB\sin 90° = (9.5\text{ A})(0.46\text{ m})(0.34\text{ T}) = \boxed{1.5\text{ N}}$$

27.
$$F = mg = ILB$$
$$B = \frac{mg}{IL} = \frac{(0.17\text{ kg})\left(9.81\ \frac{\text{m}}{\text{s}^2}\right)}{(11\text{ A})(0.45\text{ m})} = 0.34\text{ T}$$
$\boxed{\text{If up is in the positive } y\text{-direction, } \vec{\mathbf{B}} = (-0.34\text{ T})\hat{\mathbf{z}}.}$

28. **(a)** $\frac{F}{L} = IB\sin\theta$

$$B = \frac{\frac{F}{L}}{I\sin\theta} = \frac{0.033\,\frac{\text{N}}{\text{m}}}{(6.2\text{ A})\sin 7.5^\circ} = \boxed{41\text{ mT}}$$

(b) $\theta = \sin^{-1}\frac{\frac{F}{L}}{IB} = \sin^{-1}\frac{0.015\,\frac{\text{N}}{\text{m}}}{(6.2\text{ A})(0.04078\text{ T})} = \boxed{3.4^\circ}$

29. $F = mg = ILB\sin\theta$

$$I = \frac{mg}{LB\sin\theta}$$

I is minimized when $\theta = 90^\circ$.

$$I = \frac{(0.75\text{ kg})\left(9.81\,\frac{\text{m}}{\text{s}^2}\right)}{(3.7\text{ m})(0.81\text{ T})\sin 90^\circ} = \boxed{2.5\text{ A}}$$

30. **(a)** $\boxed{\text{According to the RHR, the magnetic force points towards north, 18° above the horizontal.}}$

$$F = ILB\sin\theta = (110\text{ A})(250\text{ m})(0.59\text{ G})\left(\frac{10^{-4}\text{ T}}{1\text{ G}}\right)\sin 90^\circ = \boxed{1.6\text{ N}}$$

(b) $\boxed{\text{According to the RHR, the magnetic force points towards east.}}$

$$F = ILB\sin\theta = (110\text{ A})(250\text{ m})(0.59\text{ G})\left(\frac{10^{-4}\text{ T}}{1\text{ G}}\right)\sin 72^\circ = \boxed{1.5\text{ N}}$$

31. $\Sigma F_y = 0 = T\cos\theta - mg$

$\Sigma F_x = 0 = T\sin\theta - ILB$

$$T = \frac{mg}{\cos\theta} = \frac{ILB}{\sin\theta}$$

$$\tan\theta = \frac{ILB}{mg}$$

$$\theta = \boxed{\tan^{-1}\frac{ILB}{mg}}$$

32. $I = \frac{\tau}{NAB\sin\theta} = \frac{23\text{ N}\cdot\text{m}}{(200)(0.22\text{ m})(0.16\text{ m})(0.45\text{ T})(1)} = \boxed{7.3\text{ A}}$

33. $\tau = IAB\sin\theta$

τ is maximized when $\theta = 90^\circ$.

$\tau = (2.6\text{ A})\pi(0.23\text{ m})^2(0.95\text{ T}) = \boxed{0.41\text{ N}\cdot\text{m}}$

34. $\tau = \frac{\tau_{\text{max}}}{2} = \frac{1}{2}IAB = IAB\sin\theta$

$$\theta = \sin^{-1}\left(\frac{1}{2}\right) = 30^\circ$$

The angle the plane of the loop makes with the field is $90^\circ - 30^\circ = \boxed{60^\circ}$.

35. $\tau = IAB\sin\theta = (9.5\text{ A})(0.46\text{ m})^2(0.34\text{ T})\sin 90° = \boxed{0.68\text{ N}\cdot\text{m}}$

36. (a) A circle has a larger area than a square when the perimeters of each are equal. So, since the torque is directly proportional to the area of the loop, the maximum torque of the square loop is $\boxed{\text{less than}}$ the maximum torque of the circular loop.

(b) $$\frac{\tau_{\text{square}}}{\tau_{\text{circle}}} = \frac{IA_\text{s}B}{IA_\text{c}B} = \frac{A_\text{s}}{A_\text{c}} = \frac{\left(\frac{L}{4}\right)^2}{\pi\left(\frac{L}{2\pi}\right)^2} = \left(\frac{L^2}{16}\right)\left(\frac{4\pi}{L^2}\right) = \boxed{\frac{\pi}{4}}$$

37. Let $\vec{\mathbf{B}} = (0.050\text{ T})\hat{\mathbf{x}}$.

(a) $\vec{\mathbf{F}}_{\text{top}} = NILB\sin\theta\hat{\mathbf{z}} = 10(0.22\text{ A})(0.15\text{ m})(0.050\text{ T})(\sin 25°)\hat{\mathbf{z}} = \boxed{(7.0\times10^{-3}\text{ N})\hat{\mathbf{z}}}$

$\vec{\mathbf{F}}_{\text{bottom}} = -\vec{\mathbf{F}}_{\text{top}} = \boxed{(-7.0\times10^{-3}\text{ N})\hat{\mathbf{z}}}$

$\vec{\mathbf{F}}_{\text{left}} = -NILB\sin\theta\hat{\mathbf{y}} = -10(0.22\text{ A})(0.080\text{ m})(0.050\text{ T})\sin 90°\hat{\mathbf{y}} = \boxed{(-8.8\times10^{-3}\text{ N})\hat{\mathbf{y}}}$

$\vec{\mathbf{F}}_{\text{right}} = -\vec{\mathbf{F}}_{\text{left}} = \boxed{(8.8\times10^{-3}\text{ N})\hat{\mathbf{y}}}$

(b) $\vec{\mathbf{F}}_{\text{net}} = \vec{\mathbf{F}}_{\text{top}} + \vec{\mathbf{F}}_{\text{bottom}} + \vec{\mathbf{F}}_{\text{left}} + \vec{\mathbf{F}}_{\text{right}} = \boxed{0}$

(c) $\tau = NIAB\sin\theta = 10(0.22\text{ A})(0.080\text{ m})(0.15\text{ m})(0.050\text{ T})\sin 65° = \boxed{1.2\times10^{-3}\text{ N}\cdot\text{m}}$

(d) The forces on the left and right sides of the loop will rotate it clockwise as viewed from above until its normal is aligned with $\vec{\mathbf{B}}$ (zero torque). So, the loop will end up with an orientation given by $\boxed{\theta = 0}$.

38. $$B = \frac{\mu_0 I}{2\pi r} = \frac{\left(4\pi\times10^{-7}\ \frac{\text{T}\cdot\text{m}}{\text{A}}\right)(6.81\text{ A})}{2\pi(0.0525\text{ m})} = \boxed{2.59\times10^{-5}\text{ T}}$$

39. $$r = \frac{\mu_0 I}{2\pi B} = \frac{\left(4\pi\times10^{-7}\ \frac{\text{T}\cdot\text{m}}{\text{A}}\right)(7.2\text{ A})}{2\pi(5.0\times10^{-5}\text{ T})} = \boxed{2.9\text{ cm}}$$

40. On the circle, $B = B_\perp$. Since $B_{||} = 0$, $\Sigma B_{||}\Delta L = 0 = \mu_0 I_{\text{enclosed}}$, so $I_{\text{enclosed}} = 0$.

41. $$F = \frac{\mu_0 I_1 I_2}{2\pi d}L = \frac{\left(4\pi\times10^{-7}\ \frac{\text{T}\cdot\text{m}}{\text{A}}\right)(120\text{ A})^2}{2\pi(0.35\text{ m})}(250\text{ m}) = 2.1\text{ N}$$

Wires with parallel currents attract, so $\boxed{\vec{\mathbf{F}} = 2.1\text{ N towards each other}}$.

42. $$I = \frac{2\pi rB}{\mu_0} = \frac{2\pi(0.50\text{ m})(5.0\times10^{-4}\text{ T})}{4\pi\times10^{-7}\ \frac{\text{T}\cdot\text{m}}{\text{A}}} = \boxed{1.3\text{ kA}}$$

43. (a) According to the RHR, the magnetic field due to each current is out of the page at *A*, whereas at *B*, the field due to the 6.2-A current is into the page and the field due to the 4.5-A current is out of the page. So, since the magnitudes of the fields due to each wire are the same at each point but their directions are opposite at *B*, the magnitude of the net magnetic field is greatest at $\boxed{\text{A}}$.

(b)
$$\begin{aligned}B_A &= \frac{\mu_0 I_1}{2\pi r}+\frac{\mu_0 I_2}{2\pi r}\\ &= \frac{\mu_0}{2\pi r}(I_1+I_2)\\ &= \frac{\left(4\pi\times10^{-7}\ \frac{\text{T}\cdot\text{m}}{\text{A}}\right)}{2\pi(0.16\ \text{m})}(6.2\ \text{A}+4.5\ \text{A})\\ &= \boxed{1.3\times10^{-5}\ \text{T}}\end{aligned}$$

$$\begin{aligned}B_B &= \frac{\mu_0}{2\pi r}(I_1-I_2)\\ &= \frac{\left(4\pi\times10^{-7}\ \frac{\text{T}\cdot\text{m}}{\text{A}}\right)}{2\pi(0.16\ \text{m})}(6.2\ \text{A}-4.5\ \text{A})\\ &= \boxed{2.1\times10^{-6}\ \text{T}}\end{aligned}$$

44. (a) According to the RHR, the magnetic field due to each current is out of the page at *B*, whereas at *A*, the field due to the 6.2-A current is into the page and the field due to the 4.5-A current is out of the page. So, since the magnitudes of the fields due to each wire are the same at each point but their directions are opposite at *A*, the magnitude of the net magnetic field is greatest at $\boxed{B}$.

(b)
$$\begin{aligned}B_A &= \frac{\mu_0 I_1}{2\pi r}-\frac{\mu_0 I_2}{2\pi r}\\ &= \frac{\mu_0}{2\pi r}(I_1-I_2)\\ &= \frac{\left(4\pi\times10^{-7}\ \frac{\text{T}\cdot\text{m}}{\text{A}}\right)}{2\pi(0.16\ \text{m})}(6.2\ \text{A}-4.5\ \text{A})\\ &= \boxed{2.1\times10^{-6}\ \text{T}}\end{aligned}$$

$$\begin{aligned}B_B &= \frac{\mu_0}{2\pi r}(I_1+I_2)\\ &= \frac{\left(4\pi\times10^{-7}\ \frac{\text{T}\cdot\text{m}}{\text{A}}\right)}{2\pi(0.16\ \text{m})}(6.2\ \text{A}+4.5\ \text{A})\\ &= \boxed{1.3\times10^{-5}\ \text{T}}\end{aligned}$$

45. $$I=\frac{2\pi rB}{\mu_0}=\frac{2\pi(0.25\ \text{m})\left(\frac{5.0\times10^{-5}\ \text{T}}{2}\right)}{4\pi\times10^{-7}\ \frac{\text{T}\cdot\text{m}}{\text{A}}}=\boxed{31\ \text{A}}$$

46. **(a)** $\frac{F}{L} = \frac{\mu_0 I_1 I_2}{2\pi d} = \frac{\left(4\pi \times 10^{-7}\ \frac{\text{T}\cdot\text{m}}{\text{A}}\right)(4.33\text{ A})(2.75\text{ A})}{2\pi(0.322\text{ m})} = \boxed{7.40 \times 10^{-6}\text{ N/m}}$

(b) The force exerted on a meter of the 4.33-A wire is the $\boxed{\text{same}}$ as the force exerted on a meter of the 2.75-A wire because these forces form an action-reaction pair.

47. Let I_1 be located at the origin and I_2 be located on the x-axis. Then the coordinates of P are (0, 5.0 cm).

$$\begin{aligned}\vec{\mathbf{B}} &= \vec{\mathbf{B}}_1 + \vec{\mathbf{B}}_2 \\ &= \frac{\mu_0 I_1}{2\pi r_1}\hat{\mathbf{x}} + \frac{\mu_0 I_2}{2\pi r_2}(\hat{\mathbf{x}}\cos\theta + \hat{\mathbf{y}}\sin\theta) \\ &= \frac{\left(4\pi \times 10^{-7}\ \frac{\text{T}\cdot\text{m}}{\text{A}}\right)}{2\pi}\left[\frac{3.0\text{ A}}{0.050\text{ m}}\hat{\mathbf{x}} + \frac{4.0\text{ A}}{\sqrt{2(0.050\text{ m})^2}}(\hat{\mathbf{x}}\cos 225° + \hat{\mathbf{y}}\sin 225°)\right] \\ &= (4.0 \times 10^{-6}\text{ T})\hat{\mathbf{x}} - (8.0 \times 10^{-6}\text{ T})\hat{\mathbf{y}}\end{aligned}$$

$$B = \sqrt{(4.0 \times 10^{-6}\text{ T})^2 + (-8.0 \times 10^{-6}\text{ T})^2} = \boxed{8.9 \times 10^{-6}\text{ T}}$$

$$\theta = \tan^{-1}\frac{-8.0 \times 10^{-6}\text{ T}}{4.0 \times 10^{-6}\text{ T}} = \boxed{63° \text{ below the dashed line to the right of } P}$$

48. $I = \frac{BL}{\mu_0 N} = \frac{(5.0 \times 10^{-5}\text{ T})(0.32\text{ m})}{\left(4\pi \times 10^{-7}\ \frac{\text{T}\cdot\text{m}}{\text{A}}\right)(450)} = \boxed{28\text{ mA}}$

49. $N = \frac{BL}{\mu_0 I} = \frac{(1.3\text{ T})(0.75\text{ m})}{\left(4\pi \times 10^{-7}\ \frac{\text{T}\cdot\text{m}}{\text{A}}\right)(8.4\text{ A})} = \boxed{9.2 \times 10^4}$

50. $B = \mu_0 n I = \left(4\pi \times 10^{-7}\ \frac{\text{T}\cdot\text{m}}{\text{A}}\right)(3250\text{ m}^{-1})(3.75 \times 10^3\text{ A}) = \boxed{15.3\text{ T}}$

51. The number of turns multiplied by the circumference of the tube will give the necessary length of wire.

$$NC = \frac{BLC}{\mu_0 I} = \frac{(2.5 \times 10^3\text{ G})\left(\frac{10^{-4}\text{ T}}{1\text{ G}}\right)(0.55\text{ m})\pi(0.12\text{ m})}{\left(4\pi \times 10^{-7}\ \frac{\text{T}\cdot\text{m}}{\text{A}}\right)(2.0\text{ A})} = \boxed{21\text{ km}}$$

52. In order for a magnetic field to exert a force on a particle, the particle must have charge *and* be moving, so the force on the proton is $\boxed{0}$.

53. $I = \frac{2\pi r B}{\mu_0} = \frac{2\pi(0.50\text{ m})(1.0\text{ T})}{4\pi \times 10^{-7}\ \frac{\text{T}\cdot\text{m}}{\text{A}}} = \boxed{2.5 \times 10^6\text{ A}}$

54. $I = \frac{2\pi r B}{\mu_0} = \frac{2\pi(0.050\text{ m})(1.0 \times 10^{-15}\text{ T})}{4\pi \times 10^{-7}\ \frac{\text{T}\cdot\text{m}}{\text{A}}} = \boxed{2.5 \times 10^{-10}\text{ A}}$

55. $R_1 = \frac{m_1 v}{qB} \qquad R_2 = \frac{m_2 v}{qB}$

$$\frac{m_1}{m_2} = \frac{R_1}{R_2} = \frac{48.9 \text{ cm}}{51.7 \text{ cm}} = \boxed{0.946}$$

56. $K = \frac{1}{2}mv^2$

$$v = \sqrt{\frac{2K}{m}}$$

$$B = \frac{mv}{er} = \frac{m}{er}\sqrt{\frac{2K}{m}} = \frac{\sqrt{2mK}}{er} = \frac{\sqrt{2(9.11\times10^{-31} \text{ kg})(45\times10^3 \text{ eV})\left(1.6\times10^{-19} \frac{\text{J}}{\text{eV}}\right)}}{(1.6\times10^{-19} \text{ C})(250 \text{ m})} = \boxed{2.9\ \mu\text{T}}$$

57. $I = \frac{BL}{\mu_0 N} = \frac{BL}{\mu_0\left(\frac{L}{d_{\text{wire}}}\right)} = \frac{Bd_{\text{wire}}}{\mu_0} = \frac{(1.5 \text{ T})(0.0022 \text{ m})}{4\pi\times10^{-7} \frac{\text{T·m}}{\text{A}}} = \boxed{2.6 \text{ kA}}$

58. **(a)** The current-carrying wire generates a magnetic field that is directed into the page, perpendicular to all four sides of the square loop. The force on each side of the loop is directed away from the center of the loop, perpendicular to each side, and in the plane of the loop. Because the force is stronger closer to the wire, the net force is $\boxed{\text{towards the wire}}$.

(b) Due to symmetry, the forces due to the sides of the loop cancel.

$$\begin{aligned}F_{\text{net}} &= ILB_{\text{close}} - ILB_{\text{far}}\\ &= IL\left(\frac{\mu_0 I'}{2\pi r_{\text{close}}} - \frac{\mu_0 I'}{2\pi r_{\text{far}}}\right)\\ &= \frac{\mu_0 LII'}{2\pi}\left(\frac{1}{r_{\text{close}}} - \frac{1}{r_{\text{far}}}\right)\\ &= \frac{\left(4\pi\times10^{-7} \frac{\text{T·m}}{\text{A}}\right)(1.0 \text{ m})(2.5 \text{ A})(14 \text{ A})}{2\pi}\left(\frac{1}{0.2 \text{ m}} - \frac{1}{1.2 \text{ m}}\right)\\ &= \boxed{3\times10^{-5} \text{ N}}\end{aligned}$$

59. **(a)** The magnetic field is directed out of the page, the force on each side of the loop is directed toward the loop's center, and because the force is stronger closer to the wire, the net force is $\boxed{\text{away from the wire}}$. Due to symmetry, the forces due to the sides of the loop cancel.

$$\begin{aligned}F_{\text{net}} &= ILB_{\text{close}} - ILB_{\text{far}}\\ &= IL\left(\frac{\mu_0 I'}{2\pi r_{\text{close}}} - \frac{\mu_0 I'}{2\pi r_{\text{far}}}\right)\\ &= \frac{\mu_0 LII'}{2\pi}\left(\frac{1}{r_{\text{close}}} - \frac{1}{r_{\text{far}}}\right)\\ &= \frac{\left(4\pi\times10^{-7} \frac{\text{T·m}}{\text{A}}\right)(1.0 \text{ m})(2.5 \text{ A})(14 \text{ A})}{2\pi}\left(\frac{1}{0.2 \text{ m}} - \frac{1}{1.2 \text{ m}}\right)\\ &= \boxed{3\times10^{-5} \text{ N}}\end{aligned}$$

(b) The net force increases by a factor of two, because the force $F = ILB$ on each of the two horizontal sides of the loop is doubled as their length doubles.

(c) The net force increases, because there is less force on the bottom side of the loop to cancel the force on the top side. In the calculation of the magnitude, the quantity $\frac{1}{r_{\text{far}}}$ grows smaller and has less effect on the quantity $\frac{1}{r_{\text{close}}} - \frac{1}{r_{\text{far}}}$.

60. $\vec{\mathbf{F}}_\text{M} = q\vec{\mathbf{v}} \times \vec{\mathbf{B}} = q(\vec{\mathbf{v}} \times \vec{\mathbf{B}}),$ so $\vec{\mathbf{F}}_\text{E} = q\vec{\mathbf{E}}$ must equal $-q(\vec{\mathbf{v}} \times \vec{\mathbf{B}})$ and $\vec{\mathbf{E}} = -(\vec{\mathbf{v}} \times \vec{\mathbf{B}})$.

$|\vec{\mathbf{v}}| = \sqrt{(4.4 \times 10^3 \text{ m/s})^2 + (2.7 \times 10^3 \text{ m/s})^2} = 5.16 \times 10^3$ m/s, and $\vec{\mathbf{v}}$ lies in the first quadrant of the *x*-*y* plane, forming an angle of $\theta_\text{v} = \tan^{-1}(2.7/4.4) = 32°$ with the positive *x* axis.

$\vec{\mathbf{E}} = -(\vec{\mathbf{v}} \times \vec{\mathbf{B}})$ also lies in the *xy* plane, perpendicular to both $\vec{\mathbf{v}}$ and $\vec{\mathbf{B}}$, in the direction $\theta_\text{E} = 122°$ with a magnitude of $E = vB\sin 90° = (5.16 \times 10^3 \text{ m/s})(0.73 \text{ T}) = 3.77$ kN/C. In component form,

$$\vec{\mathbf{E}} = \left(3.77 \times 10^3 \ \frac{\text{N}}{\text{C}}\right)[(\cos 122°)\hat{\mathbf{x}} + (\sin 122°)\hat{\mathbf{y}}]$$
$$= \boxed{(-2.0 \times 10^3 \text{ N/C})\hat{\mathbf{x}} + (3.2 \times 10^3 \text{ N/C})\hat{\mathbf{y}}}$$

61. (a) $\frac{1}{2}mv^2 = eV$

$$v = \sqrt{\frac{2eV}{m}}$$

$$F = evB = eB\sqrt{\frac{2eV}{m}} = B\sqrt{\frac{2e^3V}{m}} = (0.957 \text{ T})\sqrt{\frac{2(1.60 \times 10^{-19} \text{ C})^3(10.0 \times 10^3 \text{ V})}{9.11 \times 10^{-31} \text{ kg}}} = \boxed{9.08 \times 10^{-12} \text{ N}}$$

(b) Since the speed of the electron is proportional to the square root of the voltage and the force is proportional to the speed, the maximum force found in part (a) will increase if the voltage is increased.

(c) $$F = B\sqrt{\frac{2e^3V}{m}} = (0.957 \text{ T})\sqrt{\frac{2(1.60 \times 10^{-19} \text{ C})^3(25.0 \times 10^3 \text{ V})}{9.11 \times 10^{-31} \text{ kg}}} = \boxed{1.43 \times 10^{-11} \text{ N}}$$

62. $\vec{\mathbf{F}} = qv(B_y\hat{\mathbf{z}} - B_z\hat{\mathbf{y}})$

$$F = qv\sqrt{B_y{}^2 + B_z{}^2} = (34 \times 10^{-6} \text{ C})\left(62 \ \frac{\text{m}}{\text{s}}\right)\sqrt{(0.50 \text{ T})^2 + (0.75 \text{ T})^2} = \boxed{1.9 \text{ mN}}$$

$$\theta = \tan^{-1}\frac{-B_z}{B_y} = \tan^{-1}\frac{-0.75 \text{ T}}{0.50 \text{ T}} = -56°$$

The direction of the force is 56° measured from the positive *z*-axis towards the negative *y*-axis in the *yz*-plane.

63. (a) The force due to the magnetic field is in the positive *y*-direction, so the electric field needs to be in the negative *y*-direction.

$$\vec{\mathbf{E}} = -vB\hat{\mathbf{y}} = -\left(1.42 \times 10^5 \ \frac{\text{m}}{\text{s}}\right)(0.52 \text{ T})\hat{\mathbf{y}} = \boxed{(-74 \text{ kV/m})\hat{\mathbf{y}}}$$

(b) $V = Ed = \left(73{,}840\ \frac{\text{V}}{\text{m}}\right)(0.025\text{ m}) = \boxed{1.8\text{ kV}}$

(c) The electric field lines begin at the top plate, so since electric field lines begin at positive charges and end at negative charges, the $\boxed{\text{top}}$ plate should be positively charged.

64. (a) $r = \frac{mv}{qB}$

$$\frac{q}{m} = \frac{v}{Br} = \frac{8.70\times10^6\ \frac{\text{m}}{\text{s}}}{(1.21\text{ T})(0.159\text{ m})} = \boxed{4.52\times10^7\text{ C/kg}}$$

(b) Since $\frac{q}{m}$ is inversely proportional to *r*, $\frac{q}{m}$ would be $\boxed{\text{less than}}$ that found in part (a) if *r* were greater.

65. $\vec{\mathbf{B}}_\text{A} = \vec{\mathbf{B}}_{1\text{A}} + \vec{\mathbf{B}}_{2\text{A}}$

$$= \frac{\mu_0 I}{2\pi r_1}(+ \frac{\mu_0 I}{2\pi r_2}($$

$$= \frac{\mu_0 I}{2\pi}\left(\frac{1}{r_1} + \frac{1}{r_2}\right)($$

$$= \frac{\left(4\pi\times10^{-7}\ \frac{\text{T}\cdot\text{m}}{\text{A}}\right)(2.2\text{ A})}{2\pi}\left(\frac{1}{0.075\text{ m}} + \frac{1}{3(0.075\text{ m})}\right)($$

$$= \boxed{(7.8\ \mu\text{T})(}$$

$$\vec{\mathbf{B}}_\text{B} = \vec{\mathbf{B}}_{1\text{B}} + \vec{\mathbf{B}}_{2\text{B}} = \frac{\mu_0 I}{2\pi}\left(\frac{1}{r_1}\wedge + \frac{1}{r_2}(\right) = \frac{\mu_0 I}{2\pi}\left(\frac{1}{r}\wedge - \frac{1}{r}\wedge\right) = \boxed{0}$$

$$\vec{\mathbf{B}}_\text{C} = \vec{\mathbf{B}}_{1\text{C}} + \vec{\mathbf{B}}_{2\text{C}} = \frac{\mu_0 I}{2\pi}\left(\frac{1}{r_1}\wedge + \frac{1}{r_2}\wedge\right) = \frac{\left(4\pi\times10^{-7}\ \frac{\text{T}\cdot\text{m}}{\text{A}}\right)(2.2\text{ A})}{2\pi}\left(\frac{1}{3(0.075\text{ m})} + \frac{1}{0.075\text{ m}}\right)\wedge = \boxed{(7.8\ \mu\text{T})\wedge}$$

66. $\vec{\mathbf{B}}_\text{A} = \vec{\mathbf{B}}_{1\text{A}} + \vec{\mathbf{B}}_{2\text{A}}$

$$= \frac{\mu_0 I}{2\pi r_1}\wedge + \frac{\mu_0 I}{2\pi r_2}($$

$$= \frac{\mu_0 I}{2\pi}\left(\frac{1}{r_1}\wedge - \frac{1}{r_2}\wedge\right)$$

$$= \frac{\left(4\pi\times10^{-7}\ \frac{\text{T}\cdot\text{m}}{\text{A}}\right)(2.2\text{ A})}{2\pi}\left(\frac{1}{0.075\text{ m}} - \frac{1}{3(0.075\text{ m})}\right)\wedge$$

$$= \boxed{(4\ \mu\text{T})\wedge}$$

$$\vec{\mathbf{B}}_{\text{B}} = \vec{\mathbf{B}}_{1\text{B}} + \vec{\mathbf{B}}_{2\text{B}}$$
$$= \frac{\mu_0 I}{2\pi}\left(\frac{1}{r_1}(+ \frac{1}{r_2}(\right)$$
$$= \frac{\left(4\pi\times10^{-7}\ \frac{\text{T·m}}{\text{A}}\right)(2.2\text{ A})}{2\pi}\left(\frac{1}{0.075\text{ m}}+\frac{1}{0.075\text{ m}}\right)($$
$$= \boxed{(12\ \mu\text{T})(}$$

$$\vec{\mathbf{B}}_{\text{C}} = \vec{\mathbf{B}}_{1\text{C}} + \vec{\mathbf{B}}_{2\text{C}}$$
$$= \frac{\mu_0 I}{2\pi}\left(\frac{1}{r_1}(+ \frac{1}{r_2}\wedge\right)$$
$$= \frac{\mu_0 I}{2\pi}\left(-\frac{1}{r_1}+\frac{1}{r_2}\right)\wedge$$
$$= \frac{\left(4\pi\times10^{-7}\ \frac{\text{T·m}}{\text{A}}\right)(2.2\text{ A})}{2\pi}\left(-\frac{1}{3(0.075\text{ m})}+\frac{1}{0.075\text{ m}}\right)\wedge$$
$$= \boxed{(4\ \mu\text{T})\wedge}$$

67. (a) $B = \frac{\mu_0 I}{2\pi r} = \frac{\left(4\pi\times10^{-7}\ \frac{\text{T·m}}{\text{A}}\right)(225\times10^{3}\text{ A})}{2\pi(75\text{ m})} = \boxed{600\ \mu\text{T}}$

(b) $\frac{F}{L} = \frac{\mu_0 I_1 I_2}{2\pi d} = \frac{\left(4\pi\times10^{-7}\ \frac{\text{T·m}}{\text{A}}\right)(225\times10^{3}\text{ A})^2}{2\pi(25\text{ m})} = \boxed{410\text{ N/m}}$

68. (a) Since $B \propto I/r$, and since Wire 2 is closer to point *A* than is Wire 1, the magnitude of the current in Wire 2 is $\boxed{\text{less than}}$ that in Wire 1.

(b) $\frac{I_2}{r_2} = \frac{I_1}{r_1}$

$I_2 = \frac{r_2}{r_1} I_1 = \frac{11\text{ cm}}{33\text{ cm}}(3.7\text{ A}) = \boxed{1.2\text{ A}}$

The field due to Wire 2 must be directed out of the page because it must oppose the field due to Wire 1, which is into the page. So, according to the RHR, I_2 must flow $\boxed{\text{to the left}}$.

69. (a) The field due to the current in Wire 1 is into the page, so the current in Wire 2 must be flowing from left to right. When parallel wires carry currents flowing in opposite directions, the force between the wires is $\boxed{\text{repulsive}}$.

(b)
$$
\begin{aligned}
F &= \frac{\mu_0 I_1 I_2 L}{2\pi d} \\
&= \frac{\mu_0 I_1 L}{2\pi d}\left(\frac{2\pi r_2 B_2}{\mu_0}\right) \\
&= \frac{I_1 L r_2}{d}(B_{\text{net}} - B_1) \\
&= \frac{I_1 L r_2}{d}\left(B_{\text{net}} + \frac{\mu_0 I_1}{2\pi r_1}\right) \quad \text{taking (-direction as positive} \\
&= \frac{(3.7\text{ A})(0.71\text{ m})(0.11\text{ m})}{0.22\text{ m}}\left(0.21\text{ T} + \frac{\left(4\pi \times 10^{-7}\ \frac{\text{T}\cdot\text{m}}{\text{A}}\right)(3.7\text{ A})}{2\pi(0.33\text{ m})}\right) \\
&= \boxed{0.28\text{ N}}
\end{aligned}
$$

70. $B = (1.3\times10^{15})B_E = (1.3\times10^{15})(5.0\times10^{-5}\text{ T}) = 6.5\times10^{10}\text{ T}$

(a) $$\begin{aligned} F &= ILB\sin\theta \\ &= (1.8\text{ A})(2.5\text{ m})(6.5\times10^{10}\text{ T})\sin 75° \\ &= \boxed{2.8\times10^{11}\text{ N}} \end{aligned}$$

(b) $$\begin{aligned} \text{max. } F_e &= evB\sin 90° \\ &= (1.60\times10^{-19}\text{ C})\left(2.2\times10^6\ \frac{\text{m}}{\text{s}}\right)(6.5\times10^{10}\text{ T}) \\ &= 23\text{ mN} \end{aligned}$$

$$\begin{aligned} F_H &= k\frac{e^2}{r_H^2} \\ &= \left(8.99\times10^9\ \frac{\text{N}\cdot\text{m}^2}{\text{C}^2}\right)\frac{(1.60\times10^{-19}\text{ C})^2}{(5.29\times10^{-11}\text{ m})^2} \\ &= 8.2\times10^{-8}\text{ N} \end{aligned}$$

The hypothetical force from the magnetar is much greater than the electron-proton force within a hydrogen atom.

71. Let the *x*-axis be along the axis of the solenoids with the positive direction to the right.

(a) For ideal solenoids, the field between them is entirely due to the outer solenoid because the field outside the inner one is zero.

$$\vec{\mathbf{B}} = \mu_0 n_1 I_1(-\hat{\mathbf{x}}) = -\left(4\pi\times10^{-7}\ \frac{\text{T}\cdot\text{m}}{\text{A}}\right)(105\text{ cm}^{-1})\left(\frac{100\text{ cm}}{1\text{ m}}\right)(1.25\text{ A})\hat{\mathbf{x}} = \boxed{(-16.5\text{ mT})\hat{\mathbf{x}}}$$

(b) $$\begin{aligned} \vec{\mathbf{B}} &= \mu_0 n_1 I_1(-\hat{\mathbf{x}}) + \mu_0 n_2 I_2\hat{\mathbf{x}} \\ &= \mu_0(n_2 I_2 - n_1 I_1)\hat{\mathbf{x}} \\ &= \left(4\pi\times10^{-7}\ \frac{\text{T}\cdot\text{m}}{\text{A}}\right)[(125\text{ cm}^{-1})(2.17\text{ A}) - (105\text{ cm}^{-1})(1.25\text{ A})]\left(\frac{100\text{ cm}}{1\text{ m}}\right)\hat{\mathbf{x}} \\ &= \boxed{(17.6\text{ mT})\hat{\mathbf{x}}} \end{aligned}$$

72. (a) According to the RHR, the magnetic field due to the long, straight wire points in the positive *z*-direction along the positive *y*-axis and points in the negative *z*-direction along the negative *y*-axis. So, the net magnetic field of the system is zero at a point along the $\boxed{\text{negative } y\text{-axis}}$.

(b) Set $B_{\text{uniform}} = B_{\text{wire}}$.

$$\begin{aligned} B_{\text{uniform}} &= \frac{\mu_0 I}{2\pi r} \\ r &= \frac{\mu_0 I}{2\pi B_{\text{uniform}}} \\ &= \frac{\left(4\pi\times10^{-7}\ \frac{\text{T}\cdot\text{m}}{\text{A}}\right)(3.42\text{ A})}{2\pi(1.45\times10^{-6}\text{ T})} \\ &= \boxed{47.2\text{ cm}} \end{aligned}$$

73. $\tau_{\max} = IAB\sin 90° = IAB$

$$\tau = IAB\sin\theta = \frac{1}{2}\tau_{\max} = \frac{1}{2}IAB$$

$$\sin\theta = \frac{1}{2}$$

$$\theta = \sin^{-1}\left(\frac{1}{2}\right) = 30°$$

The angle the plane of the loop makes with the field is 90° – 30° = $\boxed{60°}$.

74. (a) $B = \mu_0 nI = \left(4\pi\times10^{-7}\ \frac{\text{T}\cdot\text{m}}{\text{A}}\right)(55\ \text{cm}^{-1})\left(\frac{100\ \text{cm}}{1\ \text{m}}\right)(0.150\ \text{A}) = \boxed{1.0\ \text{mT}}$

(b) $B = \frac{\mu_0 I}{2\pi r} = \mu_0 nI_\text{s}$

$I = 2\pi rnI_\text{s} = 2\pi(1.25\ \text{cm})(55\ \text{cm}^{-1})(0.150\ \text{A}) = \boxed{65\ \text{A}}$

75. $\vec{\mathbf{F}}_\text{E} = e\vec{\mathbf{E}} = (1.60\times10^{-19}\ \text{C})(220\ \text{N/C})\hat{\mathbf{x}} = (3.52\times10^{-17}\ \text{N})\hat{\mathbf{x}}$

$$\vec{\mathbf{F}}_\text{B} = e(\vec{\mathbf{v}}\times\vec{\mathbf{B}})$$

$$= e\left(\begin{vmatrix} v_y & v_z \\ B_y & B_z \end{vmatrix}\hat{\mathbf{x}} - \begin{vmatrix} v_x & v_z \\ B_x & B_z \end{vmatrix}\hat{\mathbf{y}} + \begin{vmatrix} v_x & v_y \\ B_x & B_y \end{vmatrix}\hat{\mathbf{z}}\right)$$

$$= e(v_y B_z\hat{\mathbf{x}} - v_x B_z\hat{\mathbf{y}} - v_y B_x\hat{\mathbf{z}}) \text{ since } v_z = B_y = 0$$

$$= (1.60\times10^{-19}\ \text{C})\left[\left(0.67\times10^4\ \frac{\text{m}}{\text{s}}\right)(-0.11\ \text{T})\hat{\mathbf{x}} - \left(1.5\times10^5\ \frac{\text{m}}{\text{s}}\right)(-0.11\ \text{T})\hat{\mathbf{y}} - \left(0.67\times10^4\ \frac{\text{m}}{\text{s}}\right)(0.25\ \text{T})\hat{\mathbf{z}}\right]$$

$$= (-1.18\times10^{-16}\ \text{N})\hat{\mathbf{x}} + (2.64\times10^{-15}\ \text{N})\hat{\mathbf{y}} - (2.68\times10^{-16}\ \text{N})\hat{\mathbf{z}}$$

$$\vec{\mathbf{F}}_\text{net} = \vec{\mathbf{F}}_\text{E} + \vec{\mathbf{F}}_\text{B} = (-8.3\times10^{-17}\ \text{N})\hat{\mathbf{x}} + (2.64\times10^{-15}\ \text{N})\hat{\mathbf{y}} - (2.68\times10^{-16}\ \text{N})\hat{\mathbf{z}}$$

$$F_\text{net} = \sqrt{F_x^2 + F_y^2 + F_z^2} = \boxed{2.7\times10^{-15}\ \text{N}}$$

76. (a)

$$B = \frac{N\mu_0}{2R}I = \frac{(21)\left(4\pi\times10^{-7}\ \frac{\text{T}\cdot\text{m}}{\text{A}}\right)}{2(0.060\ \text{m})}I = \left(2.20\times10^{-4}\ \frac{\text{T}}{\text{A}}\right)I$$

When I is increasing at a rate of 1.2×10^7 A/s, B is increasing at a rate of $(2.20\times10^{-4}\ \text{T/A})(1.2\times10^7\ \text{A/s}) = \boxed{2.6\times10^3\ \text{T/s}}$.

(b) B is proportional to $\frac{1}{R}$, and R is proportional to $\sqrt{A}$, so B is proportional to $\frac{1}{\sqrt{A}}$. As A goes to $\frac{A}{2}$, B $\boxed{\text{increases by a factor of } \frac{1}{\sqrt{1/2}} = \sqrt{2}}$.

77. The field lines due to the solenoid and the wire are perpendicular.

$$\begin{aligned}B&=\sqrt{{B_\text{w}}^2+{B_\text{s}}^2}\\&=\sqrt{\left(\frac{\mu_0 I_\text{w}}{2\pi r}\right)^2+(\mu_0 n I_\text{s})^2}\\&=\mu_0\sqrt{\frac{{I_\text{w}}^2}{4\pi^2 r^2}+n^2{I_\text{s}}^2}\\&=\left(4\pi\times10^{-7}\ \frac{\text{T}\cdot\text{m}}{\text{A}}\right)\sqrt{\frac{(16\text{ A})^2}{4\pi^2(0.0075\text{ m})^2}+(22\text{ cm}^{-1})^2\left(\frac{100\text{ cm}}{1\text{ m}}\right)^2(0.50\text{ A})^2}\\&=\boxed{1.4\text{ mT}}\end{aligned}$$

78. Fixed charge on a rotating ring is equivalent to a fixed wire loop with moving charge (current).

$I=\lambda\omega R$

Find the field.

$$B=\frac{\mu_0 I}{2R}=\frac{\mu_0\lambda\omega R}{2R}=\boxed{\frac{1}{2}\mu_0\lambda\omega}$$

79.

$$\begin{aligned}B&=\mu_0\frac{N}{L_\text{s}}I=\mu_0\frac{\frac{L_\text{w}}{\pi d}}{L_\text{s}}I=\frac{\mu_0 I L_\text{w}}{\pi d L_\text{s}}\\I&=\frac{\pi d L_\text{s} B}{\mu_0 L_\text{w}}\\R&=\rho\frac{L_\text{w}}{A}=\frac{\rho L_\text{w}}{\pi r^2}\\V&=IR\\&=\left(\frac{\pi d L_\text{s} B}{\mu_0 L_\text{w}}\right)\left(\frac{\rho L_\text{w}}{\pi r^2}\right)\\&=\frac{\rho d B L_\text{s}}{\mu_0 r^2}\\&=\frac{(2.3\times10^{-8}\ \Omega\cdot\text{m})(0.045\text{ m})(0.015\text{ T})(1.65\text{ m})}{\left(4\pi\times10^{-7}\ \frac{\text{T}\cdot\text{m}}{\text{A}}\right)(0.0021\text{ m})^2}\\&=\boxed{4.6\text{ V}}\end{aligned}$$

80. **(a)** According to the RHR, the field due to the straight wire is out of the page at the center of the loop. The field generated by the current in the loop must be into the page so that the net field is zero. Again using the RHR, we find that the current must flow $\boxed{\text{clockwise}}$ in the loop to oppose the field due to the straight wire.

(b)

$$\begin{aligned}B_\text{straight wire}&=\frac{\mu_0 I}{2\pi\left(R+\frac{R}{2}\right)}=\frac{\mu_0 I}{3\pi R}\\B_\text{loop}&=\frac{\mu_0 I_\text{loop}}{2R}=\frac{\mu_0 I}{3\pi R}\\I_\text{loop}&=\boxed{\frac{2I}{3\pi}}\end{aligned}$$

81. The current due to the electron is $I = \dfrac{ev}{2\pi r}$.

$$B = \frac{\mu_0 I}{2r} = \frac{\mu_0}{2r}\left(\frac{ev}{2\pi r}\right) = \frac{\mu_0 ev}{4\pi r^2} = \frac{\left(4\pi\times10^{-7}\ \frac{\text{T}\cdot\text{m}}{\text{A}}\right)(1.60\times10^{-19}\ \text{C})\left(2.2\times10^{6}\ \frac{\text{m}}{\text{s}}\right)}{4\pi(5.29\times10^{-11}\ \text{m})^2} = \boxed{13\ \text{T}}$$

82. The magnetic field exerts an upward force on one side of the square loop. When this force exceeds that due to gravity, three sides of the loop lift from the table pivoting about an axis along the line of the fourth side of the loop. So, we must find the minimum torque about this axis due to the field and thus the minimum magnetic field.

Find the center of mass of the loop. Let the *y*-axis lie along the edge which does not lift from the table, and let the *x*-axis bisect this edge so that the center of the opposite edge has coordinates (L = 15 cm, 0).

$$x_{\text{cm}} = \frac{\Sigma mx}{\Sigma m} = \frac{\frac{m}{4}\left(\frac{L}{2}\right)+\frac{m}{4}\left(\frac{L}{2}\right)+\frac{m}{4}(L)+0}{m} = \frac{1}{2}L$$

Set $\tau_{\text{gravity}} = \tau_{\text{magnetic}}$.

$$x_{\text{cm}}F_{\text{g}} = rF_B$$

$$\frac{1}{2}Lmg = LILB_{\text{min}}$$

$$B_{\text{min}} = \frac{mg}{2IL} = \frac{(0.035\ \text{kg})\left(9.81\ \frac{\text{m}}{\text{s}^2}\right)}{2(18\ \text{A})(0.15\ \text{m})} = \boxed{64\ \text{mT}}$$

83. (a) Along the bottom side of the square, wire 1 contributes a magnetic field that points straight down with magnitude

$$B_1 = \frac{\mu_0 I_1}{2\pi r_1} = \frac{\mu_0 I_1}{2\pi x}$$

while wire 2 contributes a field that points straight down with magnitude

$$B_2 = \frac{\mu_0 I_2}{2\pi r_2} = \frac{\mu_0 I_2}{2\pi(5.0\ \text{cm}-x)}$$

So the net magnetic field along the bottom of the square points $\boxed{\text{down}}$ and has magnitude

$$B = B_1 + B_2 = \frac{\mu_0}{2\pi}\left(\frac{I_1}{x}+\frac{I_2}{5.0\ \text{cm}-x}\right) = \left(2\times10^{-7}\ \frac{\text{T}\cdot\text{m}}{\text{A}}\right)\left(\frac{3.0\ \text{A}}{x}+\frac{4.0\ \text{A}}{0.050\ \text{m}-x}\right) = \boxed{\frac{6.0\times10^{-7}\ \text{T}\cdot\text{m}}{x}+\frac{8.0\times10^{-7}\ \text{T}\cdot\text{m}}{0.050\ \text{m}-x}}$$

where x is measured in meters.

(b) Along the left side of the square, wire 1 contributes a magnetic field that points in the positive x direction with magnitude

$$B_1 = \frac{\mu_0 I_1}{2\pi r_1} = \frac{\mu_0 I_1}{2\pi y}$$

Wire 2 contributes a magnetic field that points down and to the left at an angle θ to the horizontal, such that

$$\cos\theta = \frac{y}{\sqrt{(5.0\text{ cm})^2 + y^2}}$$

$$\sin\theta = \frac{5.0\text{ cm}}{\sqrt{(5.0\text{ cm})^2 + y^2}}$$

The magnetic field of the field from wire 2 is

$$B_2 = \frac{\mu_0 I_2}{2\pi r_2} = \frac{\mu_0 I_2}{2\pi\sqrt{(5.0\text{ cm})^2 + y^2}}$$

So

$$\begin{aligned}\vec{B}_2 &= -(B_2\cos\theta)\hat{\mathbf{x}} - (B_2\sin\theta)\hat{\mathbf{y}} \\ &= -\frac{\mu_0 I_2 y}{2\pi[(5.0\text{ cm})^2 + y^2]}\hat{\mathbf{x}} - \frac{\mu_0 I_2 (5.0\text{ cm})}{2\pi[(5.0\text{ cm})^2 + y^2]}\hat{\mathbf{y}}\end{aligned}$$

The magnitude of the net magnetic force along the left side of the square is then

$$\begin{aligned}B &= \sqrt{(B_1 + B_{2x})^2 + B_{2y}^2} \\ &= \sqrt{\left(\frac{\mu_0 I_1}{2\pi y} - \frac{\mu_0 I_2 y}{2\pi[(5.0\text{ cm})^2 + y^2]}\right)^2 + \left(-\frac{\mu_0 I_2 (5.0\text{ cm})}{2\pi[(5.0\text{ cm})^2 + y^2]}\right)^2} \\ &= \boxed{\left(2\times10^{-7}\ \frac{\text{T}\cdot\text{m}}{\text{A}}\right)\sqrt{\left(\frac{3.0\text{ A}}{y} - \frac{(4.0\text{ A})y}{(0.050\text{ m})^2 - y^2}\right)^2 + \left(\frac{0.20\text{ A}\cdot\text{m}}{(0.050\text{ m})^2 - y^2}\right)^2}}\end{aligned}$$

where y is measured in meters.