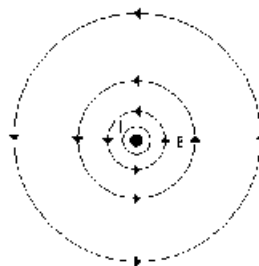
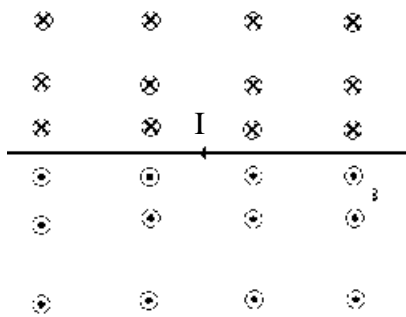


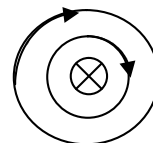
CHAPTER 20: Magnetism

Answers to Questions

1. The Earth's magnetic field is not always parallel to the surface of the Earth – it may have a component perpendicular to the Earth's surface. The compass will tend to line up with the local direction of the magnetic field, and so one end of the compass will dip downward. The angle that the Earth's magnetic field makes with the horizontal is called the angle of dip.
2. The magnetic field lines circle around the wire and get weaker as you get farther away from the wire. To determine the direction, use the Right Hand Rule. Notice, if the wire was laid horizontally on this piece of paper in a left-right direction and the current was moving to the left, the magnetic field lines would be pointing into the paper above the wire and coming out of the paper below the wire. If the wire was placed perpendicular to this page with the current coming out of the end of the wire facing us, the magnetic fields would point around the wire in a counterclockwise direction.



3. The magnetic field lines form clockwise circles centered on the wire.



4. The right-hand rule shows us that if a current in a wire is pointing directly away from you while the wire is in a magnetic field that points from left to right, the force on the wire is pointed downward. See Figure 20-11(a).
5. A magnet will not attract just any metallic object. For example, while a magnet will attract paper clips and nails, it will not attract coins or pieces of aluminum foil. This is because magnets will only attract other ferromagnetic materials (iron, cobalt, nickel, gadolinium, and some of their oxides and alloys). Iron and its alloys are the only common materials. These ferromagnetic materials contain magnetic domains that can be made to temporarily align when a strong magnet is brought near. The alignment occurs in such a way that the north pole of the domain points toward the south pole of the strong magnet, and vice versa, which creates the attraction.
6. The bars cannot both be magnets. If both were magnets, then if like poles were placed close to each other, the bars would repel each other. Only one of the bars can be a magnet.
7. Typical current in a house circuit is 60 Hz AC. Due to the mass of the compass needle, its reaction to 60 Hz (changing direction back and forth at 60 complete cycles per second) will probably not be noticeable. A DC current in a single wire could affect a compass, depending on the relative orientation of the wire and the compass, the magnitude of the current, and the distance from the wire

to the compass. A DC current being carried by two very close wires in opposite directions would not have much of an effect on the compass needle, since the two currents would cause magnetic fields that tended to cancel each other.

8. The magnetic force will be exactly perpendicular to the velocity, and so also perpendicular to the direction of motion. Since there is no component of force in the direction of motion, the work done by the magnetic force will be zero, and the kinetic energy of the particle will not change. The particle will change direction, but not change speed.
9. Use the right hand rule to determine the direction of the force on each particle. In the plane of the diagram, the magnetic field is coming out of the paper for points above the wire, and is going into the paper for points below the wire.
 - Upper left hand particle: force down, toward the wire
 - Upper right hand particle: force to the left, opposite of the direction of the current
 - Lower right hand particle: force to the left, opposite of the direction of the current
 - Lower left hand particle: force up, toward the wire

10. Charge a experiences an initial upward force. By the right hand rule, charge a must be positive. Charge b experiences no force, and so charge b must be uncharged. Charge c experiences an initial downward force. By the right hand rule, charge c must be negative.

11. The right hand rule tell us that as the positive particle moves to the right, if it is deflected upward the magnetic field must be into the paper and if it is deflected downward the magnetic field must be out of the paper. Also, the stronger the magnetic field, the more tightly the charged particle will turn. The magnetic field at the first bend must be relatively small and pointed into the paper. The magnetic field at the second bend must be medium in size and pointed out of the paper. The magnetic field at the third bend must be relatively very large and pointed into the paper.



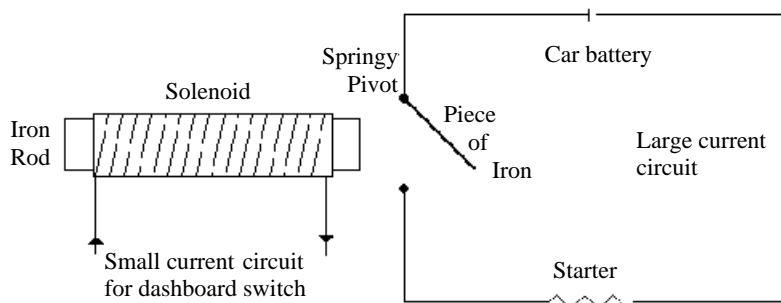
12. A magnet can attract an iron bar, so by Newton's third law, an iron bar can attract a magnet. Another consideration is that the iron has domains that can be made slightly magnetic by an external magnetic field, as opposed to a substance like plastic or wood.
13. Section 17-10 shows that a CRT television picture is created by shooting a beam of electrons at a screen, and wherever the electrons hit the screen it lights up for us to see. When you hold a strong magnet too close to the screen, the magnetic field puts a force on the moving electrons ($F = qvB \sin \theta$), which causes them to bend away from where they were supposed to hit the screen. These errant electrons then cause parts of the screen to light up that aren't supposed to be lit and cause other parts to be slightly darker than they are supposed to be. The picture sometimes goes completely black where the field is strongest because at these points all of the electrons that were supposed to hit that particular spot have been deflected by the strong field.
14. Put one end of one rod close to one end of another rod. The ends will either attract or repel. Continue trying all combinations of rods and ends until two ends repel each other. Then the two rods used in that case are the magnets.

15. No, you cannot set a resting electron into motion with a magnetic field (no matter how big the field is). A magnetic field can only put a force on a *moving* charge. Thus, with no force (which means no acceleration), the velocity of the electron will not change – it will remain at rest. However, you can set a resting electron into motion with an electric field. An electric field will put a force on *any* charged particle, moving or not. Thus, the electric force can cause the electron to accelerate from rest to a higher speed.
16. The charged particle will now travel in a helix. It will continue in its original circular path while it is traveling in the direction of the magnetic and electric fields, which is perpendicular to the plane of the original circle. For as long as the electric field stays on, the particle will move in a constantly elongating helix (the pitch of the helix will continue to increase), since the electric field will cause the charged particle to accelerate along the electric field lines.
17. Using the configuration shown in Fig. 20-48, the electric field puts a force on the charged particles and causes them to accelerate in a vertical direction from rest (the negative particles are accelerated upward and the positive particles are accelerated downward). Once the charged particles are moving, the magnetic field now also puts a force on the charged particles. Using the Right Hand Rule, both the upward-moving negative particles and the downward-moving positive particles experience a force out of the page, which is along the direction of the vessel. Thus, yes, both the positive and negative particles experience a force in the same direction.
18. The beam of electrons is deflected to the right. The magnetic field created by the current in the wire, I , is directed into the page on the side of the wire where the electron beam is located. The right hand rule tells us that the negative electrons will feel a force to the right as they move toward the wire in a downward magnetic field.
19. A moving electric charge creates both electric and magnetic fields around it. The electric field is radial and it looks very similar to the typical electric field that surrounds a stationary electric charge. The magnetic field circles the charge in a plane that is perpendicular to the direction of motion and it looks very similar to the typical magnetic field that surrounds a current-carrying wire. Both of these fields decrease in strength as you go farther away from the moving charge in any direction.
20. Yes, there could be a non-zero magnetic field in this region of space, even though the charged particle travels in a straight line. One possible situation is that the charged particle is traveling in a direction parallel (or anti-parallel) to the magnetic field lines. In this situation, no magnetic force is exerted on the charged particle, since the $\sin \theta$ term in $F = qvB \sin \theta$ is zero. The other possible situation is that the charged particle is traveling through “crossed” electric and magnetic fields in such a way that the electric force and the magnetic force are canceling each other out. For example, if a positively charged particle were moving east in a region of space where the electric field was south (which creates a force toward the south) and the magnetic field was downward (which creates a magnetic field toward the north), and the magnitudes of E and B were chosen correctly, then the electric and magnetic forces would cancel out, allowing the charged particle to travel in a straight line.
21. No, a moving charged particle can be deflected sideways with an electric field that points perpendicular to the direction of the velocity, even when the magnetic field in the region is zero.
22. No, although when an electron is injected perpendicularly into a region of uniform magnetic field, the electron is forced to travel along a curve in the shape of a perfect circle, the electron would travel in a path that is only half of a circle and at that point it would come back out of the magnetic field and head back in the direction it came. Yes, if an electron were injected into the middle of a large

- region of space occupied by a perpendicular magnetic field, the electron could travel in a closed circular path.
23. If the moving electrons are changing speed as they are being deflected, then an electric field is present. This will be the case whether or not a magnetic field exists in the same region of space. If the moving electrons are being deflected but they are not changing speed, then only a magnetic field is present.
 24. Use a small loop of current-carrying wire that is able to pivot freely along a vertical axis (the faces of the loop should be pointing horizontally). Use the right hand rule to determine which face of the loop has a magnetic north pole pointing out of it. The north and magnetic south poles created by the loop will attempt to pivot to align with Earth's magnetic field. The north face of the loop will point toward the magnetic south pole of Earth (which is near the geographic North Pole).
 25. Consider that the two wires are both horizontal, with the lower one carrying a current pointing east and with the upper one carrying a current pointing north. The magnetic field from the upper wire points downward on the east half of the lower wire and points upward on the west half of the lower wire. Using the right hand rule on the east half of the lower wire, where the magnetic field is downward, the force points to the north. Using the right hand rule on the west half of the lower wire, where the magnetic field is upward, the force points to the south. Thus, the lower wire experiences a counterclockwise torque about the vertical direction due to the magnetic forces from the upper wire. This torque is attempting to rotate the two wires so their currents are parallel. Likewise the upper wire would experience a clockwise torque tending to align the currents in the wires.
 26.
 - (a) The current in the lower wire is pointing in the opposite direction of the current in the upper wire. If the current in the lower wire is toward the north, then it creates a magnetic field pointing east at the upper wire. Using the Right Hand Rule, the current of the upper wire must be toward the south so that the magnetic force created on it is upward.
 - (b) Yes, the upper wire is vertically stable. If the upper wire falls toward the lower wire slightly, then the magnetic force increases to push it back up to its stable position. If the upper wire rises away from the lower wire slightly, although the magnetic field decreases, gravity will pull it back into its stable position.
 27. The magnetic domains in the unmagnetized piece of iron are initially pointing in random directions (which is why it appears to be unmagnetized). When the south pole of a strong external magnet is brought close to the random magnetic domains of the iron, many of the domains will rotate slightly so that their north poles are closer to the external south pole, which causes the unmagnetized iron to be attracted to the magnet. Of course, when the north pole of a strong external magnet is brought close to the random magnetic domains of the iron, many of the domains will rotate slightly so that their south poles are closer to the external north pole, which causes the unmagnetized iron to now be attracted to the magnet. Thus, either pole of a magnet will attract an unmagnetized piece of iron.
 28. Initially, both the nail and the paper clip have all of their magnetic domains pointing in random directions (which is why they appear to be unmagnetized). Thus, when you bring them close to each other, they are not attracted to or repelled from each other. Once the nail is in contact with a magnet (let's say the north pole), though, many of the nail's domains will align in such a way that the end touching the magnet becomes a south pole, due to the strong attraction, and the opposite end of the nail then becomes a north pole. Now, when you bring the nail close to the paper clip, there are mainly north poles of nail domains close to the paper clip, which causes some of the domains in the paper clip to align in such a way that the end near the nail becomes a south pole, which is exactly the same procedure that the nail was "magnetized." Since the nail's domains are only partially aligned,

it will not be a strong magnet and thus the alignment of the paper clip's domains will be even weaker. The attraction of the paper clip to the nail will be weaker than the attraction of the nail to the magnet.

29. The two ions will come out of the velocity selector portion of the mass spectrometer at the same speed, since $v = E/B$ (where the charge q has canceled out). Once the charges reach the area of the mass spectrometer where there is only a magnetic field, then the difference in the ions' charges will have an effect. The equation for the mass spectrometer is $m = qBB'r/E$, which can be rearranged as $r = mE/qBB'$. Since every quantity in the equation is constant except q , the doubly ionized ion will hit the film at a half of the radius as the singly ionized ion.
30. The equation for the magnetic field inside of a solenoid is $B = \mu_0 NI/l$.
- Nothing would happen to B if the loop diameter was doubled. The equation shows that the magnetic field is independent of the diameter of the solenoid.
 - B would decrease by a factor of 2. When the spacing between the loops is doubled, the number of loops per length, N/l , is cut in half, which decreases B by a factor of 2.
 - Nothing would happen to B if both the length and the number of loops were doubled. The magnetic field does depend on the number of loops per length, N/l , but if both the number of loops and the length of the solenoid are doubled, this ratio remains constant and the magnetic field doesn't change.
31. To design a relay, place the iron rod inside of a solenoid, then point one end of the solenoid/rod combination at the piece of iron on a pivot. A spring normally holds the piece of iron away from a switch, making an open circuit where current cannot flow. When the relay is activated with a small current, a relatively strong magnetic field is created inside the solenoid, which aligns most of the magnetic domains in the iron rod and produces a strong magnetic field at the end of the solenoid/rod combination. This magnetic field attracts the piece of iron on the springy pivot, which causes it to move toward the switch, connecting it and allowing current to flow through the large current circuit.



Solutions to Problems

1. (a) Use Eq. 20-1 to calculate the force with an angle of 90° and a length of 1 meter.

$$F = IlB \sin \theta \rightarrow \frac{F}{l} = IB \sin \theta = (8.40 \text{ A})(0.90 \text{ T}) \sin 90^\circ = \boxed{7.6 \text{ N/m}}$$

$$(b) \frac{F}{l} = IB \sin \theta = (8.40 \text{ A})(0.90 \text{ T}) \sin 45.0^\circ = \boxed{5.3 \text{ N/m}}$$

2. Use Eq. 20-1 to calculate the force.

$$F = IlB \sin \theta = (150 \text{ A})(160 \text{ m})(5.0 \times 10^{-5} \text{ T}) \sin 65^\circ = \boxed{1.1 \text{ N}}$$

3. Use Eq. 20-2.

$$F_{\max} = IlB \rightarrow I = \frac{F_{\max}}{lB} = \frac{0.750 \text{ N}}{(4.80 \text{ m})(8.00 \times 10^{-2} \text{ T})} = \boxed{1.95 \text{ A}}$$

4. The dip angle is the angle between the Earth's magnetic field and the current in the wire. Use Eq. 20-1 to calculate the force.

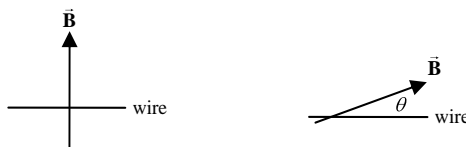
$$F = IlB \sin \theta = (4.5 \text{ A})(1.5 \text{ m})(5.5 \times 10^{-5} \text{ T}) \sin 38^\circ = \boxed{2.3 \times 10^{-4} \text{ N}}$$

5. Use Eq. 20-2. The length of wire in the B-field is the same as the diameter of the pole faces.

$$F_{\max} = IlB \rightarrow B = \frac{F_{\max}}{Il} = \frac{1.28 \text{ N}}{(8.75 \text{ A})(0.555 \text{ m})} = \boxed{0.264 \text{ T}}$$

6. To have the maximum force, the current must be perpendicular to the magnetic field, as shown in the first diagram. Use $\frac{F}{l} = 0.35 \frac{F_{\max}}{l}$ to find the angle between the wire and the magnetic field, illustrated in the second diagram.

$$\frac{F}{l} = 0.35 \frac{F_{\max}}{l} \rightarrow IB \sin \theta = 0.35 IB \rightarrow \theta = \sin^{-1} 0.35 = \boxed{20^\circ}$$



7. (a) By the right hand rule, the magnetic field must be pointing up, and so the top pole face must be a **South pole**.
 (b) Use Eq. 20-2 to relate the maximum force to the current. The length of wire in the magnetic field is equal to the diameter of the pole faces.

$$F_{\max} = IlB \rightarrow I = \frac{F_{\max}}{lB} = \frac{(6.50 \times 10^{-2} \text{ N})}{(0.100 \text{ m})(0.16 \text{ T})} = 4.063 \text{ A} \approx \boxed{4.1 \text{ A}}$$

- (c) Multiply the maximum force by the sine of the angle between the wire and the magnetic field.

$$F = F_{\max} \sin \theta = (6.50 \times 10^{-2} \text{ N}) \sin 80.0^\circ = \boxed{6.40 \times 10^{-2} \text{ N}}$$

8. The magnetic force must be equal in magnitude to the force of gravity on the wire. The maximum magnetic force is applicable since the wire is perpendicular to the magnetic field. The mass of the wire is the density of copper times the volume of the wire.

$$F_B = mg \rightarrow IlB = \rho \pi \left(\frac{d}{2}\right)^2 l g \rightarrow$$

$$I = \frac{\rho \pi d^2 g}{4B} = \frac{(8.9 \times 10^3 \text{ kg/m}^3) \pi (1.00 \times 10^{-3} \text{ m})^2 (9.80 \text{ m/s}^2)}{4(5.0 \times 10^{-5} \text{ T})} = \boxed{1400 \text{ A}}$$

This answer does not seem feasible. The current is very large, and the Joule heating in the thin copper wire would probably melt it.

9. In this scenario, the magnetic force is causing centripetal motion, and so must have the form of a centripetal force. The magnetic force is perpendicular to the velocity at all times for circular motion.

$$F_{\max} = qvB = m \frac{v^2}{r} \rightarrow B = \frac{mv}{qr} = \frac{(6.6 \times 10^{-27} \text{ kg})(1.6 \times 10^7 \text{ m/s})}{2(1.60 \times 10^{-19} \text{ C})(0.25 \text{ m})} = \boxed{1.3 \text{ T}}$$

10. The maximum magnetic force as given in Eq. 20-4 can be used since the velocity is perpendicular to the magnetic field.

$$F_{\max} = qvB = (1.60 \times 10^{-19} \text{ C})(8.75 \times 10^5 \text{ m/s})(0.75 \text{ T}) = \boxed{1.05 \times 10^{-13} \text{ N}}$$

By the right hand rule, the force must be directed to the **North**.

11. Since the charge is negative, the answer is the OPPOSITE of the result given from the right hand rule applied to the velocity and magnetic field.

- (a) left
- (b) left
- (c) upward
- (d) inward into the paper
- (e) no force
- (f) downward

12. The right hand rule applied to the velocity and magnetic field would give the direction of the force. Use this to determine the direction of the magnetic field given the velocity and the force.

- (a) downward
- (b) inward into the paper
- (c) right

13. The magnetic force will cause centripetal motion, and the electron will move in a clockwise circular path if viewed in the direction of the magnetic field. The radius of the motion can be determined.

$$F_{\max} = qvB = m \frac{v^2}{r} \rightarrow r = \frac{mv}{qB} = \frac{(9.11 \times 10^{-31} \text{ kg})(1.70 \times 10^6 \text{ m/s})}{(1.60 \times 10^{-19} \text{ C})(0.350 \text{ T})} = \boxed{2.77 \times 10^{-5} \text{ m}}$$

14. The kinetic energy of the proton can be used to find its velocity. The magnetic force produces centripetal acceleration, and from this the radius can be determined.

$$\text{KE} = \frac{1}{2}mv^2 \rightarrow \sqrt{\frac{2\text{KE}}{m}} \quad qvB = \frac{mv^2}{r} \rightarrow$$

$$r = \frac{mv}{qB} = \frac{m\sqrt{\frac{2\text{KE}}{m}}}{qB} = \frac{\sqrt{2\text{KE}m}}{qB} = \frac{\sqrt{2(5.0 \times 10^6 \text{ eV})(1.60 \times 10^{-19} \text{ J/eV})(1.67 \times 10^{-27} \text{ kg})}}{(1.60 \times 10^{-19} \text{ C})(0.20 \text{ T})} = \boxed{1.6 \text{ m}}$$

15. The magnetic field can be found from Eq. 20-4, and the direction is found from the right hand rule. Remember that the charge is negative.

$$F_{\max} = qvB \rightarrow B = \frac{F_{\max}}{qv} = \frac{7.2 \times 10^{-13} \text{ N}}{(1.60 \times 10^{-19} \text{ C})(2.9 \times 10^6 \text{ m/s})} = \boxed{1.6 \text{ T}}$$

The direction would have to be **East** for the right hand rule, applied to the velocity and the magnetic field, to give the proper direction of force.

16. The force on the electron due to the electric force must be the same magnitude as the force on the electron due to the magnetic force.

$$F_E = F_B \rightarrow qE = qvB \rightarrow v = \frac{E}{B} = \frac{8.8 \times 10^3 \text{ V/m}}{3.5 \times 10^{-3} \text{ T}} = 2.514 \times 10^6 \text{ m/s} \approx \boxed{2.5 \times 10^6 \text{ m/s}}$$

If the electric field is turned off, the magnetic force will cause circular motion.

$$F_{\text{max}} = qvB = m \frac{v^2}{r} \rightarrow r = \frac{mv}{qB} = \frac{(9.11 \times 10^{-31} \text{ kg})(2.514 \times 10^6 \text{ m/s})}{(1.60 \times 10^{-19} \text{ C})(3.5 \times 10^{-3} \text{ T})} = \boxed{4.1 \times 10^{-3} \text{ m}}$$

17. (a) The velocity of the ion can be found using energy conservation. The electrical potential energy of the ion becomes kinetic energy as it is accelerated. Then, since the ion is moving perpendicular to the magnetic field, the magnetic force will be a maximum. That force will cause the ion to move in a circular path.

$$E_{\text{initial}} = E_{\text{final}} \rightarrow qV = \frac{1}{2}mv^2 \rightarrow v = \sqrt{\frac{2qV}{m}}$$

$$F_{\text{max}} = qvB = m \frac{v^2}{r} \rightarrow$$

$$r = \frac{mv}{qB} = \frac{m \sqrt{\frac{2qV}{m}}}{qB} = \frac{1}{B} \sqrt{\frac{2mV}{q}} = \frac{1}{0.340 \text{ T}} \sqrt{\frac{2(6.6 \times 10^{-27} \text{ kg})(2100 \text{ V})}{2(1.60 \times 10^{-19} \text{ C})}} = \boxed{2.7 \times 10^{-2} \text{ m}}$$

- (b) The period can be found from the speed and the radius. Use the expressions for the radius and the speed from above.

$$v = \frac{2\pi r}{T} \rightarrow T = \frac{2\pi r}{v} = \frac{2\pi \frac{1}{B} \sqrt{\frac{2mV}{q}}}{\sqrt{\frac{2qV}{m}}} = \frac{2\pi m}{qB} = \frac{2\pi(6.6 \times 10^{-27} \text{ kg})}{2(1.60 \times 10^{-19} \text{ C})(0.340 \text{ T})} = \boxed{3.8 \times 10^{-7} \text{ s}}$$

18. The velocity of each charged particle can be found using energy conservation. The electrical potential energy of the particle becomes kinetic energy as it is accelerated. Then, since the particle is moving perpendicularly to the magnetic field, the magnetic force will be a maximum. That force will cause the ion to move in a circular path, and the radius can be determined in terms of the mass and charge of the particle.

$$E_{\text{initial}} = E_{\text{final}} \rightarrow qV = \frac{1}{2}mv^2 \rightarrow v = \sqrt{\frac{2qV}{m}}$$

$$F_{\text{max}} = qvB = m \frac{v^2}{r} \rightarrow r = \frac{mv}{qB} = \frac{m \sqrt{\frac{2qV}{m}}}{qB} = \frac{1}{B} \sqrt{\frac{2mV}{q}}$$

$$\frac{r_d}{r_p} = \frac{\frac{1}{B} \sqrt{\frac{2m_d V}{q_d}}}{\frac{1}{B} \sqrt{\frac{2m_p V}{q_p}}} = \frac{\sqrt{\frac{m_d}{q_d}}}{\sqrt{\frac{m_p}{q_p}}} = \frac{\sqrt{2}}{\sqrt{1}} = \sqrt{2} \rightarrow \boxed{r_d = 2r_p}$$

$$\frac{r_\alpha}{r_p} = \frac{\frac{1}{B} \sqrt{\frac{2m_\alpha V}{q_\alpha}}}{\frac{1}{B} \sqrt{\frac{2m_p V}{q_p}}} = \frac{\sqrt{\frac{m_\alpha}{q_\alpha}}}{\sqrt{\frac{m_p}{q_p}}} = \frac{\sqrt{4}}{\sqrt{2}} = \sqrt{2} \rightarrow \boxed{r_\alpha = 2r_p}$$

19. From Example 20-5, we have that $r = \frac{mv}{qB}$. Then, from chapter 5, the period for an object moving in uniform circular motion is given by $T = \frac{2\pi r}{v}$. Combine these two relationships.

$$T = \frac{2\pi r}{v} = \frac{2\pi \frac{mv}{qB}}{v} = \frac{2\pi m}{qB}$$

20. From Example 20-5, we have that $r = \frac{mv}{qB}$. The quantity mv is the momentum, p , and so $r = \frac{p}{qB}$. Thus $p = qBr$.

21. From Example 20-5, we have that $r = \frac{mv}{qB}$, and so $v = \frac{rqB}{m}$. The kinetic energy is given by

$$\text{KE} = \frac{1}{2}mv^2 = \frac{1}{2}m \left(\frac{rqB}{m} \right)^2 = \frac{r^2 q^2 B^2}{2m} \text{ and so we see that } \text{KE} \propto r^2.$$

22. The angular momentum of a particle moving in a circular path is given by $L = mvr$. From Example 20-5, we have that $r = \frac{mv}{qB}$, and so $v = \frac{rqB}{m}$. Combining these relationships gives the following.

$$L = mvr = m \frac{rqB}{m} r = qBr^2$$

23. The magnetic force produces an acceleration that is perpendicular to the original motion. If that perpendicular acceleration is small, it will produce a small deflection, and the original velocity can be assumed to always be perpendicular to the magnetic field. This leads to a constant perpendicular acceleration. The time that this (approximately) constant acceleration acts can be found from the original velocity v and the distance traveled L . The starting speed in the perpendicular direction will be zero.

$$F_\perp = ma_\perp = qvB \rightarrow a_\perp = \frac{qvB}{m}$$

$$d_{\perp} = v_{0\perp}t + \frac{1}{2}a_{\perp}t^2 = \frac{1}{2}\frac{qvB}{m}\left(\frac{L}{v}\right)^2 = \frac{qBL^2}{2mv} = \frac{(13.5 \times 10^{-9} \text{ C})(5.00 \times 10^{-5} \text{ T})(1.00 \times 10^3 \text{ m})^2}{2(3.40 \times 10^{-3} \text{ kg})(160 \text{ m/s})}$$

$$= \boxed{6.2 \times 10^{-7} \text{ m}}$$

This small distance justifies the assumption of constant acceleration.

24. The magnetic force will produce centripetal acceleration. Use that relationship to calculate the speed. The radius of the Earth is $6.38 \times 10^6 \text{ km}$, and the altitude is added to that.

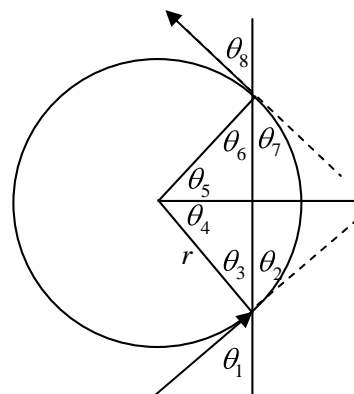
$$F_B = qvB = m\frac{v^2}{r} \rightarrow v = \frac{qrB}{m} = \frac{(1.60 \times 10^{-19} \text{ C})(6.385 \times 10^6 \text{ m})(0.40 \times 10^{-4} \text{ T})}{238(1.66 \times 10^{-27} \text{ kg})} = \boxed{1.0 \times 10^8 \text{ m/s}}$$

Compare the size of the magnetic force to the force of gravity on the ion.

$$\frac{F_B}{F_g} = \frac{qvB}{mg} = \frac{(1.60 \times 10^{-19} \text{ C})(1.0 \times 10^8 \text{ m/s})(0.40 \times 10^{-4} \text{ T})}{238(1.66 \times 10^{-27} \text{ kg})(9.80 \text{ m/s}^2)} = \boxed{1.7 \times 10^8}$$

It is fine to ignore gravity – the magnetic force is more than 100 million times larger than gravity.

25. (a) In the magnetic field, the proton will move along an arc of a circle. The distance x in the diagram is a chord of that circle, and so the center of the circular path lies on the perpendicular bisector of the chord. That perpendicular bisector bisects the central angle of the circle which subtends the chord. Also recall that a radius is perpendicular to a tangent. In the diagram, $\theta_1 = \theta_2$ because they are vertical angles. Then $\theta_2 = \theta_4$, because they are both complements of θ_3 , so $\theta_1 = \theta_4$. We have $\theta_4 = \theta_5$ since the central angle is bisected by the perpendicular bisector of the chord. $\theta_5 = \theta_7$ because they are both complements of θ_6 , and $\theta_7 = \theta_8$ because they are vertical angles. Thus



$\theta_1 = \theta_2 = \theta_4 = \theta_5 = \theta_7 = \theta_8$, and so in the textbook diagram, the angle at which the proton leaves is $\boxed{\theta = 45^\circ}$.

- (b) The radius of curvature is given by $r = \frac{mv}{qB}$, and the distance x is twice the value of $r \cos \theta$.

$$x = 2r \cos \theta = 2\frac{mv}{qB} \cos \theta = 2\frac{(1.67 \times 10^{-27} \text{ kg})(2.0 \times 10^5 \text{ m/s})}{(1.60 \times 10^{-19} \text{ C})(0.850 \text{ T})} \cos 45^\circ = \boxed{3.5 \times 10^{-3} \text{ m}}$$

26. We assume the jumper cable is a long straight wire, and use Eq. 20-6.

$$B_{\text{cable}} = \frac{\mu_0 I}{2\pi r} = \frac{(4\pi \times 10^{-7} \text{ T}\cdot\text{m/A})(65 \text{ A})}{2\pi(6.0 \times 10^{-2} \text{ m})} = 2.167 \times 10^{-4} \text{ T} \approx \boxed{2.2 \times 10^{-4} \text{ T}}$$

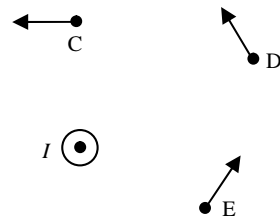
Compare this to the Earth's field of $0.5 \times 10^{-4} \text{ T}$.

$$B_{\text{cable}}/B_{\text{Earth}} = \frac{2.167 \times 10^{-4} \text{ T}}{0.5 \times 10^{-4} \text{ T}} = 4.33, \text{ so } \boxed{\text{the field of the cable is about 4 times that of the Earth.}}$$

27. We assume that the wire is long and straight, and use Eq. 20-6.

$$B_{\text{wire}} = \frac{\mu_0 I}{2\pi r} \rightarrow I = \frac{2\pi r B_{\text{wire}}}{\mu_0} = \frac{2\pi(0.25\text{ m})(0.55 \times 10^{-4}\text{ T})}{4\pi \times 10^{-7}\text{ T}\cdot\text{m/A}} = \boxed{69\text{ A}}$$

28. To find the direction, draw a radius line from the wire to the field point. Then at the field point, draw a perpendicular to the radius line, directed so that the perpendicular line would be part of a counterclockwise circle.



29. Since the force is attractive, the currents must be in the same direction, so the current in the second wire must also be upward. Use Eq. 20-7 to calculate the magnitude of the second current.

$$F_2 = \frac{\mu_0}{2\pi} \frac{I_1 I_2}{d} l_2 \rightarrow I_2 = \frac{2\pi F_2 d}{\mu_0 l_2 I_1} = \frac{2\pi}{4\pi \times 10^{-7}\text{ T}\cdot\text{m/A}} (8.8 \times 10^{-4}\text{ N/m}) \frac{7.0 \times 10^{-2}\text{ m}}{24\text{ A}} = \boxed{13\text{ A upward}}$$

30. Since the currents are parallel, the force on each wire will be attractive, toward the other wire. Use Eq. 20-7 to calculate the magnitude of the force.

$$F_2 = \frac{\mu_0}{2\pi} \frac{I_1 I_2}{d} l_2 = \frac{(4\pi \times 10^{-7}\text{ T}\cdot\text{m/A})}{2\pi} \frac{(25\text{ A})^2}{(6.0 \times 10^{-2}\text{ m})} (35\text{ m}) = \boxed{7.3 \times 10^{-2}\text{ N, attractive}}$$

31. For the experiment to be accurate to $\pm 1.0\%$, the magnetic field due to the current in the cable must be less than or equal to 1.0% of the Earth's magnetic field. Use Eq. 20-6 to calculate the magnetic field due to the current in the cable.

$$B_{\text{cable}} = \frac{\mu_0 I}{2\pi r} \leq 0.01 B_{\text{Earth}} \rightarrow I \leq \frac{2\pi r (0.01 B_{\text{Earth}})}{\mu_0} = \frac{2\pi(1.00\text{ m})(0.01)(0.5 \times 10^{-4}\text{ T})}{4\pi \times 10^{-7}\text{ T}\cdot\text{m/A}} = 2.5\text{ A}$$

Thus the maximum allowable current is $\boxed{2.5\text{ A}}$.

32. We assume that the power line is long and straight, and use Eq. 20-6.

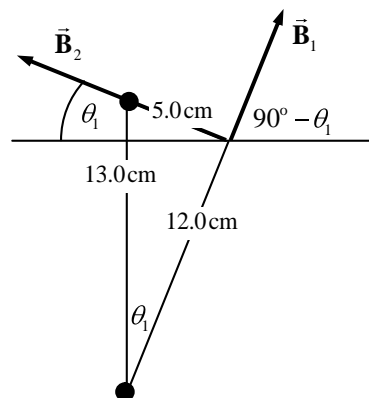
$$B_{\text{line}} = \frac{\mu_0 I}{2\pi r} = \frac{(4\pi \times 10^{-7}\text{ T}\cdot\text{m/A})(95\text{ A})}{2\pi(8.5\text{ m})} = 2.235 \times 10^{-6}\text{ T} \approx \boxed{2.2 \times 10^{-6}\text{ T}}$$

Compare this to the Earth's field of $0.5 \times 10^{-4}\text{ T}$.

$$B_{\text{line}}/B_{\text{Earth}} = \frac{2.235 \times 10^{-6}\text{ T}}{0.5 \times 10^{-4}\text{ T}} = 0.0447$$

$\boxed{\text{The field of the cable is about 4\% that of the Earth.}}$

33. The field from each wire makes concentric circles about the source wire. The individual fields at point P are perpendicular to the lines from the wires to point P. We define \vec{B}_1 as the field from the closer point, and \vec{B}_2 as the field from the further point. Use Eq. 20-6 to calculate each individual field.



$$B_1 = \frac{\mu_0 I}{2\pi r_1} = \frac{(4\pi \times 10^{-7} \text{ T}\cdot\text{m/A})(25 \text{ A})}{2\pi(0.050 \text{ m})} = 1.0 \times 10^{-4} \text{ T}$$

$$B_2 = \frac{\mu_0 I}{2\pi r_2} = \frac{(4\pi \times 10^{-7} \text{ T}\cdot\text{m/A})(25 \text{ A})}{2\pi(0.120 \text{ m})} = 4.167 \times 10^{-5} \text{ T}$$

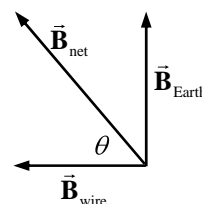
$$\theta_1 = \tan^{-1} \frac{5}{12} = 22.6^\circ \quad \vec{B}_{\text{net}} = \vec{B}_1 + \vec{B}_2$$

$$B_{\text{net } x} = B_1 \cos(90^\circ - \theta_1) - B_2 \cos \theta_1 = (1.0 \times 10^{-4} \text{ T}) \cos 67.4^\circ - (4.167 \times 10^{-5} \text{ T}) \cos 22.6^\circ \\ = -4.1 \times 10^{-8} \text{ T} \approx 0 \text{ T}$$

$$B_{\text{net } y} = B_1 \sin(90^\circ - \theta_1) + B_2 \sin \theta_1 = (1.0 \times 10^{-4} \text{ T}) \sin 67.4^\circ + (4.167 \times 10^{-5} \text{ T}) \sin 22.6^\circ \\ = 1.1 \times 10^{-4} \text{ T}$$

$$B_{\text{net}} = \boxed{1.1 \times 10^{-4} \text{ T @ } 90^\circ}$$

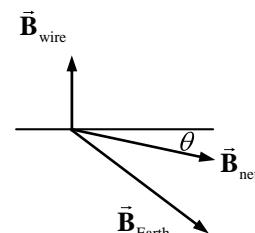
34. At the location of the compass, the magnetic field caused by the wire will point to the west, and the Earth's magnetic field points due North. The compass needle will point in the direction of the NET magnetic field.



$$B_{\text{wire}} = \frac{\mu_0 I}{2\pi r} = \frac{(4\pi \times 10^{-7} \text{ T}\cdot\text{m/A})(35 \text{ A})}{2\pi(0.18 \text{ m})} = 3.89 \times 10^{-5} \text{ T}$$

$$\theta = \tan^{-1} \frac{B_{\text{Earth}}}{B_{\text{wire}}} = \tan^{-1} \frac{0.45 \times 10^{-4} \text{ T}}{3.89 \times 10^{-5} \text{ T}} = \boxed{49^\circ \text{ N of W}}$$

35. The magnetic field due to the long horizontal wire points straight up at the point in question, and its magnitude is given by Eq. 20-6. The two fields are oriented as shown in the diagram. The net field is the vector sum of the two fields.



$$B_{\text{wire}} = \frac{\mu_0 I}{2\pi r} = \frac{(4\pi \times 10^{-7} \text{ T}\cdot\text{m/A})(22.0 \text{ A})}{2\pi(0.200 \text{ m})} = 2.2 \times 10^{-5} \text{ T}$$

$$B_{\text{Earth}} = 5.0 \times 10^{-5} \text{ T}$$

$$B_{\text{net } x} = B_{\text{Earth}} \cos 37^\circ = 4.00 \times 10^{-5} \text{ T} \quad B_{\text{net } y} = B_{\text{wire}} - B_{\text{Earth}} \sin 37^\circ = -0.81 \times 10^{-5} \text{ T}$$

$$B_{\text{net}} = \sqrt{B_{\text{net } x}^2 + B_{\text{net } y}^2} = \sqrt{(4.00 \times 10^{-5} \text{ T})^2 + (-0.81 \times 10^{-5} \text{ T})^2} = \boxed{4.1 \times 10^{-5} \text{ T}}$$

$$\theta = \tan^{-1} \frac{B_{\text{net } y}}{B_{\text{net } x}} = \tan^{-1} \frac{-0.81 \times 10^{-5} \text{ T}}{4.00 \times 10^{-5} \text{ T}} = \boxed{11^\circ \text{ below the horizontal}}$$

36. The stream of protons constitutes a current, whose magnitude is found by multiplying the proton rate times the charge of a proton. Then use Eq. 20-6 to calculate the magnetic field.

$$B_{\text{stream}} = \frac{\mu_0 I}{2\pi r} = \frac{(4\pi \times 10^{-7} \text{ T}\cdot\text{m/A})(1.5 \times 10^9 \text{ protons/s})(1.60 \times 10^{-19} \text{ C/proton})}{2\pi(2.0 \text{ m})} = \boxed{2.4 \times 10^{-17} \text{ T}}$$

37. (a) If the currents are in the same direction, the magnetic fields at the midpoint between the two currents will oppose each other, and so their magnitudes should be subtracted.

$$B_{\text{net}} = \frac{\mu_0 I_1}{2\pi r_1} - \frac{\mu_0 I_2}{2\pi r_2} = \frac{(4\pi \times 10^{-7} \text{ T}\cdot\text{m/A})}{2\pi(1.0 \times 10^{-2} \text{ m})}(I - 15 \text{ A}) = (2 \times 10^{-5} \text{ T/A})(I - 15 \text{ A})$$

- (b) If the currents are in the opposite direction, the magnetic fields at the midpoint between the two currents will reinforce each other, and so their magnitudes should be added.

$$B_{\text{net}} = \frac{\mu_0 I_1}{2\pi r_1} + \frac{\mu_0 I_2}{2\pi r_2} = \frac{(4\pi \times 10^{-7} \text{ T}\cdot\text{m/A})}{2\pi(1.0 \times 10^{-2} \text{ m})}(I + 15 \text{ A}) = (2 \times 10^{-5} \text{ T/A})(I + 15 \text{ A})$$

38. The fields created by the two wires will oppose each other, so the net field is the difference of the magnitudes of the two fields. The positive direction for the fields is taken to be into the paper, and so the closer wire creates a field in the positive direction, and the farther wire creates a field in the negative direction.

$$\begin{aligned} B_{\text{net}} &= \frac{\mu_0 I}{2\pi r_{\text{closer}}} - \frac{\mu_0 I}{2\pi r_{\text{farther}}} = \frac{\mu_0 I}{2\pi} \left(\frac{1}{r_{\text{closer}}} - \frac{1}{r_{\text{farther}}} \right) \\ &= \frac{(4\pi \times 10^{-7} \text{ T}\cdot\text{m/A})(25.0 \text{ A})}{2\pi} \left(\frac{1}{(0.10 \text{ m} - 0.0014 \text{ m})} - \frac{1}{(0.10 \text{ m} + 0.0014 \text{ m})} \right) \\ &= 1.400 \times 10^{-6} \text{ T} \approx \boxed{1.4 \times 10^{-6} \text{ T}} \end{aligned}$$

Compare this to the Earth's field of $0.5 \times 10^{-4} \text{ T}$.

$$B_{\text{net}}/B_{\text{Earth}} = \frac{1.400 \times 10^{-6} \text{ T}}{0.5 \times 10^{-4} \text{ T}} = 0.028$$

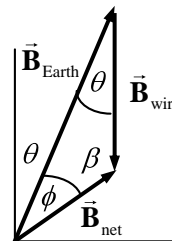
The field of the wires is about 3% that of the Earth.

39. The center of the third wire is 5.6 mm from the left wire, and 2.8 mm from the right wire. The force on the near (right) wire will attract the near wire, since the currents are in the same direction. The force on the far (left) wire will repel the far wire, since the currents oppose each other. Use Eq. 20-7 to calculate the force per unit length.

$$F_{\text{near}} = \frac{\mu_0 I_1 I_2}{2\pi d_{\text{near}}} l_{\text{near}} \rightarrow \frac{F_{\text{near}}}{l_{\text{near}}} = \frac{\mu_0 I_1 I_2}{2\pi d_{\text{near}}} = \frac{4\pi \times 10^{-7} \text{ T}\cdot\text{m/A} (25.0 \text{ A})^2}{2\pi (2.8 \times 10^{-3} \text{ m})} = \boxed{4.5 \times 10^{-2} \text{ N/m, attract}}$$

$$F_{\text{far}} = \frac{\mu_0 I_1 I_2}{2\pi d_{\text{far}}} l_{\text{far}} \rightarrow \frac{F_{\text{far}}}{l_{\text{far}}} = \frac{\mu_0 I_1 I_2}{2\pi d_{\text{far}}} = \frac{4\pi \times 10^{-7} \text{ T}\cdot\text{m/A} (25.0 \text{ A})^2}{2\pi (5.6 \times 10^{-3} \text{ m})} = \boxed{2.2 \times 10^{-2} \text{ N/m, repel}}$$

40. The Earth's magnetic field is present at both locations in the problem, and we assume it is the same at both locations. The field east of a vertical wire must be pointing either due north or due south. The compass shows the direction of the net magnetic field, and it changes from 23° E of N to 55° E of N when taken inside. That is a "southerly" change (rather than a "northerly" change), and so the field due to the wire must be pointing due south. See the diagram. For the angles, $\theta = 23^\circ$, $\theta + \phi = 55^\circ$, and $\beta + \theta + \phi = 180^\circ$ and so $\phi = 32^\circ$ and $\beta = 125^\circ$. Use the law of sines to find the magnitude of \vec{B}_{wire} , and then use Eq. 20-6 to find the magnitude of the current.



$$\frac{B_{\text{wire}}}{\sin \phi} = \frac{B_{\text{Earth}}}{\sin \beta} \rightarrow B_{\text{wire}} = B_{\text{Earth}} \frac{\sin \phi}{\sin \beta} = \frac{\mu_0 I}{2\pi r} \rightarrow$$

$$I = B_{\text{Earth}} \frac{\sin \phi}{\sin \beta} \frac{2\pi r}{\mu_0} = (5.0 \times 10^{-5} \text{ T}) \frac{\sin 32^\circ}{\sin 125^\circ} \frac{2\pi}{4\pi \times 10^{-7} \text{ T}\cdot\text{m}/\text{A}} (0.120 \text{ m}) = \boxed{19.4 \text{ A}}$$

Since the field due to the wire is due south, the current in the wire must be **down**.

41. The magnetic field at the loop due to the long wire is into the page, and can be calculated by Eq. 20-6. The force on the segment of the loop closest to the wire is towards the wire, since the currents are in the same direction. The force on the segment of the loop farthest from the wire is away from the wire, since the currents are in the opposite direction.

Because the magnetic field varies with distance, it is difficult to calculate the total force on either the left or right segments of the loop. Using the right hand rule, the force on each small piece of the left segment of wire is to the left, and the force on each small piece of the right segment of wire is to the right. If left and right small pieces are chosen that are equidistant from the long wire, the net force on those two small pieces is zero. Thus the total force on the left and right segments of wire is zero, and so only the parallel segments need to be considered in the calculation. Use Eq. 20-7.

$$F_{\text{net}} = F_{\text{near}} - F_{\text{far}} = \frac{\mu_0 I_1 I_2}{2\pi d_{\text{near}}} l_{\text{near}} - \frac{\mu_0 I_1 I_2}{2\pi d_{\text{far}}} l_{\text{far}} = \frac{\mu_0}{2\pi} I_1 I_2 l \left(\frac{1}{d_{\text{near}}} - \frac{1}{d_{\text{far}}} \right)$$

$$= \frac{4\pi \times 10^{-7} \text{ T}\cdot\text{m}/\text{A}}{2\pi} (2.5 \text{ A})^2 (0.100 \text{ m}) \left(\frac{1}{0.030 \text{ m}} - \frac{1}{0.080 \text{ m}} \right) = \boxed{2.6 \times 10^{-6} \text{ N, towards wire}}$$

42. (a) The magnetic force exerted on the lower wire must be upwards, and must be the same magnitude as the gravitational force on the lower wire. Consider a length L of the copper wire.

$$F_g = F_B \rightarrow m_{\text{Cu}} g = \frac{\mu_0 I_{\text{top}} I_{\text{Cu}}}{2\pi d} L_{\text{Cu}} \rightarrow I_{\text{Cu}} = \frac{2\pi d m_{\text{Cu}} g}{\mu_0 I_{\text{top}} L_{\text{Cu}}} = \frac{2\pi d \rho_{\text{Cu}} L_{\text{Cu}} \pi r_{\text{Cu}}^2 g}{\mu_0 I_{\text{top}} L_{\text{Cu}}}$$

$$= \frac{2\pi d \rho_{\text{Cu}} \pi r_{\text{Cu}}^2 g}{\mu_0 I_{\text{top}}} = \frac{2\pi (0.15 \text{ m}) (8900 \text{ kg}/\text{m}^3) \pi (1.25 \times 10^{-3} \text{ m})^2 (9.80 \text{ m}/\text{s}^2)}{(4\pi \times 10^{-7} \text{ T}\cdot\text{m}/\text{A}) (48 \text{ A})} = \boxed{6700 \text{ A}}$$

The currents must be in the same direction for the magnetic force to be upward, so the current is to the **right**.

- (b) If the wire is displaced slightly downward, the magnetic force would be less than the force of gravity, so the object would continue to move downward and it would fall. Thus the lower wire is **not in stable equilibrium**.

- (c) Because the wires are the same distance apart, the current must be the same, **6700 A**. The current in the upper wire must now be to the **left** so that the magnetic force is upwards. If the

wire is now displaced upwards, the magnetic force decreases, and the object starts to fall, moving toward its original position. If the wire is displaced downwards, the magnetic force increases, and the object would move back toward its original position. Thus the wire **is in stable equilibrium**.

43. The magnetic fields created by the individual currents will be at right angles to each other. The field due to the top wire will be to the right, and the field due to the bottom wire will be out of the page. Since they are at right angles, the net field is the hypotenuse of the two individual fields.

$$B_{\text{net}} = \sqrt{\left(\frac{\mu_0 I_{\text{top}}}{2\pi r_{\text{top}}}\right)^2 + \left(\frac{\mu_0 I_{\text{bottom}}}{2\pi r_{\text{bottom}}}\right)^2} = \frac{\mu_0}{2\pi r} \sqrt{I_{\text{top}}^2 + I_{\text{bottom}}^2} = \frac{4\pi \times 10^{-7} \text{ T}\cdot\text{m}/\text{A}}{2\pi (0.100 \text{ m})} \sqrt{(20.0 \text{ A})^2 + (5.0 \text{ A})^2}$$

$$= \boxed{4.12 \times 10^{-5} \text{ T}}$$

44. (a) Use Eq. 20-6 to calculate the field due to a long straight wire.

$$B_{\text{A at B}} = \frac{\mu_0 I_{\text{A}}}{2\pi r_{\text{A to B}}} = \frac{(4\pi \times 10^{-7} \text{ T}\cdot\text{m}/\text{A})(2.0 \text{ A})}{2\pi (0.15 \text{ m})} = 2.667 \times 10^{-6} \text{ T} \approx \boxed{2.7 \times 10^{-6} \text{ T}}$$

$$(b) B_{\text{B at A}} = \frac{\mu_0 I_{\text{B}}}{2\pi r_{\text{B to A}}} = \frac{(4\pi \times 10^{-7} \text{ T}\cdot\text{m}/\text{A})(4.0 \text{ A})}{2\pi (0.15 \text{ m})} = 5.333 \times 10^{-6} \text{ T} \approx \boxed{5.3 \times 10^{-6} \text{ T}}$$

- (c) The two fields are not equal and opposite. Each individual field is due to a single wire, and has no dependence on the other wire. The magnitude of current in the second wire has nothing to do with the value of the field caused by the first wire.
- (d) Use Eq. 20-7 to calculate the force due to one wire on another. The forces are attractive since the currents are in the same direction.

$$\frac{F_{\text{on A due to B}}}{l_{\text{A}}} = \frac{F_{\text{on B due to A}}}{l_{\text{B}}} = \frac{\mu_0}{2\pi} \frac{I_{\text{A}} I_{\text{B}}}{d_{\text{A to B}}} = \frac{(4\pi \times 10^{-7} \text{ T}\cdot\text{m}/\text{A})(2.0 \text{ A})(4.0 \text{ A})}{2\pi (0.15 \text{ m})}$$

$$= 1.067 \times 10^{-5} \text{ N/m} \approx \boxed{1.1 \times 10^{-5} \text{ N/m}}$$

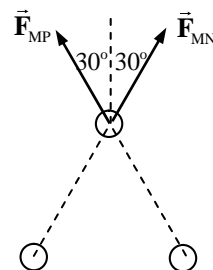
These two forces per unit length are equal and opposite because they are a Newton's Third Law pair of forces.

45. The forces on wire M due to the other wires are repelling forces, away from the other wires. Use Eq. 20-7 to calculate the force per unit length on wire M due to each of the other wires, and then add the force vectors together. The horizontal parts of the forces cancel, and the sum is vertical.

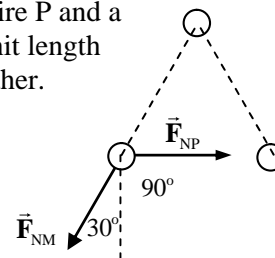
$$\frac{F_{\text{M net y}}}{l_{\text{M}}} = \frac{F_{\text{MN}}}{l_{\text{M}}} \cos 30^\circ + \frac{F_{\text{MP}}}{l_{\text{M}}} \cos 30^\circ$$

$$= \frac{\mu_0}{2\pi} \frac{I_{\text{M}} I_{\text{N}}}{d_{\text{MN}}} (1 \text{ m}) \cos 30^\circ + \frac{\mu_0}{2\pi} \frac{I_{\text{M}} I_{\text{P}}}{d_{\text{MP}}} (1 \text{ m}) \cos 30^\circ$$

$$= 2 \frac{(4\pi \times 10^{-7} \text{ T}\cdot\text{m}/\text{A})(8.00 \text{ A})^2}{2\pi (0.038 \text{ m})} \cos 30^\circ = \boxed{5.8 \times 10^{-4} \text{ N/m}, 90^\circ}$$



The forces on wire N due to the other wires are an attractive force towards wire P and a repelling force away from wire M. Use Eq. 20-7 to calculate the force per unit length on wire N due to each of the other wires, and then add the force vectors together. From the symmetry, we expect the net force to lie exactly between the two individual force vectors, which is 60° below the horizontal.



$$F_{N_{\text{net } y}} = -F_{NM} \cos 30^\circ = -\frac{\mu_0 I_M I_N}{2\pi d_{MN}} \cos 30^\circ$$

$$= -\frac{(4\pi \times 10^{-7} \text{ T}\cdot\text{m/A}) (8.00 \text{ A})^2}{2\pi (0.038 \text{ m})} \cos 30^\circ = -2.917 \times 10^{-4} \text{ N/m}$$

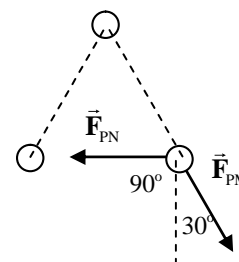
$$F_{N_{\text{net } x}} = -F_{NM} \sin 30^\circ + F_{NP}$$

$$= -\frac{(4\pi \times 10^{-7} \text{ T}\cdot\text{m/A}) (8.00 \text{ A})^2}{2\pi (0.038 \text{ m})} \sin 30^\circ + \frac{(4\pi \times 10^{-7} \text{ T}\cdot\text{m/A}) (8.00 \text{ A})^2}{2\pi (0.038 \text{ m})}$$

$$= 1.684 \times 10^{-5} \text{ N/m}$$

$$F_{N_{\text{net}}} = \sqrt{F_{N_{\text{net } x}}^2 + F_{N_{\text{net } y}}^2} = \boxed{3.4 \times 10^{-4} \text{ N/m}} \quad \theta = \tan^{-1} \frac{F_{N_{\text{net } y}}}{F_{N_{\text{net } x}}} = \tan^{-1} \frac{-2.917}{1.684} = \boxed{300^\circ}$$

The forces on wire P due to the other wires are an attractive force towards wire N and a repelling force away from wire M. Use Eq. 20-7 to calculate the force per unit length on wire P due to each of the other wires, and then add the force vectors together. From symmetry, this is just a mirror image of the previous solution, and so the net force is as follows.



$$F_{P_{\text{net}}} = \boxed{3.4 \times 10^{-4} \text{ N/m}} \quad \theta = \boxed{240^\circ}$$

46. There will be three magnetic fields to sum – one from each wire. Each field will point perpendicularly to the line connecting the wire to the midpoint. The two fields due to M and N are drawn slightly separated from each other, but should be collinear. The magnitude of each field is given by Eq. 29-6.

$$\vec{B}_{\text{net}} = \vec{B}_M + \vec{B}_N + \vec{B}_P$$

$$B_M = B_N = \frac{\mu_0 I}{2\pi r_M} = \frac{(4\pi \times 10^{-7} \text{ T}\cdot\text{m/A}) 8.00 \text{ A}}{2\pi 0.019 \text{ m}} = 8.421 \times 10^{-5} \text{ T}$$

$$B_P = \frac{\mu_0 I}{2\pi r_P} = \frac{(4\pi \times 10^{-7} \text{ T}\cdot\text{m/A}) 8.00 \text{ A}}{2\pi \sqrt{3}(0.019 \text{ m})} = 4.862 \times 10^{-5} \text{ T}$$

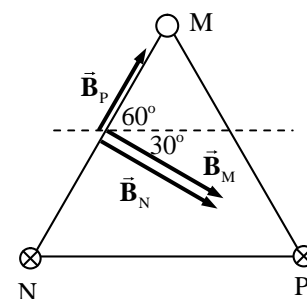
$$B_{\text{net } x} = 2B_M \cos 30^\circ + B_P \cos 60^\circ = 2(8.421 \times 10^{-5} \text{ T}) \cos 30^\circ + (4.862 \times 10^{-5} \text{ T}) \cos 60^\circ$$

$$= 1.702 \times 10^{-4} \text{ T}$$

$$B_{\text{net } y} = -2B_M \sin 30^\circ + B_P \sin 60^\circ = -2(8.421 \times 10^{-5} \text{ T}) \sin 30^\circ + (4.862 \times 10^{-5} \text{ T}) \sin 60^\circ$$

$$= -4.210 \times 10^{-5} \text{ T}$$

$$B_{\text{net}} = \sqrt{B_{\text{net } x}^2 + B_{\text{net } y}^2} = \sqrt{(1.702 \times 10^{-4} \text{ T})^2 + (-4.210 \times 10^{-5} \text{ T})^2} = \boxed{1.75 \times 10^{-4} \text{ T}}$$



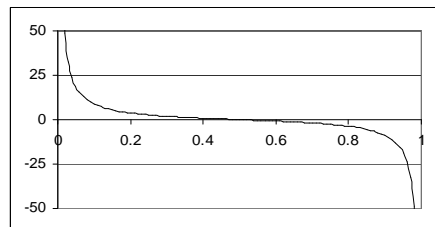
$$\theta_{\text{net}} = \tan^{-1} \frac{B_{\text{net},y}}{B_{\text{net},x}} = \tan^{-1} \frac{-4.210 \times 10^{-5} \text{ T}}{1.702 \times 10^{-4} \text{ T}} = \boxed{-14^\circ}$$

The net field points slightly below the horizontal direction.

47. The left wire will cause a field on the x -axis that points in the y -direction, and the right wire will cause a field on the x -axis that points in the negative y -direction. The distance from the left wire to a point on the x -axis is x , and the distance from the right wire is $d - x$.

$$B_{\text{net}} = \frac{\mu_0 I}{2\pi x} - \frac{\mu_0 I}{2\pi(d-x)} = \frac{\mu_0 I}{2\pi} \left(\frac{1}{x} - \frac{1}{d-x} \right)$$

A graph of the above function is shown here.



48. Use Eq. 20-8 for the field inside a solenoid.

$$B = \mu_0 IN/l = \frac{(4\pi \times 10^{-7} \text{ T}\cdot\text{m/A})(2.0 \text{ A})(420)}{0.12 \text{ m}} = \boxed{8.8 \times 10^{-3} \text{ T}}$$

49. Use Eq. 20-8 for the field inside a solenoid.

$$B = \mu_0 IN/l \rightarrow I = \frac{Bl}{\mu_0 N} = \frac{(0.385 \text{ T})(0.300 \text{ m})}{(4\pi \times 10^{-7} \text{ T}\cdot\text{m/A})(975)} = \boxed{94.3 \text{ A}}$$

50. The field due to the solenoid is given by Eq. 20-8. Since the field due to the solenoid is perpendicular to the current in the wire, Eq. 20-2 can be used to find the force on the wire segment.

$$F = I_{\text{wire}} l_{\text{wire}} B_{\text{solenoid}} = I_{\text{wire}} l_{\text{wire}} \frac{\mu_0 I_{\text{solenoid}} N}{l_{\text{solenoid}}} = (22 \text{ A})(0.030 \text{ m}) \frac{(4\pi \times 10^{-7} \text{ T}\cdot\text{m/A})(33 \text{ A})(550)}{(0.15 \text{ m})}$$

$$= \boxed{0.10 \text{ N}}$$

51. Since the mass of copper is fixed and the density is fixed, the volume is fixed, and we designate it as $V_{\text{Cu}} = m_{\text{Cu}} \rho_{\text{Cu}} = L_{\text{Cu}} A_{\text{Cu}}$. We call the fixed voltage V_0 . The magnetic field in the solenoid is given by Eq. 20-8.

$$B = \frac{\mu_0 IN}{L_{\text{sol}}} = \mu_0 V_0 \frac{N}{R_{\text{Cu}} L_{\text{sol}}} = \frac{\mu_0 V_0}{\rho_{\text{RCu}}} \frac{N}{\frac{L_{\text{Cu}}}{A_{\text{Cu}}} L_{\text{sol}}} = \frac{\mu_0 V_0}{\rho_{\text{RCu}}} \frac{N}{L_{\text{sol}}} \frac{A_{\text{Cu}}}{L_{\text{Cu}}} = \frac{\mu_0 V_0}{\rho_{\text{RCu}}} \frac{N}{L_{\text{sol}}} \frac{m_{\text{Cu}} \rho_{\text{Cu}}}{L_{\text{Cu}}^2}$$

$$= \frac{\mu_0 V_0 m_{\text{Cu}} \rho_{\text{Cu}}}{\rho_{\text{RCu}}} \frac{N}{L_{\text{sol}} L_{\text{Cu}}^2}$$

The number of turns of wire is the length of wire divided by the circumference of the solenoid.

$$N = \frac{L_{\text{Cu}}}{2\pi r_{\text{sol}}} \rightarrow B = \frac{\mu_0 V_0 m_{\text{Cu}} \rho_{\text{Cu}}}{\rho_{\text{RCu}}} \frac{N}{L_{\text{sol}} L_{\text{Cu}}^2} = \frac{\mu_0 V_0 m_{\text{Cu}} \rho_{\text{Cu}}}{\rho_{\text{RCu}}} \frac{\frac{L_{\text{Cu}}}{2\pi r_{\text{sol}}}}{L_{\text{sol}} L_{\text{Cu}}^2} = \frac{\mu_0 V_0 m_{\text{Cu}} \rho_{\text{Cu}}}{2\pi \rho_{\text{RCu}}} \frac{1}{L_{\text{sol}} r_{\text{sol}} L_{\text{Cu}}}$$

The first factor in the expression for B is made of constants, so we have $B \propto \frac{1}{L_{\text{sol}} r_{\text{sol}} L_{\text{Cu}}}$. Thus we want the wire to be **short and fat**. Also the radius of the solenoid should be small and the length of the solenoid small.

52. (a) Each loop of wire produces a field along its axis, similar to Figure 20-9. For path 1, with all the loops taken together, that symmetry leads to a magnetic field that is the same anywhere along the path, and parallel to the path. One side of every turn of the wire is enclosed by path 1, and so the enclosed current is NI . Apply Eq. 20-9.

$$\sum B_{\parallel} \Delta l = \mu_0 NI \rightarrow B(2\pi R) = \mu_0 NI \rightarrow \boxed{B = \mu_0 NI / 2\pi R}$$

- (b) For path 2, each loop of wire pierces the enclosed area twice – once going up and once going down. Ampere's law takes the direction of the current into account, and so the net current through the area enclosed by path 2 is 0.

$$\sum B_{\parallel} \Delta l = \mu_0 NI \rightarrow B(2\pi R) = 0 \rightarrow \boxed{B = 0}$$

- (c) The field inside a toroid is **not uniform**. As seen in the result to part (a), the field varies inversely as the radius of the toroid, and so $B \propto \frac{1}{R}$. The field is strongest at the inside wall of the toroid, and weakest at the outside wall.

53. (a) Ampere's Law says that along a closed path, $\sum B_{\parallel} \Delta l = \mu_0 I_{\text{encl}}$. For the path choose a circle of radius r , centered on the center of the wire, greater than the radius of the inner wire and less than the radius of the outer cylindrical braid. Because the wire is long and straight, the magnetic field is tangent to the chosen path, and so $B_{\parallel} = B$. The current enclosed by the path is I .

$$\mu_0 I_{\text{encl}} = \sum B_{\parallel} \Delta l = \sum B \Delta l = B \sum \Delta l = B(2\pi r) \rightarrow B = \frac{\mu_0 I}{2\pi r}$$

- (b) We make a similar argument, but now choose the path to be a circle of radius r , greater than the radius of the outer cylindrical braid. Because the wire and the braid are long and straight, the magnetic field is tangent to the chosen path, and so $B_{\parallel} = B$. The current enclosed by the path is zero, since there are two equal but oppositely directed currents.

$$\mu_0 I_{\text{encl}} = \sum B_{\parallel} \Delta l = \sum B \Delta l = B \sum \Delta l = B(2\pi r) \rightarrow B = \frac{\mu_0 I_{\text{encl}}}{2\pi r} = 0$$

54. If the face of the loop of wire is parallel to the magnetic field, the angle between the perpendicular to the loop and the magnetic field is 90° . Use Eq. 20-10 to calculate the magnetic field strength.

$$\tau = NIAB \sin \theta \rightarrow B = \frac{\tau}{NIA \sin \theta} = \frac{0.325 \text{ m}\cdot\text{N}}{(1)(6.30 \text{ A})(0.220 \text{ m})^2 \sin 90^\circ} = \boxed{1.07 \text{ T}}$$

55. In section 20-10, it is shown that the deflection of the galvanometer needle is proportional to the product of the current and the magnetic field. Thus if the magnetic field is decreased to 0.860 times its original value, the current must be increased by dividing the original value by 0.860 to obtain the same deflection.

$$(IB)_{\text{initial}} = (IB)_{\text{final}} \rightarrow I_{\text{final}} = \frac{I_{\text{initial}} B_{\text{initial}}}{B_{\text{final}}} = \frac{(53.0 \mu\text{A}) B_{\text{initial}}}{0.860 B_{\text{initial}}} = \boxed{61.6 \mu\text{A}}$$

56. From the galvanometer discussion in section 20-10, the amount of deflection is proportional to the ratio of the current and the spring constant: $\phi \propto \frac{I}{k}$. Thus if the spring constant decreases by 25%, the current can decrease by 25% to produce the same deflection. The new current will be 75% of the original current.

$$I_{\text{final}} = 0.75I_{\text{initial}} = 0.75(36\mu\text{A}) = \boxed{27\mu\text{A}}$$

57. From section 20-9, we see that the torque is proportional to the current, so if the current drops by 12%, the output torque will also drop by 12%. Thus the final torque is 0.88 times the initial torque.
58. The magnetic dipole moment is defined in Eq. 20-11 as $M = NIA$. The number of turns, N , is 1. The current is the charge per unit time passing a given point, which on the average is the charge on the electron divided by the period of the circular motion, $I = e/T$. If we assume the electron is moving in a circular orbit of radius r , then the area is πr^2 . The period of the motion is the circumference of the orbit divided by the speed, $T = 2\pi r/v$. Finally, the angular momentum of an object moving in a circle is given by $L = mrv$. Combine these relationships to find the magnetic moment.

$$M = NIA = \frac{e}{T} \pi r^2 = \frac{e}{2\pi r/v} \pi r^2 = \frac{e\pi r^2 v}{2\pi r} = \frac{erv}{2} = \frac{emrv}{2m} = \frac{e}{2m} mrv = \frac{e}{2m} L$$

59. (a) The torque is given by Eq. 20-10. The angle is the angle between the B-field and the perpendicular to the coil face.

$$\tau = NIAB \sin \theta = 9(7.20\text{ A}) \left[\pi(0.080\text{ m})^2 \right] (5.50 \times 10^{-5}\text{ T}) \sin 34^\circ = \boxed{4.01 \times 10^{-5}\text{ m}\cdot\text{N}}$$

- (b) In Example 20-12 it is stated that if the coil is free to turn, it will rotate toward the orientation so that the angle is 0. In this case, that means the north edge of the coil will rise, so that a perpendicular to its face will be parallel with the Earth's magnetic field.

60. The radius and magnetic field values can be used to find the speed of the protons. The electric field is then found from the fact that the magnetic force must be the same magnitude as the electric force for the protons to have straight paths.

$$qvB = mv^2/r \rightarrow v = qBr/m \quad F_E = F_B \rightarrow qE = qvB \rightarrow$$

$$E = vB = qB^2 r/m = \frac{(1.60 \times 10^{-19}\text{ C})(0.566\text{ T})^2 (5.10 \times 10^{-2}\text{ cm})}{1.67 \times 10^{-27}\text{ kg}} = \boxed{1.57 \times 10^6\text{ V/m}}$$

The direction of the electric field must be perpendicular to both the velocity and the magnetic field, and must be in the opposite direction to the magnetic force on the protons.

61. The magnetic force on the ions causes them to move in a circular path, so the magnetic force is a centripetal force. This results in the ion mass being proportional to the path's radius of curvature.

$$qvB = mv^2/r \rightarrow m = qBr/v \rightarrow m/r = qB/v = \text{constant} = 76\text{ u}/22.8\text{ cm}$$

$$\frac{m_{21.0}}{21.0\text{ cm}} = \frac{76\text{ u}}{22.8\text{ cm}} \rightarrow m_{21.0} = 70\text{ u} \quad \frac{m_{21.6}}{21.6\text{ cm}} = \frac{76\text{ u}}{22.8\text{ cm}} \rightarrow m_{21.6} = 72\text{ u}$$

$$\frac{m_{21.9}}{21.9\text{ cm}} = \frac{76\text{ u}}{22.8\text{ cm}} \rightarrow m_{21.9} = 73\text{ u} \quad \frac{m_{22.2}}{22.2\text{ cm}} = \frac{76\text{ u}}{22.8\text{ cm}} \rightarrow m_{22.2} = 74\text{ u}$$

The other masses are 70 u, 72 u, 73 u, and 74 u.

62. The location of each line on the film is twice the radius of curvature of the ion. The radius of curvature can be found from the expression given in section 20-11.

$$m = \frac{qBB'r}{E} \rightarrow r = \frac{mE}{qBB'} \rightarrow 2r = \frac{2mE}{qBB'}$$

$$2r_{12} = \frac{2(12)(1.67 \times 10^{-27} \text{ kg})(2.48 \times 10^4 \text{ V/m})}{(1.60 \times 10^{-19} \text{ C})(0.68 \text{ T})^2} = 1.344 \times 10^{-2} \text{ m}$$

$$2r_{13} = 1.455 \times 10^{-2} \text{ m} \quad 2r_{14} = 1.567 \times 10^{-2} \text{ m}$$

The distances between the lines are

$$2r_{13} - 2r_{12} = 1.455 \times 10^{-2} \text{ m} - 1.344 \times 10^{-2} \text{ m} = 1.11 \times 10^{-3} \text{ m} \approx \boxed{1.1 \times 10^{-3} \text{ m}}$$

$$2r_{14} - 2r_{13} = 1.567 \times 10^{-2} \text{ m} - 1.455 \times 10^{-2} \text{ m} = 1.12 \times 10^{-3} \text{ m} \approx \boxed{1.1 \times 10^{-3} \text{ m}}$$

If the ions are doubly charged, the value of q in the denominator of the expression would double, and so the actual distances on the film would be halved. Thus the distances between the lines would also be halved.

$$2r_{13} - 2r_{12} = 7.277 \times 10^{-3} \text{ m} - 6.718 \times 10^{-3} \text{ m} = 5.59 \times 10^{-4} \text{ m} \approx \boxed{5.6 \times 10^{-4} \text{ m}}$$

$$2r_{14} - 2r_{13} = 7.837 \times 10^{-3} \text{ m} - 7.277 \times 10^{-3} \text{ m} = 5.60 \times 10^{-4} \text{ m} \approx \boxed{5.6 \times 10^{-4} \text{ m}}$$

63. The particles in the mass spectrometer follow a semicircular path as shown in Fig. 20-39. A particle has a displacement of $2r$ from the point of entering the semicircular region to where it strikes the film. So if the separation of the two molecules on the film is 0.50 mm, the difference in radii of the two molecules is 0.25 mm. The mass to radius ratio is the same for the two molecules.

$$qvB = mv^2/r \rightarrow m = qBr/v \rightarrow m/r = \text{constant}$$

$$\left(\frac{m}{r}\right)_{\text{CO}} = \left(\frac{m}{r}\right)_{\text{N}_2} \rightarrow \frac{28.0106 \text{ u}}{r} = \frac{28.0134 \text{ u}}{r + 2.5 \times 10^{-4} \text{ m}} \rightarrow r = 2.5 \text{ m}$$

64. The velocity of the ions is found using energy conservation. The electrical potential energy of the ions becomes kinetic energy as they are accelerated. Then, since the ions move perpendicularly to the magnetic field, the magnetic force will be a maximum. That force will cause the ions to move in a circular path.

$$qvB = \frac{mv^2}{R} \rightarrow v = \frac{qBR}{m} \quad qV = \frac{1}{2}mv^2 = \frac{1}{2}m\left(\frac{qBR}{m}\right)^2 = \frac{q^2B^2R^2}{2m} \rightarrow m = \frac{qR^2B^2}{2V}$$

65. The field inside the solenoid is given by Eq. 20-8 with μ_0 replaced by the permeability of the iron.

$$B = \frac{\mu NI}{l} = \frac{3000(4\pi \times 10^{-7} \text{ T}\cdot\text{m/A})(430)(25 \text{ A})}{(1.0 \text{ m})} = \boxed{41 \text{ T}}$$

66. The field inside the solenoid is given by Eq. 20-8 with μ_0 replaced by the permeability of the iron.

$$B = \frac{\mu NI}{l} \rightarrow \mu = \frac{Bl}{NI} = \frac{(2.2 \text{ T})(0.38 \text{ m})}{(640)(48 \text{ A})} = \boxed{2.7 \times 10^{-5} \text{ T}\cdot\text{m/A}} \approx 22\mu_0$$

67. The magnetic force produces centripetal acceleration.

$$qvB = mv^2/r \rightarrow mv = p = qBr \rightarrow B = \frac{p}{qr} = \frac{4.8 \times 10^{-16} \text{ kg}\cdot\text{m/s}}{(1.60 \times 10^{-19} \text{ C})(1.0 \times 10^3 \text{ m})} = \boxed{3.0 \text{ T}}$$

The magnetic field must point upward to cause an inward-pointing (centripetal) force that steers the protons clockwise.

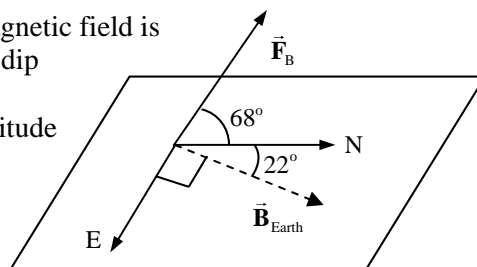
68. The kinetic energy is used to determine the speed of the particles, and then the speed can be used to determine the radius of the circular path, since the magnetic force is causing centripetal acceleration.

$$\text{KE} = \frac{1}{2}mv^2 \rightarrow v = \sqrt{\frac{2\text{KE}}{m}} \quad qvB = \frac{mv^2}{r} \rightarrow r = \frac{mv}{qB} = \frac{m\sqrt{\frac{2\text{KE}}{m}}}{qB} = \frac{\sqrt{2m\text{KE}}}{qB}$$

$$\frac{r_p}{r_e} = \frac{\frac{\sqrt{2m_p\text{KE}}}{qB}}{\frac{\sqrt{2m_e\text{KE}}}{qB}} = \sqrt{\frac{m_p}{m_e}} = \sqrt{\frac{1.67 \times 10^{-27} \text{ kg}}{9.11 \times 10^{-31} \text{ kg}}} = \boxed{42.8}$$

69. We assume that the horizontal component of the Earth's magnetic field is pointing due north. The Earth's magnetic field also has the dip angle of
- 22°
- . The angle between the magnetic field and the eastward current is
- 90°
- . Use Eq. 20-1 to calculate the magnitude of the force.

$$F = I\ell B \sin \theta = (330 \text{ A})(15 \text{ m})(5.0 \times 10^{-5} \text{ T}) \sin 90^\circ = \boxed{0.25 \text{ N}}$$



Using the right hand rule with the eastward current and the Earth's magnetic field, the force on the wire is northerly and 68° above the horizontal.

70. The airplane is a charge moving in a magnetic field. Since it is flying perpendicular to the magnetic field, Eq. 20-4 applies.

$$F_{\text{max}} = qvB = (1550 \times 10^{-6} \text{ C})(120 \text{ m/s})(5.0 \times 10^{-5} \text{ T}) = \boxed{9.3 \times 10^{-6} \text{ N}}$$

71. The magnetic force must be equal in magnitude to the weight of the electron.

$$mg = qvB \rightarrow v = \frac{mg}{qB} = \frac{(9.11 \times 10^{-31} \text{ kg})(9.80 \text{ m/s}^2)}{(1.60 \times 10^{-19} \text{ C})(0.50 \times 10^{-4} \text{ T})} = \boxed{1.1 \times 10^{-6} \text{ m/s}}$$

The magnetic force must point upwards, and so by the right hand rule and the negative charge of the electron, the electron must be moving west.

- 72.** (a) The velocity of the ions is found using energy conservation. The electrical potential energy of the ions becomes kinetic energy as they are accelerated. Then, assuming the ions move perpendicularly to the magnetic field, the magnetic force will be a maximum. That force will cause the ion to move in a circular path.

$$\text{PE}_{\text{initial}} = \text{KE}_{\text{final}} \rightarrow qV = \frac{1}{2}mv^2 \rightarrow v = \sqrt{\frac{2qV}{m}} \quad qvB = \frac{mv^2}{r} \rightarrow$$

$$r = \frac{mv}{qB} = \frac{m\sqrt{\frac{2qV}{m}}}{qB} = \sqrt{\frac{2mV}{qB^2}} = \sqrt{\frac{2(6.6 \times 10^{-27} \text{ kg})(2400 \text{ V})}{2(1.60 \times 10^{-19} \text{ C})(0.240 \text{ T})^2}} = 4.146 \times 10^{-2} \text{ m} \approx \boxed{4.1 \times 10^{-2} \text{ m}}$$

(b) The period is the circumference of the circular path divided by the speed.

$$T = \frac{2\pi r}{v} = \frac{2\pi\sqrt{\frac{2mV}{qB^2}}}{\sqrt{\frac{2qV}{m}}} = \frac{2\pi m}{qB} = \frac{2\pi(6.6 \times 10^{-27} \text{ kg})}{2(1.60 \times 10^{-19} \text{ C})(0.240 \text{ T})} = \boxed{5.5 \times 10^{-7} \text{ s}}$$

73. The accelerating force on the bar is due to the magnetic force on the current. If the current is constant, the magnetic force will be constant, and so constant acceleration kinematics can be used.

$$v^2 = v_0^2 + 2a\Delta x \rightarrow a = \frac{v^2 - 0}{2\Delta x} = \frac{v^2}{2\Delta x}$$

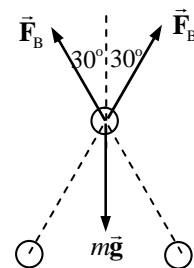
$$F_{\text{net}} = ma = ILB \rightarrow I = \frac{ma}{LB} = \frac{m\left(\frac{v^2}{2\Delta x}\right)}{LB} = \frac{mv^2}{2\Delta x LB} = \frac{(1.5 \times 10^{-3} \text{ kg})(28 \text{ m/s})^2}{2(1.0 \text{ m})(0.22 \text{ m})(1.7 \text{ T})} = \boxed{1.6 \text{ A}}$$

Using the right hand rule, for the force on the bar to be in the direction of the acceleration shown in Fig. 20-65, the magnetic field must be **down**.

74. Each of the bottom wires will repel the top wire since each bottom current is opposite to the top current. The repelling forces will be along the line directly from the bottom wires to the top wires. Only the vertical components of those forces will be counteracting gravity. Use Eq. 20-7 to calculate the magnetic forces. The mass of the wire is its density times its volume. The length of the wire is represented by L .

$$mg = 2F_B \cos 30^\circ \rightarrow \rho_{\text{Cu}} L \pi \left(\frac{1}{2} d_{\text{Cu}}\right)^2 g = 2 \frac{\mu_0 I_{\text{bottom}} I_{\text{Cu}}}{2\pi d} L \cos 30^\circ \rightarrow$$

$$I_{\text{Cu}} = \frac{\rho_{\text{Cu}} \pi^2 \left(\frac{1}{2} d_{\text{Cu}}\right)^2 dg}{\mu_0 I_{\text{bottom}}} = \frac{(8900 \text{ kg/m}^3) \pi^2 (5.0 \times 10^{-4} \text{ m})^2 (0.038 \text{ m})(9.80 \text{ m/s}^2)}{(4\pi \times 10^{-7} \text{ T}\cdot\text{m/A})(95 \text{ A})(\cos 30^\circ)} = \boxed{79 \text{ A}}$$



75. (a) There will be one force on the rod, due to the magnetic force on the charge carriers in the rod. That force is of magnitude $F_B = ILB$, and by Newton's 2nd law is equal to the mass of the rod times its acceleration. That force is constant, so the acceleration will be constant, and constant acceleration kinematics can be used.

$$F_{\text{net}} = F_B = ILB = ma \rightarrow a = \frac{ILB}{m} = \frac{v - v_0}{t} = \frac{v}{t} \rightarrow v = \boxed{\frac{ILB}{m} t}$$

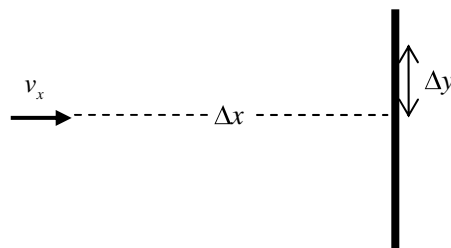
(b) Now the net force is the vector sum of the magnetic force and the force of kinetic friction.

$$F_{\text{net}} = F_B - F_{\text{fr}} = ILB - \mu_k F_N = ILB - \mu_k mg = ma \rightarrow$$

$$a = \frac{ILB}{m} - \mu_k g = \frac{v - v_0}{t} = \frac{v}{t} \rightarrow v = \boxed{\left(\frac{ILB}{m} - \mu_k g\right) t}$$

(c) Using the right hand rule, we find that the force on the rod is to the east, and the rod moves **east**.

76. The speed of the electrons is found by assuming the energy supplied by the accelerating voltage becomes kinetic energy of the electrons. We assume that those electrons are initially directed horizontally, and that the television set is oriented so that the electron velocity is perpendicular to the Earth's magnetic field, resulting in the largest possible force. Finally, we assume that the magnetic force on the electrons is small enough that the electron velocity is essentially perpendicular to the Earth's field for the entire trajectory. This results in a constant acceleration for the electrons.



(a) Acceleration:

$$PE_{\text{initial}} = KE_{\text{final}} \rightarrow eV = \frac{1}{2}mv_x^2 \rightarrow v_x = \sqrt{\frac{2eV}{m}}$$

Deflection:

$$\text{time in field: } \Delta x_{\text{field}} = v_x t_{\text{field}} \rightarrow t_{\text{field}} = \frac{\Delta x_{\text{field}}}{v_x}$$

$$F_y = qv_x B_{\text{Earth}} = ma_y \rightarrow a_y = \frac{qv_x B_{\text{Earth}}}{m} = \frac{e\sqrt{\frac{2eV}{m}} B_{\text{Earth}}}{m} = \sqrt{\frac{2e^3 V}{m^3}} B_{\text{Earth}}$$

$$\begin{aligned} \Delta y &= \frac{1}{2} a_y t^2 = \frac{1}{2} \sqrt{\frac{2e^3 V}{m^3}} B_{\text{Earth}} \left(\frac{\Delta x_{\text{field}}}{v_x} \right)^2 = \frac{1}{2} \sqrt{\frac{2e^3 V}{m^3}} B_{\text{Earth}} (\Delta x)^2 \frac{m}{2eV} \\ &= \sqrt{\frac{e}{8mV}} B_{\text{Earth}} (\Delta x)^2 = \sqrt{\frac{1.60 \times 10^{-19} \text{ C}}{8(9.11 \times 10^{-31} \text{ kg})(2000 \text{ V})}} (0.5 \times 10^{-4} \text{ T})(0.22 \text{ m})^2 \\ &= 8.02 \times 10^{-3} \text{ m} \approx \boxed{8 \text{ mm}} \end{aligned}$$

$$\begin{aligned} (b) \quad \Delta y &= \sqrt{\frac{e}{8mV}} B_{\text{Earth}} (\Delta x)^2 = \sqrt{\frac{1.60 \times 10^{-19} \text{ C}}{8(9.11 \times 10^{-31} \text{ kg})(30,000 \text{ V})}} (0.5 \times 10^{-4} \text{ T})(0.22 \text{ m})^2 \\ &= 2.07 \times 10^{-3} \text{ m} \approx \boxed{2 \text{ mm}} \end{aligned}$$

Note that the deflection is significantly smaller than the horizontal distance traveled, and so the assumptions made above are verified.

77. (a) The frequency of the voltage must match the frequency of circular motion of the particles, so that the electric field is synchronized with the circular motion. The radius of each circular orbit is given in Example 20-5 as $r = \frac{mv}{qB}$. For an object moving in circular motion, the period is

given by $T = \frac{2\pi r}{v}$, and the frequency is the reciprocal of the period.

$$T = \frac{2\pi r}{v} \rightarrow f = \frac{v}{2\pi r} = \frac{v}{2\pi \frac{mv}{qB}} = \boxed{\frac{Bq}{2\pi m}}$$

In particular we note that this frequency is independent of the radius, and so the same frequency can be used throughout the acceleration.

- (b) For a small gap, the electric field across the gap will be approximately constant and uniform as the particles cross the gap. If the motion and the voltage are synchronized so that the maximum voltage occurs when the particles are at the gap, the particles receive an energy increase of $\text{KE} = qV_0$ as they pass each gap. The energy gain from one revolution will include the passing of 2 gaps, so the total KE increase is $\boxed{2qV_0}$.

- (c) The maximum kinetic energy will occur at the outside of the cyclotron.

$$v = \frac{rqB}{m}$$

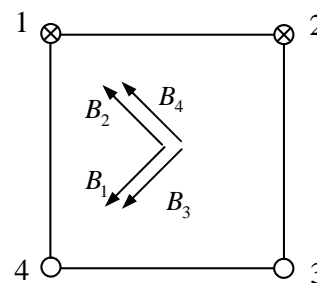
$$\begin{aligned} \text{KE}_{\text{max}} &= \frac{1}{2}mv_{\text{max}}^2 = \frac{1}{2}m\left(\frac{r_{\text{max}}qB}{m}\right)^2 = \frac{1}{2}\frac{r_{\text{max}}^2q^2B^2}{m} = \frac{1}{2}\frac{(2.0\text{m})^2(1.60\times 10^{-19}\text{C})^2(0.50\text{T})^2}{1.67\times 10^{-27}\text{kg}} \\ &= 7.66\times 10^{-12}\text{J}\left(\frac{1\text{eV}}{1.60\times 10^{-19}\text{J}}\right)\left(\frac{1\text{MeV}}{10^6\text{eV}}\right) = \boxed{48\text{MeV}} \end{aligned}$$

78. Each individual wire would cause a magnetic field given by Eq. 20-6 with the appropriate distance. The four individual magnetic fields are shown in the diagram. Note that all four magnitudes are the same.

Also $\vec{B}_1 = \vec{B}_3$ and $\vec{B}_2 = \vec{B}_4$, but in the diagram they are shown as slightly displaced from each other. The vertical components all cancel, and so the net magnetic field is 4 times the horizontal component of one of the individual fields.

$$B_1 = B_2 = B_3 = B_4 = \frac{\mu_0 I}{2\pi r} = \frac{\mu_0 I}{2\pi l/\sqrt{2}}$$

$$B_{\text{net}} = 4\left(\frac{\mu_0 I}{2\pi l/\sqrt{2}}\right)\cos 45^\circ = 4\left(\frac{\mu_0 I}{2\pi l/\sqrt{2}}\right)\frac{\sqrt{2}}{2} = \boxed{\frac{2\mu_0 I}{\pi l}, \text{ left}}$$



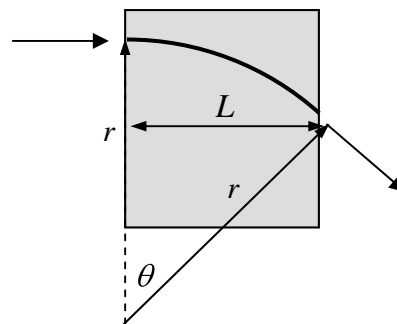
79. The protons will follow a circular path as they move through the region of magnetic field, with a radius of curvature given in

Example 20-5 as $r = \frac{mv}{qB}$. Fast-moving protons will have a

radius of curvature that is too large and so they will exit above the second tube. Likewise, slow-moving protons will have a radius of curvature that is too small and so they will exit below the second tube. Since the exit velocity is perpendicular to the radius line from the center of curvature, the bending angle can be calculated.

$$\sin \theta = \frac{L}{r} \rightarrow$$

$$\theta = \sin^{-1} \frac{L}{r} = \sin^{-1} \frac{LqB}{mv} = \sin^{-1} \frac{(5.0\times 10^{-2}\text{m})(1.60\times 10^{-19}\text{C})(0.33\text{T})}{(1.67\times 10^{-27}\text{kg})(1.0\times 10^7\text{m/s})} = \sin^{-1} 0.158 = \boxed{9.1^\circ}$$



80. (a) The electromagnet must dissipate 4.0 kW of power if the power supply is to supply that power. Use that power with the voltage across the electromagnet to find the resistance of the electromagnet. Then calculate how much copper wire is needed to provide that resistance. The copper wire is a square of side length d , and the copper wire has length L .

$$P = \frac{V^2}{R} \rightarrow R = \frac{V^2}{P} \quad R = \rho_{\text{Cu}} \frac{L}{A} = \rho_{\text{Cu}} \frac{L}{d^2} \quad N = \frac{L}{2\pi r}$$

$$N = \frac{L}{2\pi r} = \frac{\frac{Rd^2}{\rho_{\text{Cu}}}}{2\pi r} = \frac{Rd^2}{2\pi r \rho_{\text{Cu}}} = \frac{V^2 d^2}{2\pi r \rho_{\text{Cu}} P} = \frac{(120 \text{ V})^2 (1.6 \times 10^{-3} \text{ m})^2}{2\pi (0.6 \text{ m})(1.68 \times 10^{-7} \Omega \cdot \text{m})(4.0 \times 10^3 \text{ W})}$$

$$= \boxed{14.6 \text{ turns}}$$

- (b) To calculate the magnetic field at the center of the coil, the current must be known, and it can be found from the power and the voltage since $P = IV$.

$$B = \frac{\mu_0 NI}{2r} = \frac{\mu_0 NP}{2rV} = \frac{(4\pi \times 10^{-7} \text{ T} \cdot \text{m/A})(14.6)(4.0 \times 10^3 \text{ W})}{2(0.6 \text{ m})(120 \text{ V})} = \boxed{5.1 \times 10^{-4} \text{ T}}$$

- (c) It would appear from $B = \frac{\mu_0 NI}{2r}$ that an increase in N would increase B , but the increase in N must arise from a longer wire, which has more resistance, and so the current is lower. We need to express B in terms of the number of turns alone.

$$B = \frac{\mu_0 NI}{2r} = \frac{\mu_0 N \frac{V}{R}}{2r} = \frac{\mu_0 N}{2rR} = \frac{\mu_0}{2rR} \frac{Rd^2}{2\pi r \rho_{\text{Cu}}} = \frac{\mu_0 d^2}{4\pi r^2 \rho_{\text{Cu}}} = \text{constant}$$

The magnetic field will remain constant.

81. From problem 80, with one turn of wire, we have $B = \frac{\mu_0 I}{2r}$. Use the radius of the Earth for r .

$$B = \frac{\mu_0 I}{2r} \rightarrow I = \frac{2rB}{\mu_0} = \frac{2(6.38 \times 10^6 \text{ m})(1 \times 10^{-4} \text{ T})}{4\pi \times 10^{-7} \text{ T} \cdot \text{m/A}} = \boxed{1 \times 10^9 \text{ A}}$$

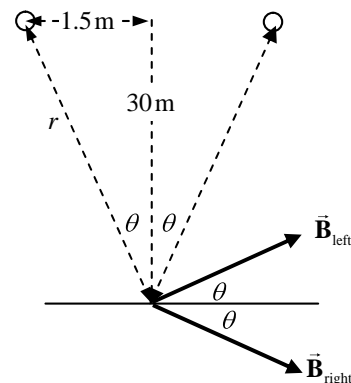
82. From Eq. 18-9(a) we calculate the rms current, given the power and the rms voltage, assuming that each wire provides half the power.

$$P = V_{\text{rms}} I_{\text{rms}} \rightarrow I_{\text{rms}} = \frac{P}{V_{\text{rms}}} \rightarrow$$

$$I_{\text{max}} = \frac{\sqrt{2}P}{V_{\text{rms}}} = \frac{\sqrt{2}(20 \times 10^6 \text{ W})}{10 \times 10^3 \text{ V}} = 2830 \text{ A}$$

From the geometry of the problem, we can calculate the magnetic field that is expected. Note that the drawing is NOT to scale.

$$r = \sqrt{(30 \text{ m})^2 + (1.5 \text{ m})^2} = 30.04 \text{ m} \quad \theta = \tan^{-1} \frac{1.5}{30} = 2.86^\circ$$



$$\begin{aligned}
 B_{\text{net}} &= B_{\text{left},x} + B_{\text{right},x} = 2 \frac{\mu_0 I}{2\pi r} \cos \theta \\
 &= 2 \frac{(4\pi \times 10^{-7} \text{ T}\cdot\text{m/A})}{2\pi} \frac{2830 \text{ A}}{30.04 \text{ m}} \cos 2.86^\circ \approx \boxed{4 \times 10^{-5} \text{ T}}
 \end{aligned}$$

This is comparable in magnitude to the Earth's field.

83. (a) For the beam of electrons to be undeflected, the magnitude of the magnetic force must equal the magnitude of the electric force. We assume that the magnetic field will be perpendicular to the velocity of the electrons so that the maximum magnetic force is obtained.

$$F_B = F_E \rightarrow qvB = qE \rightarrow B = \frac{E}{v} = \frac{10,000 \text{ V/m}}{4.8 \times 10^6 \text{ m/s}} = 2.083 \times 10^{-3} \text{ T} \approx \boxed{2.1 \times 10^{-3} \text{ T}}$$

- (b) Since the electric field is pointing up, the electric force is down. Thus the magnetic force must be up. Using the right hand rule with the negative electrons, the magnetic field must be out of the plane of the plane formed by the electron velocity and the electric field.
- (c) If the electric field is turned off, then the magnetic field will cause a centripetal force, moving the electrons in a circular path. The frequency is the reciprocal of the period of the motion.

$$\begin{aligned}
 qvB &= \frac{mv^2}{r} \rightarrow v = \frac{qBr}{m} \\
 f &= \frac{1}{T} = \frac{v}{2\pi r} = \frac{qBr}{2\pi r m} = \frac{qB}{2\pi m} = \frac{qE}{2\pi mv} = \frac{(1.60 \times 10^{-19} \text{ C})(10,000 \text{ V/m})}{2\pi(9.11 \times 10^{-31} \text{ kg})(4.8 \times 10^6 \text{ m/s})} = \boxed{5.8 \times 10^7 \text{ Hz}}
 \end{aligned}$$

84. The speed of the proton can be calculated based on the radius of curvature of the (almost) circular motion. From that the kinetic energy can be calculated.

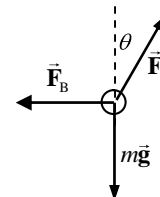
$$\begin{aligned}
 qvB &= \frac{mv^2}{r} \rightarrow v = \frac{qBr}{m} \quad \text{KE} = \frac{1}{2}mv^2 = \frac{1}{2}m \left(\frac{qBr}{m} \right)^2 = \frac{q^2 B^2 r^2}{2m} \\
 \Delta \text{KE} &= \frac{q^2 B^2}{2m} (r_2^2 - r_1^2) = \frac{(1.60 \times 10^{-19} \text{ C})^2 (0.010 \text{ T})^2}{2(1.67 \times 10^{-27} \text{ kg})} \left[(8.5 \times 10^{-3} \text{ m})^2 - (10.0 \times 10^{-3} \text{ m})^2 \right] \\
 &= \boxed{-2.1 \times 10^{-20} \text{ J}} \text{ or } -0.13 \text{ eV}
 \end{aligned}$$

85. The field inside a solenoid is given by Eq. 20-8.

$$B = \mu_0 IN/l \rightarrow N = \frac{Bl}{\mu_0 I} = \frac{(0.30 \text{ T})(0.32 \text{ m})}{(4\pi \times 10^{-7} \text{ T}\cdot\text{m/A})(5.7 \text{ A})} = \boxed{1.3 \times 10^4 \text{ turns}}$$

86. There are three forces on each wire – its weight, the magnetic force of repulsion from the other wire, and the tension in the attached string. See the diagram. The magnetic force is given by Eq. 20-7. The mass of the wire is its density times its volume. The length of the wire is represented by L . The net force in both the vertical and horizontal directions is zero.

$$F_B = F_T \sin \theta \quad F_T \cos \theta = mg \rightarrow F_T = \frac{mg}{\cos \theta} \rightarrow$$



$$F_B = \frac{mg}{\cos \theta} \sin \theta = mg \tan \theta = \rho_{\text{Al}} \pi r_{\text{Al}}^2 L g \tan \theta$$

$$F_B = \frac{\mu_0 I^2}{2\pi S} L \rightarrow \frac{\mu_0 I^2}{2\pi S} L = \rho_{\text{Al}} \pi r_{\text{Al}}^2 L g \tan \theta \rightarrow$$

$$I = \sqrt{\frac{2\pi S \rho_{\text{Al}} \pi r_{\text{Al}}^2 g \tan \theta}{\mu_0}} = \sqrt{\frac{2\pi [2(0.50 \text{ m}) \sin 3^\circ] (2700 \text{ kg/m}^3) \pi (2.5 \times 10^{-4} \text{ m})^2 (9.8 \text{ m/s}^2) \tan 3^\circ}{(4\pi \times 10^{-7} \text{ T}\cdot\text{m/A})}}$$

$$= \boxed{8.4 \text{ A}}$$

87. The centripetal force is caused by the magnetic field, and is given by Eq. 20-3.

$$F = qvB \sin \theta = qv_{\perp} B = m \frac{v_{\perp}^2}{r} \rightarrow$$

$$r = \frac{mv_{\perp}}{qB} = \frac{(9.11 \times 10^{-31} \text{ kg})(3.0 \times 10^6 \text{ m/s}) \sin 45^\circ}{(1.60 \times 10^{-19} \text{ C})(0.23 \text{ T})} = 5.251 \times 10^{-5} \text{ m} \approx \boxed{5.3 \times 10^{-5} \text{ m}}$$

The component of the velocity that is parallel to the magnetic field is unchanged, and so the pitch is that velocity component times the period of the circular motion.

$$T = \frac{2\pi r}{v_{\perp}} = \frac{2\pi \frac{mv_{\perp}}{qB}}{v_{\perp}} = \frac{2\pi m}{qB}$$

$$p = v_{\parallel} T = v \cos 45^\circ \left(\frac{2\pi m}{qB} \right) = (3.0 \times 10^6 \text{ m/s}) \cos 45^\circ \frac{2\pi (9.11 \times 10^{-31} \text{ kg})}{(1.60 \times 10^{-19} \text{ C})(0.23 \text{ T})} = \boxed{3.3 \times 10^{-4} \text{ m}}$$