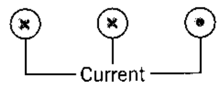
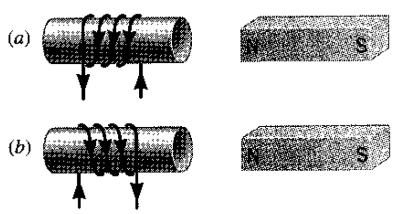
current in the circuit causes the light bulb to glow. Does the bulb glow continually, glow briefly and then go out, or repeatedly turn on and off like a turn signal on a car? Explain.

**14.** In Figure 21.28, assume that the current $I_1$ is larger than the current $I_2$. In parts *a* and *b*, decide whether there are places where the total magnetic field is zero. State whether they are located to the left of both wires, between the wires, or to the right of both wires. Give your reasoning.

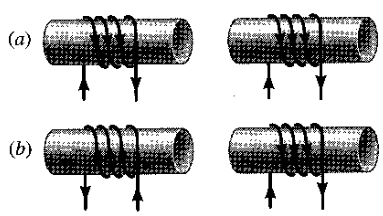
**15.** The drawing shows an end-on view of three parallel wires that are perpendicular to the plane of the paper. In two of the wires the current is directed into the paper, while in the remaining wire the current is directed out of the paper. The two outermost wires are held rigidly in place. Which way will the middle wire move? Explain.




**16.** For each electromagnet at the left of the drawing, explain whether it will be attracted to or repelled from the permanent magnet at the right.

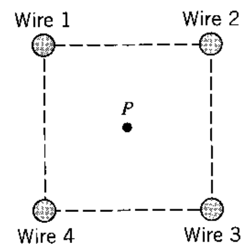



**17.** For each electromagnet at the left of the drawing, explain whether it will be attracted to or repelled from the adjacent electromagnet at the right.




**18.** Refer to Figure 21.5. If the earth's magnetism is assumed to originate from a large circular loop of current within the earth, how is the plane of this current loop oriented relative to the magnetic axis, and what is the direction of the current around the loop?

**19.** There are four wires viewed end-on in the drawing. They are long, straight, and perpendicular to the plane of the paper. Their cross sections lie at the corners of a square. Currents of the same magnitude are in each of these wires. Choose the direction of the current for each wire, so that when any single current is turned off, the total magnetic field at point *P* (the center of the square) is directed toward a corner of the square. Account for your answer.




**20.** Suppose you have two bars, one of which is a permanent magnet and the other of which is not a magnet, but is made from a ferromagnetic material like iron. The two bars look exactly alike. (a) Using a third bar, which is known to be a magnet, how can you determine which of the look-alike bars is the permanent magnet and which is not? (b) Can you determine the identities of the look-alike bars with the aid of a third bar that is not a magnet, but is made from a ferromagnetic material? Give reasons for your answers.

**21.** In a TV commercial that advertises a soda pop, a strong electromagnet picks up a delivery truck carrying cans of the soft drink. The picture switches to the interior of the truck, where cans are seen to fly upward and stick to the roof just beneath the electromagnet. Are these cans made entirely of aluminum? Justify your answer.

# PROBLEMS

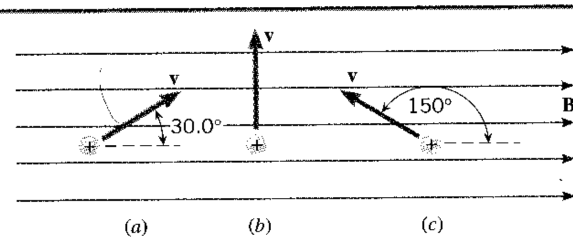
**ssm** Solution is in the Student Solutions Manual. **www** Solution is available on the World Wide Web at http://www.wiley.com/college/cutnell

**This icon represents a biomedical application.**

## Section 21.1 Magnetic Fields, Section 21.2 The Force That a Magnetic Field Exerts on a Moving Charge

**1. ssm** A charge of 12 $\mu$C, traveling with a speed of $9.0 \times 10^6$ m/s in a direction perpendicular to a magnetic field, experiences a magnetic force of $8.7 \times 10^{-3}$ N. What is the magnitude of the field?

**2.** A particle with a charge of +8.4 $\mu$C and a speed of 45 m/s enters a uniform magnetic field whose magnitude is 0.30 T. For each of the cases in the drawing, find the magnitude and direction of the magnetic force on the particle.




**3.** A charge $q_1 = 25.0$ $\mu$C moves with a speed of $4.50 \times 10^3$ m/s perpendicular to a uniform magnetic field. The charge experiences a magnetic force of $7.31 \times 10^{-3}$ N. A second charge

$q_2 = 5.00\ \mu C$ travels at an angle of 40.0° with respect to the same magnetic field and experiences a $1.90 \times 10^{-3}$-N force. Determine (a) the magnitude of the magnetic field and (b) the speed of $q_2$.

**4.** Two charged particles move in the same direction with respect to the same magnetic field. Particle 1 travels three times faster than particle 2. However, each particle experiences a magnetic force of the same magnitude. Find the ratio $q_1/q_2$ of the magnitudes of the charges.

**5.** **ssm** At a certain location, the horizontal component of the earth's magnetic field is $2.5 \times 10^{-5}$ T, due north. A proton moves eastward with just the right speed, so the magnetic force on it balances its weight. Find the speed of the proton.

**6.** When a charged particle moves at an angle of 25° with respect to a magnetic field, it experiences a magnetic force of magnitude $F$. At what angle (less than 90°) with respect to this field will this particle, moving at the same speed, experience a magnetic force of magnitude $2F$?

**7.** An electron is moving through a magnetic field whose magnitude is $8.70 \times 10^{-4}$ T. The electron experiences only a magnetic force and has an acceleration of magnitude $3.50 \times 10^{14}\ m/s^2$. At a certain instant, it has a speed of $6.80 \times 10^6$ m/s. Determine the angle $\theta$ (less than 90°) between the electron's velocity and the magnetic field.

***8.** There is a 0.200-T magnetic field directed along the $+x$ axis and a field of unknown magnitude along the $+y$ axis. A particle carrying a charge of $6.50 \times 10^{-5}$ C experiences a maximum force of 0.455 N when traveling at a speed of $2.00 \times 10^4$ m/s through the region where the fields are. Find the magnitude of the unknown field.

***9.** **ssm www** The electrons in the beam of a television tube have a kinetic energy of $2.40 \times 10^{-15}$ J. Initially, the electrons move horizontally from west to east. The vertical component of the earth's magnetic field points down, toward the surface of the earth, and has a magnitude of $2.00 \times 10^{-5}$ T. (a) In what direction are the electrons deflected by this field component? (b) What is the acceleration of an electron in part (a)?

### Section 21.3 The Motion of a Charged Particle in a Magnetic Field, Section 21.4 The Mass Spectrometer

**10.** An electron moves at a speed of $6.0 \times 10^6$ m/s perpendicular to a constant magnetic field. The path is a circle of radius $1.3 \times 10^{-3}$ m. (a) Draw a sketch showing the magnetic field and the electron's path. (b) What is the magnitude of the field? (c) Find the magnitude of the electron's acceleration.

**11.** An ionized helium atom has a mass of $6.6 \times 10^{-27}$ kg and a speed of $4.4 \times 10^5$ m/s. The atom moves perpendicular to a 0.75-T magnetic field on a circular path of radius 0.012 m. Determine whether the charge of the ionized helium atom is $+e$ or $+2e$.

**12.** A magnetic field has a magnitude of $1.2 \times 10^{-3}$ T, and an electric field has a magnitude of $4.6 \times 10^3$ N/C. Both fields point in the same direction. A positive 1.8-$\mu C$ charge moves at a speed of $3.1 \times 10^6$ m/s in a direction that is perpendicular to both fields. Determine the magnitude of the net force that acts on the charge.

**13.** **ssm** A beam of protons moves in a circle of radius 0.25 m. The protons move perpendicular to a 0.30-T magnetic field. (a) What is the speed of each proton? (b) Determine the magnitude of the centripetal force that acts on each proton.

**14.** The solar wind is a thin, hot gas given off by the sun. Charged particles in this gas enter the magnetic field of the earth and can experience a magnetic force. Suppose a charged particle traveling with a speed of $9.0 \times 10^6$ m/s encounters the earth's magnetic field at an altitude where the field has a magnitude of $1.2 \times 10^{-7}$ T. Assuming that the particle's velocity is perpendicular to the magnetic field, find the radius of the circular path on which the particle would move if it were (a) an electron and (b) a proton.

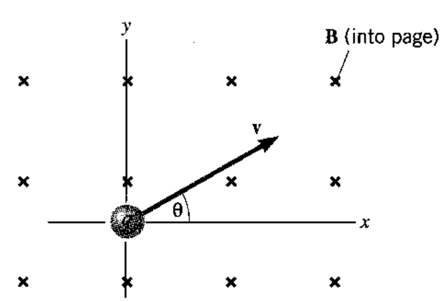
**15.** **ssm www** A charged particle with a charge-to-mass ratio of $q/m = 5.7 \times 10^8$ C/kg travels on a circular path that is perpendicular to a magnetic field whose magnitude is 0.72 T. How much time does it take for the particle to complete one revolution?

**16.** Review Conceptual Example 2 before attempting this problem. Derive an expression for the magnitude $v$ of the velocity "selected" by the velocity selector. This expression should give $v$ in terms of the strengths $E$ and $B$ of the electric and magnetic fields, respectively.

**17.** Suppose that an ion source in a mass spectrometer produces *doubly* ionized gold ions ($Au^{2+}$), each with a mass of $3.27 \times 10^{-25}$ kg. The ions are accelerated from rest through a potential difference of 1.00 kV. Then, a 0.500-T magnetic field causes the ions to follow a circular path. Determine the radius of the path.

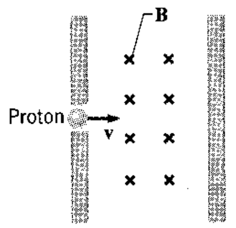
***18.** The ion source in a mass spectrometer produces both singly and doubly ionized species, $X^+$ and $X^{2+}$. The difference in mass between these species is too small to be detected. Both species are accelerated through the same electric potential difference, and both experience the same magnetic field, which causes them to move on circular paths. The radius of the path for the species $X^+$ is $r_1$, while the radius for species $X^{2+}$ is $r_2$. Find the ratio $r_1/r_2$ of the radii.

***19.** **ssm** A particle of charge $+7.3\ \mu C$ and mass $3.8 \times 10^{-8}$ kg is traveling perpendicular to a 1.6-T magnetic field, as the drawing shows. The speed of the particle is 44 m/s. (a) What is the value of the angle $\theta$, such that the particle's subsequent path will intersect the $y$ axis at the greatest possible value of $y$? (b) Determine this value of $y$.



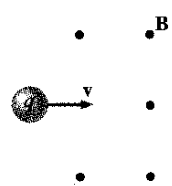
*20. Review Conceptual Example 2 as background for this problem. A charged particle moves through a velocity selector at a constant speed in a straight line. The electric field of the velocity selector is $3.80 \times 10^3$ N/C, while the magnetic field is 0.360 T. When the electric field is turned off, the charged particle travels on a circular path whose radius is 4.30 cm. Find the charge-to-mass ratio of the particle.

*21. A proton with a speed of $2.2 \times 10^6$ m/s is shot into a region between two plates that are separated by a distance of 0.18 m. As the drawing shows, a magnetic field exists between the plates, and it is perpendicular to the velocity of the proton. What must be the magnitude of the magnetic field, so the proton just misses colliding with the opposite plate?




*22. As preparation for this problem, review Conceptual Example 4. The radius of the track for particle 3 (kinetic energy = $KE_3$) is exactly 22 times larger than the initial radius of the track for particle 1 (initial kinetic energy = $KE_1$). Determine the ratio $KE_3/KE_1$.

*23. **ssm** Review Conceptual Example 2 as an aid in understanding this problem. The drawing shows a positively charged particle entering a 0.52-T magnetic field. The particle has a speed of 270 m/s and moves perpendicular to the magnetic field. Just as the particle enters the magnetic field, an electric field is turned on. What must be the magnitude and direction of the electric field such that the *net* force on the particle is twice the magnetic force?




*24. An $\alpha$-particle is the nucleus of a helium atom; the orbiting electrons are missing. The $\alpha$-particle contains two protons and two neutrons, and has a mass of $6.64 \times 10^{-27}$ kg. Suppose an $\alpha$-particle is accelerated from rest through a potential difference and then enters a region where its velocity is perpendicular to a 0.0210-T magnetic field. With what angular speed $\omega$ does the $\alpha$-particle move on its circular path?

**25. Refer to question 11 (not problem 11) before starting this problem. Suppose that the target discussed there is located at the coordinates $x = -0.10$ m and $y = -0.10$ m. In addition, suppose that the particle is a proton and the magnetic field has a magnitude of 0.010 T. The speed at which the particle is projected is the same for either of the two paths leading to the target. Find the speed.

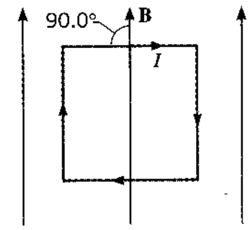
### Section 21.5 The Force on a Current in a Magnetic Field

26. A wire carries a current of 0.66 A. This wire makes an angle of 58° with respect to a magnetic field of magnitude $4.7 \times 10^{-5}$ T. The wire experiences a magnetic force of magnitude $7.1 \times 10^{-5}$ N. What is the length of the wire?

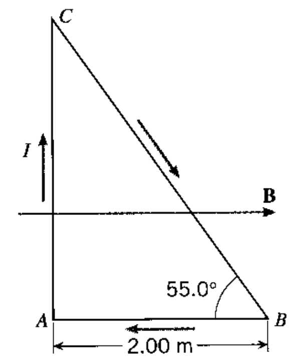
27. **ssm** An electric power line carries a current of 1400 A in a location where the earth's magnetic field is $5.0 \times 10^{-5}$ T. The line makes an angle of 75° with respect to the field. Determine the magnitude of the magnetic force on a 120-m length of line.

28. A straight wire in a magnetic field experiences a force of 0.030 N when the current in the wire is 2.7 A. What is the current in the wire when it experiences a force of 0.047 N?

29. A square coil of wire containing a single turn is placed in a uniform 0.25-T magnetic field, as the drawing shows. Each side has a length of 0.32 m, and the current in the coil is 12 A. Determine the magnitude of the magnetic force on each of the four sides.



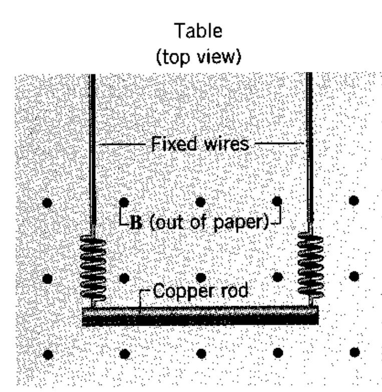

30. The triangular loop of wire shown in the drawing carries a current of $I = 4.70$ A. A uniform magnetic field is directed parallel to side $AB$ of the triangle and has a magnitude of 1.80 T. (a) Find the magnitude and direction of the magnetic force exerted on each side of the triangle. (b) Determine the magnitude of the net force exerted on the triangle.



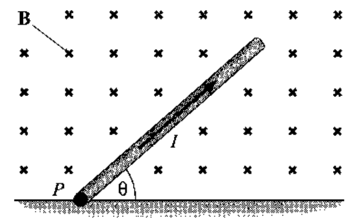

31. **ssm** A wire of length 0.655 m carries a current of 21.0 A. In the presence of a 0.470-T magnetic field, the wire experiences a force of 5.46 N. What is the angle (less than 90°) between the wire and the magnetic field?

32. The $x$, $y$, and $z$ components of a magnetic field are $B_x = 0.10$ T, $B_y = 0.15$ T, and $B_z = 0.17$ T. A 25-cm wire is oriented along the $z$ axis and carries a current of 4.3 A. What is the magnitude of the magnetic force that acts on this wire?

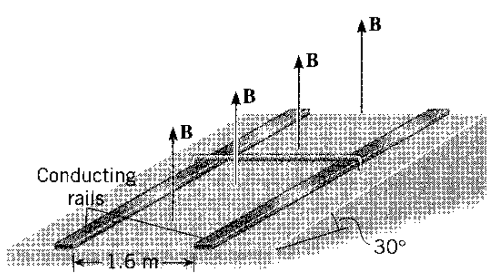
*33. **ssm** A copper rod of length 0.85 m is lying on a frictionless table (see the drawing). Each end of the rod is attached to a fixed wire by an unstretched spring whose spring constant is $k = 75$ N/m. A magnetic field with a strength of 0.16 T is oriented perpendicular to the surface of the table. (a) What must be the direction of the current in the copper rod that causes the springs to stretch? (b) If the current is 12 A, by how much does each spring stretch?



*34. The drawing shows a thin, uniform rod, which has a length of 0.40 m and a mass of 0.080 kg. This rod lies in the plane of the paper and is attached to the floor by a hinge at point *P*. A uniform magnetic field of 0.31 T is directed perpendicularly into the plane of the paper. There is a current $I = 3.8$ A in the rod, which does not rotate clockwise or counterclockwise. Find the angle $\theta$. *(Hint: The magnetic force may be taken to act at the center of gravity.)*




**35. The two conducting rails in the drawing are tilted upward so they each make an angle of 30.0° with respect to the ground. The vertical magnetic field has a magnitude of 0.050 T. The 0.20-kg aluminum rod (length = 1.6 m) slides *without friction* down the rails at a constant velocity. How much current flows through the bar?




## Section 21.6 The Torque on a Current-Carrying Coil

36. A 0.50-m length of wire is formed into a single-turn, square loop in which there is a current of 12 A. The loop is placed in a magnetic field of 0.12 T, as in Figure 21.22*a*. What is the maximum torque that the loop can experience?

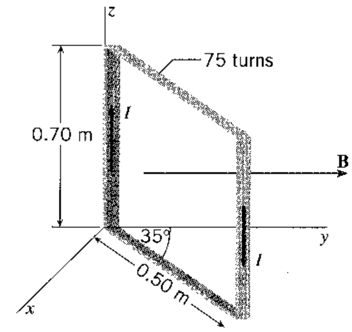
37. **ssm** A circular coil of wire has a radius of 0.10 m. The coil has 50 turns and a current of 15 A, and is placed in a magnetic field whose magnitude is 0.20 T. (a) Determine the magnetic moment of the coil. (b) What is the maximum torque the coil can experience in this field?

38. Two coils have the same number of circular turns and carry the same current. Each rotates in a magnetic field as in Figure 21.21. Coil 1 has a radius of 5.0 cm and rotates in a 0.18-T field. Coil 2 rotates in a 0.42-T field. Each coil experiences the same maximum torque. What is the radius (in cm) of coil 2?

39. Suppose the current-carrying triangle in problem 30 is free to rotate about an axis that is attached along side *AC*. Using the data in that problem, find (a) the magnetic moment of the triangle and (b) the magnitude of the net torque exerted on it by the magnetic field.

40. A coil carries a current and experiences a torque due to a magnetic field. The value of the torque is 80.0% of the maximum possible torque. (a) What is the smallest angle between the magnetic field and the normal to the plane of the coil? (b) Make a drawing, showing how this coil would be oriented relative to the magnetic field. Be sure to include the angle in the drawing.

41. **ssm www** The rectangular loop in the drawing consists of 75 turns and carries a current of $I = 4.4$ A. A 1.8-T magnetic field is directed along the $+y$ axis. The loop is free to rotate about the $z$ axis. (a) Determine the magnitude of the net torque exerted on the loop and (b) state whether the 35° angle will increase or decrease.




42. The maximum torque experienced by a coil in a 0.75-T magnetic field is $8.4 \times 10^{-4}$ N·m. The coil is circular and consists of only one turn. The current in the coil is 3.7 A. What is the length of the wire from which the coil is made?

*43. The coil in Figure 21.22*a* contains 380 turns and has an area per turn of $2.5 \times 10^{-3}$ m$^2$. The magnetic field is 0.12 T, and the current in the coil is 0.16 A. A brake shoe is pressed perpendicularly against the shaft to keep the coil from turning. The coefficient of static friction between the shaft and the brake shoe is 0.70. The radius of the shaft is 0.010 m. What is the magnitude of the minimum normal force that the brake shoe exerts on the shaft?

*44. A square coil and a rectangular coil are each made from the same length of wire. Each contains a single turn. The long sides of the rectangle are twice as long as the short sides. Find the ratio $\tau_{square}/\tau_{rectangle}$ of the maximum torques that these coils experience in the same magnetic field when they contain the same current.

**45. **ssm** In the model of the hydrogen atom due to Niels Bohr, the electron moves around the proton at a speed of $2.2 \times 10^6$ m/s in a circle of radius $5.3 \times 10^{-11}$ m. Considering the orbiting electron to be a small current loop, determine the magnetic moment associated with this motion. *(Hint: The electron travels around the circle in a time equal to the period of the motion.)*

## Section 21.7 Magnetic Fields Produced by Currents

46. A long, straight wire carries a current of 48 A. The magnetic field produced by this current at a certain point is $8.0 \times 10^{-5}$ T. How far is the point from the wire?

47. In a lightning bolt, 15 C of charge flows in a time of $1.5 \times 10^{-3}$ s. Assuming that the lightning bolt can be represented as a long, straight line of current, what is the magnitude of the magnetic field at a distance of 25 m from the bolt?

48. What must be the radius of a circular loop of wire so the magnetic field at its center is $1.8 \times 10^{-4}$ T when the loop carries a current of 12 A?

49. **ssm** A long solenoid consists of 1400 turns of wire and has a length of 0.65 m. There is a current of 4.7 A in the wire. What is the magnitude of the magnetic field within the solenoid?

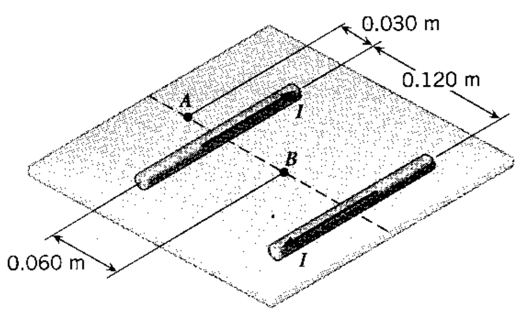
50. Suppose in Figure 21.28*a* that $I_1 = I_2 = 25$ A and that the separation between the wires is 0.016 m. By applying an external

magnetic field (created by a source other than the wires) it is possible to cancel the mutual repulsion of the wires. This external field must point along the vertical direction. (a) Does the external field point up or down? Explain. (b) What is the magnitude of the external field?

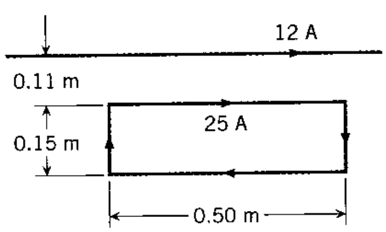
**51.** **ssm** Two rigid rods are oriented parallel to each other and to the ground. The rods carry the same current in the same direction. The length of each rod is 0.85 m, while the mass of each is 0.073 kg. One rod is held in place above the ground, and the other floats beneath it at a distance of $8.2 \times 10^{-3}$ m. Determine the current in the rods.

**52.** Two circular loops of wire, each containing a single turn, have the same radius of 4.0 cm and a common center. The planes of the loops are perpendicular. Each carries a current of 1.7 A. What is the magnitude of the net magnetic field at the common center?

**53.** Two long, straight wires are separated by 0.120 m. The wires carry currents of 8.0 A in opposite directions, as the drawing indicates. Find the magnitude of the net magnetic field at the points labeled (a) $A$ and (b) $B$.




***54.** As background for this problem, review Conceptual Example 9. A rectangular current loop is located near a long, straight wire that carries a current of 12 A (see the drawing). The current in the loop is 25 A. Determine the magnitude of the net magnetic force that acts on the loop.

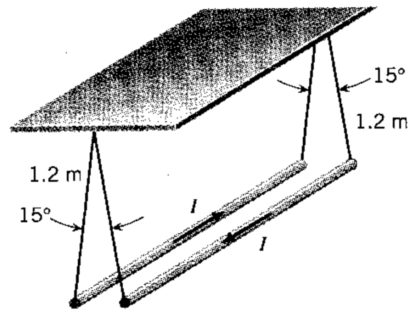



***55.** Two circular coils are concentric and lie in the same plane. The inner coil contains 120 turns of wire, has a radius of 0.012 m, and carries a current of 6.0 A. The outer coil contains 150 turns and has a radius of 0.017 m. What must be the magnitude and direction (relative to the current in the inner coil) of the current in the outer coil, such that the net magnetic field at the common center of the two coils is zero?

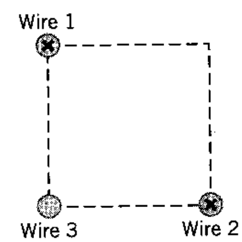
***56.** Two parallel rods are each 0.50 m in length. They are attached at their centers to a spring that is initially neither stretched nor compressed. The spring has a spring constant of 150 N/m. When 950 A of current is in each rod in the same direction, the spring is observed to be compressed by 2.0 cm. Treat the rods as long, straight wires and find the separation between them when the current is present.

***57.** **ssm** A piece of copper wire has a resistance per unit length of $5.90 \times 10^{-3}$ Ω/m. The wire is wound into a thin, flat coil of many turns that has a radius of 0.140 m. The ends of the wire are connected to a 12.0-V battery. Find the magnetic field strength at the center of the coil.

****58.** The drawing shows two long, straight wires that are suspended from a ceiling. The mass per unit length of each wire is 0.050 kg/m. Each of the four strings suspending the wires has a length of 1.2 m. When the wires carry identical currents in opposite directions, the angle between the strings holding the two wires is 15°. What is the current in each wire?




****59.** The drawing shows an end-on view of three wires. They are long, straight, and perpendicular to the plane of the paper. Their cross sections lie at the corners of a square. The currents in wires 1 and 2 are $I_1 = I_2 = I$ and are directed into the paper. What is the direction of the current in wire 3, and what is the ratio $I_3/I$, such that the net magnetic field at the empty corner is zero?




### Section 21.8 Ampere's Law

**60.** Suppose a uniform magnetic field is everywhere perpendicular to this page. The field points directly upward toward you. A circular path is drawn on the page. Use Ampere's law to show that there can be no net current passing through the circular surface.

**61.** **ssm** The wire in Figure 21.40 carries a current of 12 A. Suppose that a second long, straight wire is placed right next to this wire. The current in the second wire is 28 A. Use Ampere's law to find the magnitude of the magnetic field at a distance of $r = 0.72$ m from the wires when the currents are (a) in the same direction and (b) in opposite directions.

***62.** A very long, hollow cylinder is formed by rolling up a thin sheet of copper. Electric charges flow along the copper sheet parallel to the axis of the cylinder. The arrangement is, in effect, a hollow tube of current $I$. Use Ampere's law to show that the magnetic field (a) is $\mu_0 I/(2\pi r)$ outside the cylinder at a distance $r$ from the axis and (b) is zero at any point within the hollow interior of the cylinder. *(Hint: For closed paths, use* *circles perpendicular to and centered on the axis of the cylinder.)*

****63.** A long, cylindrical conductor is solid throughout and has a radius $R$. Electric charges flow parallel to the axis of the cylinder and pass uniformly through the entire cross section. The arrangement is, in effect, a solid tube of current $I_0$. The current per unit cross-sectional area (i.e., the current density) is $I_0/(\pi R^2)$. Use Ampere's law to show that the magnetic field inside the conductor at a distance $r$ from the axis is $\mu_0 I_0 r/(2\pi R^2)$. *(Hint: For a closed path, use a circle of radius r perpendicular to and centered on the axis. Note that the current through any surface is the area of the surface times the current density.)*

## ADDITIONAL PROBLEMS

**64.** In a television set, electrons are accelerated from rest through a potential difference of 19 kV. The electrons then pass through a 0.28-T magnetic field that deflects them to the appropriate spot on the screen. Find the magnitude of the maximum magnetic force that an electron can experience.

**65. ssm** A long solenoid has 1400 turns per meter of length, and it carries a current of 3.5 A. A small circular coil of wire is placed inside the solenoid with the normal to the coil oriented at an angle of 90.0° with respect to the axis of the solenoid. The coil consists of 50 turns, has an area of $1.2 \times 10^{-3}$ m$^2$, and carries a current of 0.50 A. Find the torque exerted on the coil.

**66.** A proton, traveling with a velocity of $4.5 \times 10^6$ m/s due east, experiences a maximum magnetic force of $8.0 \times 10^{-14}$ N due south. (a) What are the magnitude and direction of the magnetic field? (b) Answer part (a), assuming the proton is replaced by an electron.

**67.** The proton has an intrinsic magnetic moment of $1.4 \times 10^{-26}$ A · m$^2$. If the magnetic moment makes an angle of $\phi = 64°$ with respect to a 0.65-T magnetic field, what is the torque exerted on the proton?

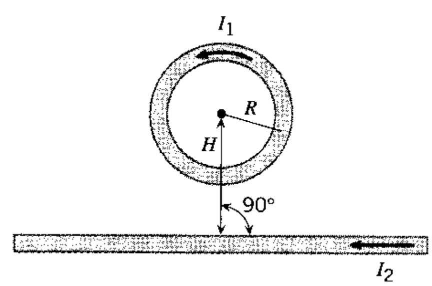
**68.** A long, straight wire carrying a current of 305 A is placed in a uniform magnetic field whose magnitude is $7.00 \times 10^{-3}$ T. The wire is perpendicular to the field. Find a point in space where the net magnetic field is zero. Locate this point by specifying its perpendicular distance from the wire.

**69. ssm** Due to friction with the air, an airplane has acquired a net charge of $1.70 \times 10^{-5}$ C. The plane moves with a speed of $2.80 \times 10^2$ m/s at an angle $\theta$ with respect to the earth's magnetic field, the magnitude of which is $5.00 \times 10^{-5}$ T. The magnetic force on the airplane has a magnitude of $2.30 \times 10^{-7}$ N. Find the angle $\theta$. (There are two possible angles.)

**70.** Near the equator in South America the earth's magnetic field has a strength of $3.2 \times 10^{-5}$ T; the field is parallel to the surface of the earth and points due north. A straight wire, 46 m in length, has an east-west orientation and experiences a magnetic force of 0.058 N, directed vertically down (toward the earth). What is the magnitude and direction of the current in the wire?

**71.** An ion source in a mass spectrometer produces deuterons. (A deuteron is a particle that has approximately twice the mass of a proton but the same charge.) Each deuteron is accelerated from rest through a potential difference of $2.00 \times 10^3$ V, after which it enters a 0.600-T magnetic field. Find the radius of its circular path.

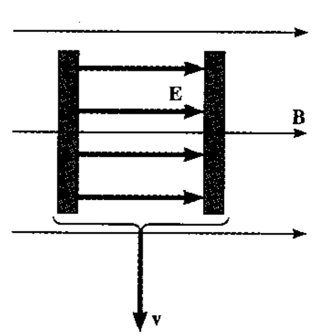
**72.** A circular loop of wire and a long, straight wire carry currents of $I_1$ and $I_2$ (see the drawing), where $I_2 = 6.6I_1$. The loop and the straight wire lie in the same plane. The net magnetic field at the center of the loop is zero. Find the distance $H$, expressing your answer in terms of $R$, the radius of the loop.



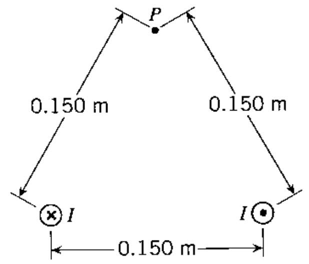

***73. ssm www** A particle of mass $6.0 \times 10^{-8}$ kg and charge $+7.2$ $\mu$C is traveling due east. It enters perpendicularly a magnetic field whose magnitude is 3.0 T. After entering the field, the particle completes one-half of a circle and exits the field traveling due west. How much time does the particle spend in the magnetic field?

***74.** Two long, straight, parallel wires $A$ and $B$ are separated by a distance of one meter. They carry currents in opposite directions, and the current in wire $A$ is one-third of that in wire $B$. On a line drawn perpendicular to the wires, find the point where the net magnetic field is zero. Determine this point relative to wire $A$.

***75.** The drawing shows a parallel plate capacitor that is moving with a speed of 32 m/s through a 3.6-T magnetic field. The velocity **v** is perpendicular to the magnetic field. The electric field within the capacitor has a value of 170 N/C, and each plate has an area of $7.5 \times 10^{-4}$ m$^2$. What is the magnetic force (magnitude and direction) exerted on the positive plate of the capacitor?



**76. The drawing shows two wires that carry the same current of $I = 85.0$ A and are oriented perpendicular to the plane of the paper. The current in one wire is directed out of the paper, while the current in the other is directed into the paper. Find the magnitude and direction of the net magnetic field at point $P$.




**77. **ssm** A charge of $4.0 \times 10^{-6}$ C is placed on a small conducting sphere that is located at the end of a thin insulating rod whose length is 0.20 m. The rod rotates with an angular speed of $\omega = 150$ rad/s about an axis that passes perpendicularly through its other end. Find the magnetic moment of the rotating charge. *(Hint: The charge travels around a circle in a time equal to the period of the motion.)*

## CONCEPTS & CALCULATIONS

### GROUP LEARNING PROBLEMS

*Note: Each of these problems consists of Concept Questions followed by a related quantitative Problem. They are designed for use by students working alone or in small learning groups. The Concept Questions involve little or no mathematics and are intended to stimulate group discussions. They focus on the concepts with which the problems deal. Recognizing the concepts is the essential initial step in any problem-solving technique.*

**78. Concept Questions** (a) A charge moves along the $+x$ axis and experiences no magnetic force, although there is a magnetic field. What can you conclude about the direction of the magnetic field? (b) A moving charge experiences the maximum possible magnetic force when moving in a magnetic field. What can you conclude about the angle $\theta$ that the charge's velocity makes with respect to the magnetic field? Explain your answers.

**Problem** A particle that has a 8.2-$\mu$C charge moves with a velocity of magnitude $5.0 \times 10^5$ m/s. When the velocity points along the $+x$ axis, the particle experiences no magnetic force, although there is a magnetic field present. The maximum possible magnetic force that the charge could experience has a magnitude of 0.48 N. Find the magnitude and direction of the magnetic field. Note that there are two possible answers for the direction of the field. Make sure that your answers are consistent with your answers to the Concept Questions.

**79. Concept Questions** (a) A proton is projected perpendicularly into a magnetic field with a certain velocity and follows a circular path. Then an electron is projected perpendicularly into the same magnetic field with the same velocity. Does the electron follow the exact same circular path that the proton followed? (b) To make the electron follow the exact same circular path, should the field direction be kept the same or reversed, and (c) should the field magnitude be increased, reduced, or kept the same? Account for your answers.

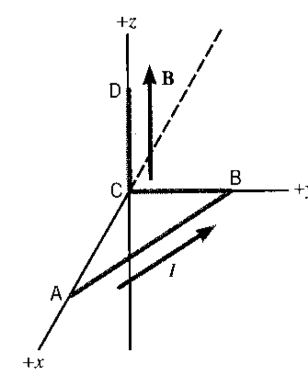
**Problem** A proton is projected perpendicularly into a magnetic field that has a magnitude of 0.50 T. The field is then adjusted so that an electron will follow the exact same circular path when it is projected perpendicularly into the field with the same velocity that the proton had. What is the magnitude of the field used for the electron? Verify that your answer is consistent with your answers to the Concept Questions.

**80. Concept Questions** Particle 1 and particle 2 carry the same charge $q$, but particle 1 has a smaller mass than particle 2. These two particles accelerate from rest through the same electric potential difference $V$ and enter the same magnetic field, which has a magnitude $B$. The particles travel perpendicular to the field on circular paths. Upon entering the field region, which particle, if either, has the greater (a) kinetic energy and (b) speed? Give your reasoning.

**Problem** The masses of the particles are $m_1 = 2.3 \times 10^{-8}$ kg and $m_2 = 5.9 \times 10^{-8}$ kg. The radius of the circular path for particle 1 is $r_1 = 12$ cm. What is the radius of the circular path for particle 2?

**81. Concept Question** The drawing shows a wire comprised of three segments, AB, BC, and CD. There is a current $I$ in the wire. There is also a magnetic field **B** that is the same everywhere and points in the direction of the $+z$ axis. Rank the wire segments according to the magnetic force (largest first) that they experience. Justify your ranking.

**Problem** The lengths of the wire segments are $L_{AB} = 1.1$ m, $L_{BC} = 0.55$ m, and $L_{CD} = 0.55$ m. The current is $I = 2.8$ A, and the magnitude of the magnetic field is $B = 0.26$ T. Find the magnitude of the force that acts on each segment. Be sure your answers are consistent with your answer to the Concept Question.




**82. Concept Question** You have a wire of length $L$ from which to make the square coil of a dc motor. In a given magnetic field a coil of $N$ turns each with area $A$ produces more torque when its total effective area of $NA$ is greater rather than smaller. This follows directly from Equation 21.4. Is more torque obtained by using the length of wire to make a single-turn coil or a two-turn coil? Explain.

**Problem** The length of the wire is $L = 1.00$ m. The current in the coil is $I = 1.7$ A, and the magnetic field of the motor is 0.34 T. Find the maximum torque when the wire is used to make a single-turn square coil and a two-turn square coil. Verify that your answers are consistent with your answer to the Concept Question.

**83. Concept Questions** The drawing shows two perpendicular, long, straight wires that lie in the plane of the paper. Each wire carries the same current $I$. What is the direction of the net magnetic field at (a) point $A$ and (b) point $B$? (c) Is the magnitude of the net field at point $A$ greater than, less than, or equal to the magnitude of the net field at point $B$?

**Problem** The current in each of the wires is $I = 5.6$ A. Find the magnitudes of the net fields at points $A$ and $B$. Verify that your answers are consistent with your answers to the Concept Questions.