Q10 An iron bar magnet makes a pattern of magnetic field that looks just like the pattern of magnetic field outside a long current-carrying coil of wire. Are there currents in the iron? Explain briefly.

Q11 Suppose you have two alnico bar magnets, one with a mass of 100 g and one with a mass of a kg. At a distance of a meter from the center of either one, how would the magnetic field differ? Why?

Q12 Conventional current flows in a ring in the direction indicated in Figure 17.74. If you stand at location A, on the $+x$ axis, and look toward the ring, current flows clockwise. At each of the locations labeled by a letter, find the direction of the magnetic field at that location due to the current in the ring.

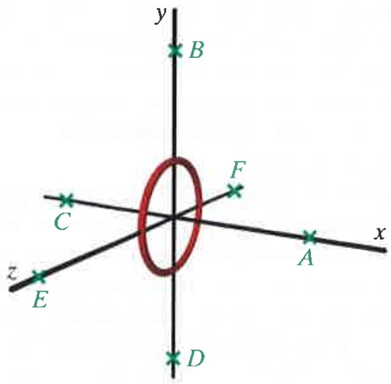

Figure 17.74

Q13 **(a)** How can you produce a magnetic field that is nearly uniform in a region? **(b)** How can you produce a magnetic field that falls off like $1/r$? **(c)** How can you produce a magnetic field that falls off like $1/r^2$? (Note that you *cannot* use just a short piece of current-carrying wire, because the other parts of the wire also contribute.) **(d)** How can you produce a magnetic field that falls off like $1/r^3$?

Q14 What is the direction of the magnetic field at the indicated locations inside and outside this current-carrying rectangular coil of wire in Figure 17.75? Explain briefly. (The direction of conventional current is shown.)

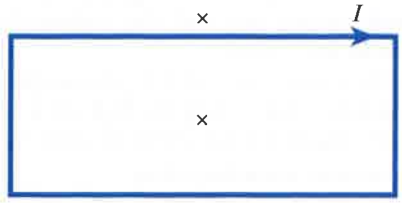

Figure 17.75

PROBLEMS

Section 17.3

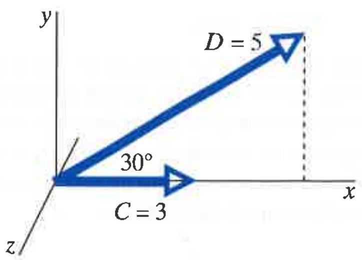

Figure 17.76

•P15 A vector $\vec{C}$ of magnitude 3 lies along the x axis, and a vector $\vec{D}$ of magnitude 5 lies in the xy plane, 30° from the x axis (Figure 17.76). What are the magnitude and direction of the cross product $\vec{C} \times \vec{D}$? What are the magnitude and direction of the cross product $\vec{D} \times \vec{C}$? Draw both vectors on a diagram.

•P16 If $\vec{v} = \langle 390, -480, 333 \rangle$ m/s and $\hat{r} = \langle 0.577, 0.577, -0.577 \rangle$ what is $\vec{v} \times \hat{r}$?

•P17 What is $\langle 2, 0, -5 \rangle \times \langle -5, 3, 5 \rangle$?

•P18 To get an idea of the size of magnetic fields at the atomic level, consider the magnitude of the magnetic field due to the electron in the simple Bohr model of the hydrogen atom. In the ground state the Bohr model predicts that the electron speed would be 2.2×10^6 m/s, and the distance from the proton would be 0.5×10^{-10} m. What is B at the location of the proton?

•P19 An electron is moving horizontally to the right with speed 4×10^6 m/s (Figure 17.77). Each of the indicated locations is 5 cm from the electron. What is the magnetic field due to this moving electron at the indicated locations? Give both magnitude and direction of the magnetic field at each location.

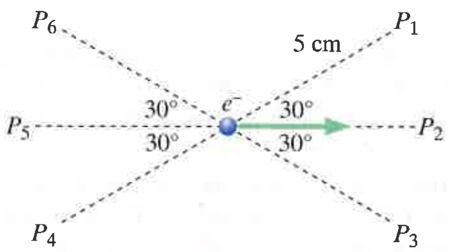

Figure 17.77

•P20 At a particular instant, a proton at the origin has velocity $\langle 2 \times 10^4, -2 \times 10^4, 0 \rangle$ m/s. You need to calculate the magnetic field at location $\langle 0.02, 0.06, 0 \rangle$ m due to the moving proton. **(a)** What is $\vec{r}$? **(b)** What is $\hat{r}$? **(c)** What is $\vec{v} \times \hat{r}$? **(d)** What is the magnetic field at the observation location due to the moving proton?

•**P21** In Figure 17.78 a proton is moving upward with speed 5×10^6 m/s. What is the magnetic field due to this moving proton at the indicated locations? Each location is a distance $r = 8$ cm from the proton. Give both magnitude and direction of the magnetic field at each location.

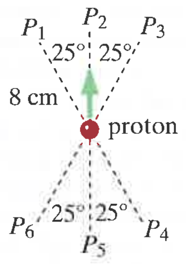

Figure 17.78

••**P22** At a particular instant a proton is at the origin, moving with velocity $\langle 3 \times 10^4, -2 \times 10^4, -7 \times 10^4 \rangle$ m/s. **(a)** At this instant, what is the electric field at location $\langle 4 \times 10^{-3}, 4 \times 10^{-3}, 3 \times 10^{-3} \rangle$ m, due to the proton? **(b)** At this instant, what is the magnetic field at the same location due to the proton?

••**P23** The electron in Figure 17.79 is traveling with a speed of 3×10^6 m/s.

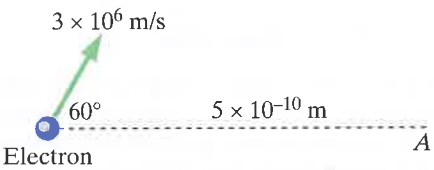

Figure 17.79

(a) At location A, what are the directions of the electric and magnetic fields contributed by the electron? **(b)** Calculate the magnitudes of the electric and magnetic fields at location A.

Section 17.6

•**P24** The electron current in a horizontal metal wire is 3.7×10^{18} electrons/s, and the electrons are moving to the right. What are the magnitude and direction of the conventional current?

•**P25** A conventional current of 12 A runs to the right in a horizontal metal wire. **(a)** How many electrons pass some point in the wire per second? **(b)** In what direction are the electrons moving? **(c)** The electron mobility in this metal is 2.1×10^{-4} (m/s)/(N/C) and the electric field in the wire is 0.15 N/C. What is the average drift speed of the electrons?

•**P26** You have used copper wires in your circuits. Let's calculate the mobile electron density n for copper. A mole of copper has a mass of 64 g (0.064 kg), and one mobile electron is released by each atom in metallic copper. The density of copper is about 9 g/cm^3, or 9×10^3 kg/m^3. Show that the number of mobile electrons per cubic meter in copper is 8.4×10^{28} m^{-3}.

•**P27** Calculate the mobile electron density for nickel. A mole of nickel has a mass of 59 g (0.059 kg), and one mobile electron is released by each atom in metallic nickel. The density of nickel is about 8.8 g/cm^3, or 8.8×10^3 kg/m^3.

Section 17.7

•**P28** In a circuit consisting of a long bulb and two flashlight batteries in series the conventional current is about 0.1 A. What is the magnetic field 5 mm from the wire? (This is about how far away the compass needle is when you place the wire on top of the compass.) Is this a big or a small field?

•**P29** A current-carrying wire oriented north–south and laid over a compass deflects the compass 10° to the east. **(a)** What is the magnitude of the magnetic field made by the current? The horizontal component of Earth's magnetic field is about 2×10^{-5} T. **(b)** In what direction does the electron current flow in the wire?

•**P30** A straight wire of length 0.62 m carries a conventional current of 0.8 A. What is the magnitude of the magnetic field made by the current at a location that is a perpendicular distance 2.9 cm from the center of the wire? Use both the exact equation and the approximate equation to calculate the field.

•**P31** A long straight wire carries a conventional current of 0.9 A. What is the approximate magnitude of the magnetic field at a location a perpendicular distance of 0.035 m from the wire due to the current in the wire?

•**P32** A battery is connected to a Nichrome wire and a conventional current of 0.3 A runs through the wire. The wire is laid out in the form of a rectangle 50 cm by 3 cm. **(a)** What is the approximate magnetic field at the center of the rectangle? Give the direction as well as the magnitude. **(b)** What approximations did you make?

•**P33** A wire through which a current is flowing lies along the x axis in Figure 17.80. Connecting wires that are not shown in the diagram connect the ends of the wire to batteries (which are also not shown). Electron current flows through the wire in the $-x$ direction, as indicated in the figure. To calculate the magnetic field at location A due to the current in the wire, we divide the wire into pieces, approximate each piece as a point charge moving in the direction of conventional current, and calculate the magnetic field at the observation location due only to this piece; then add the contributions of all pieces to get the net magnetic field.

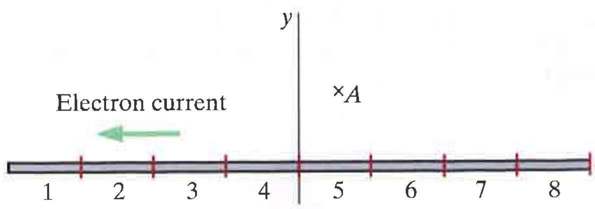

Figure 17.80

The wire is 1.3 m long, and is divided into eight pieces. The observation location A is located at $\langle 0.081, 0.178, 0 \rangle$ m. The conventional current running through the wire is 6.5 A. In this exercise you will calculate the magnetic field at the observation location due only to segment 4 of the wire. **(a)** What is the direction of conventional current in this wire? **(b)** How long is segment 4? **(c)** What is the magnitude of the vector $\Delta\vec{l}$ for segment 4? **(d)** What is the vector $\Delta\vec{l}$ for segment 4? **(e)** What is the location of the center of segment 4? **(f)** What is the vector $\vec{r}$ from source to observation location for segment 4? **(g)** What is the unit vector $\hat{r}$? **(h)** What is $\Delta\vec{l} \times \hat{r}$? **(i)** Calculate the magnetic field $\Delta\vec{B}$ at the observation location due only to the current in segment 4 of the wire.

••**P34** You place a long straight wire on top of your compass, and the wire is a height of 5 mm above the compass needle

(Figure 17.81). If the conventional current in the wire is $I = 0.2$ A and runs left to right as shown, calculate the approximate angle the needle deflects away from north and draw the position of the compass needle.

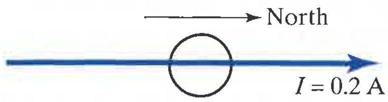

Figure 17.81

••P35 When you bring a current-carrying wire down onto the top of a compass, aligned with the original direction of the needle and 5 mm above the needle, the needle deflects by 10° (Figure 17.82).

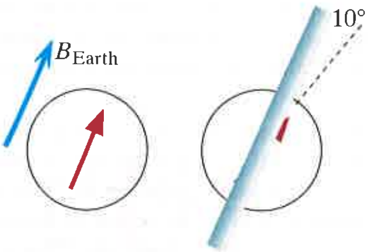

Figure 17.82

(a) Show on a diagram the direction of conventional current in the wire and the direction of the additional magnetic field made by the wire underneath the wire, where the compass needle is located. Explain briefly. **(b)** Calculate the amount of current flowing in the wire. The measurement was made at a location where the horizontal component of the Earth's magnetic field is $B_{Earth} \approx 2 \times 10^{-5}$ T.

••P36 A compass is placed inside a triangular coil of wire with three turns, as shown in Figure 17.83. Each side of the triangle has a length L. The compass is a perpendicular distance d from the center of each side of the triangle. The coil is in the xy plane; magnetic north (due to the Earth) is in the negative x direction. Conventional current runs in the coil as shown (clockwise, as viewed from a location on the $+z$ axis).

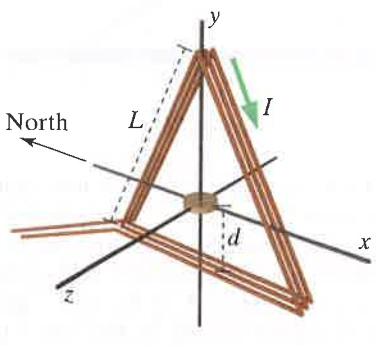

Figure 17.83

(a) While current is running through the coil, in what direction does the compass needle point? **(b)** Which of the following statements about how to model the coil are reasonable? List all that apply. (1) Since the coil is made from a single wire, we could model one turn of the coil as one long wire. (2) A circular loop is a poor model for one turn of the coil, because the distance from the wire to the compass varies so much. (3) One turn of the coil could be modeled as three short straight wires. **(c)** A current of 0.62 A runs through the wires. If $L = 8.3$ cm and $d = 2.4$ cm, what is the magnitude of the magnetic field at the location of the compass due to the coil? (Remember that the coil has three turns.) **(d)** What is the approximate magnitude of the compass deflection in degrees?

••P37 A thin wire is part of a complete electrical circuit that carries a current I. For this problem consider only the piece of wire of length d as shown in Figure 17.84. Answer the following questions based on this figure. **(a)** What are the magnitude and direction of the magnetic field due to the wire at Q (location $\langle -w,0,0\rangle$)? **(b)** Set up the integrals necessary to determine the x, y, and z components of the magnetic field at P (location $\langle -w,h,0\rangle$). The integrals must be in a form that can be evaluated (no cross products in the integrand), but you do not need to evaluate them. **(c)** What is the direction of the magnetic field at location P?

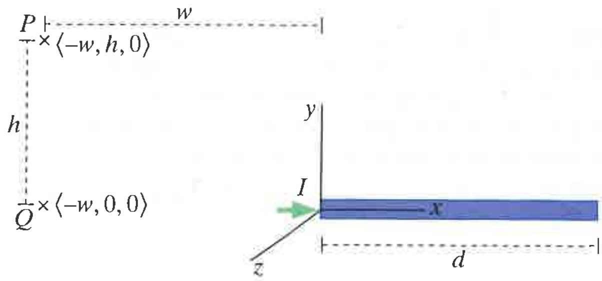

Figure 17.84

••P38 In Figure 17.85 a long current-carrying wire, oriented north–south, lies on a table (it is connected to batteries that are not shown). A compass lies on top of the wire, with the compass needle about 3 mm above the wire. With the current running, the compass deflects 11° to the west. At this location, the horizontal component of the Earth's magnetic field is about 2×10^{-5} T.

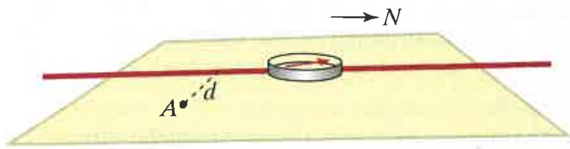

Figure 17.85

(a) What is the magnitude of the magnetic field at location A, on the tabletop, a distance 2.8 cm to the east of the wire, due only to the current in the wire? **(b)** What is the direction of the magnetic field at location A, due only to the current in the wire?

••P39 In Figure 17.86 a wire is connected to batteries (not shown) and current flows through the wire. The wire lies flat on a table, and you are looking down on it from above. The wire is laid on top of a compass, resting about 3 mm above the needle. The distance d between the straight wires is 4.5 cm. The compass needle deflects 17° from north, as shown. At this location the horizontal component of the Earth's magnetic field is 2×10^{-5} T.

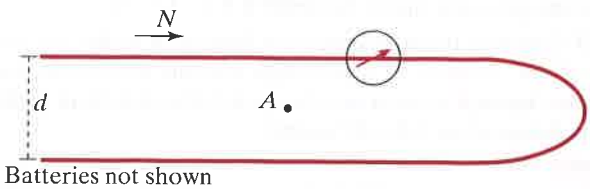

Figure 17.86

(a) What is the direction of the magnetic field at location A, midway between the straight wires, due to the current in the wire? (b) What is the approximate magnitude of the magnetic field at location A, due to the current in the wire? (c) What approximations or assumptions did you make in determining the magnetic field at location A?

••P40 At one time, concern was raised about the possible health effects of the small alternating (60-Hz) magnetic fields created by electric currents in houses and near power lines. In a house, most wires carry a maximum of 15 A (there are 15-A fuses that melt and break the circuit if this current is exceeded). The two wires in a home power cord are about 3 mm apart as shown in Figure 17.87, and at any instant they carry currents in opposite directions (both of which change direction 60 times per second).

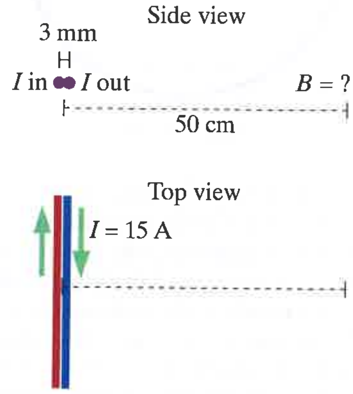

Figure 17.87

(a) Calculate the maximum magnitude of the alternating magnetic field, 50 cm away from the center of a long straight power cord that carries a current of 15 A. Both wires are at the same height as the observation location. (b) Explain briefly why twisting the pair of wires into a braid as shown in Figure 17.88 greatly decreases the magnetic field at the location discussed in (a), a generally useful technique.

Figure 17.88

(c) Optional: For two long parallel wires like those shown in part (a), a distance d apart and carrying conventional current I in opposite directions, find an *algebraic* equation for the magnetic field a perpendicular distance $r \gg d$ to the right of the wires.

(The magnitude of the field that you calculated in part (a) is very small compared to the Earth's magnetic field, but there were questions as to whether a very small alternating magnetic field might have health effects. After many detailed studies, the consensus of most scientists now seems to be that these small alternating magnetic fields are not a hazard after all.)

Section 17.8

•P41 **(a)** A loop of wire carries a conventional current of 0.8 A. The radius of the loop is 0.09 m. Calculate the magnitude of the magnetic field at a distance of 0.32 m from the center of the loop, along the axis of the loop. **(b)** What would be the magnitude of the magnetic field at the same location if there were 100 loops of wire in a coil instead of one loop?

•P42 A thin circular coil of wire of radius 5 cm consists of 100 turns of wire (Figure 17.89). If the conventional current in the wire is 4 A, what are the magnitude and direction of the magnetic field at the center of the coil? (The direction of conventional current is shown.)

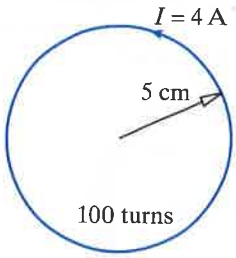

Figure 17.89

•P43 A conventional current of 6 A runs clockwise in a circular loop of wire in the xy plane, with center at the origin and with radius 0.08 m. Another circular loop of wire lies in the same plane, with its center at the origin and with radius 0.02 m. How much conventional current must run counterclockwise in this smaller loop in order for the magnetic field at the origin to be zero?

•P44 How much conventional current must you run in a solenoid with radius = 0.04 m and length = 0.35 m to produce a magnetic field inside the solenoid of 2×10^{-5} T, the approximate field of the Earth? The solenoid has 200 turns.

••P45 In Figure 17.90 two long wires lie very close together and carry a conventional current I as shown and each wire has a semicircular kink, one of radius R_1 and the other of radius R_2. Calculate the magnitude and direction of the magnetic field at the common center of the two semicircular arcs.

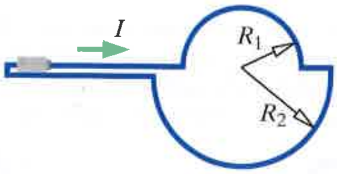

Figure 17.90

••P46 A very long wire carrying a conventional current of 3.5 A is straight except for a circular loop of radius 5.8 cm (Figure 17.91). Calculate the approximate magnitude and the direction of the magnetic field at the center of the loop.

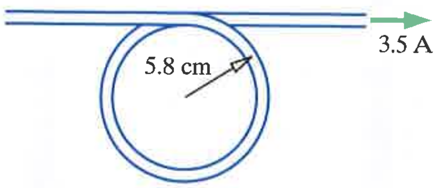

Figure 17.91

••P47 You can use measurements of the magnetic field of a coil to determine how much current your battery is supplying to the coil. Using your value of B (Experiment EXP5), determine the conventional current I through your coil. If this current is less than 3 A, you should replace the battery.

••P48 A thin circular coil of radius $r = 15$ cm contains $N = 3$ turns of Nichrome wire. A small compass is placed at the center of the coil, as shown in Figure 17.92. With the battery disconnected, the compass needle points to the right, in the plane of the coil. Assume that the horizontal component of the Earth's magnetic field is about $B_{\text{Earth}} \approx 2 \times 10^{-5}$ T.

When the battery is connected, a current of 0.25 A runs through the coil. Predict the deflection of the compass needle. If you have to make any approximations, state what they are. Is the deflection outward or inward as seen from above? What is the magnitude of the deflection?

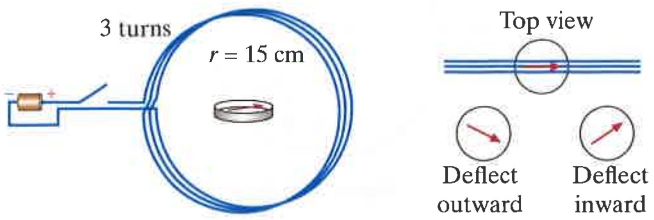

Figure 17.92

••**P49** The circuit in Figure 17.93 consists of a battery and a Nichrome wire, through which runs a current I.

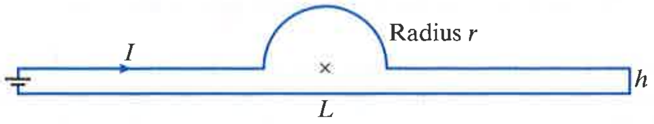

Figure 17.93

(a) At the location marked × (the center of the semicircle), what is the direction of the magnetic field? **(b)** At the location marked × (the center of the semicircle), what is the magnitude of the magnetic field? If you have to make any approximations, state what they are.

••**P50** Two thin coils of radius 3 cm are 20 cm apart and concentric with a common axis (Figure 17.94). Both coils contain 10 turns of wire with a conventional current of 2 A that runs counterclockwise as viewed from the right side.

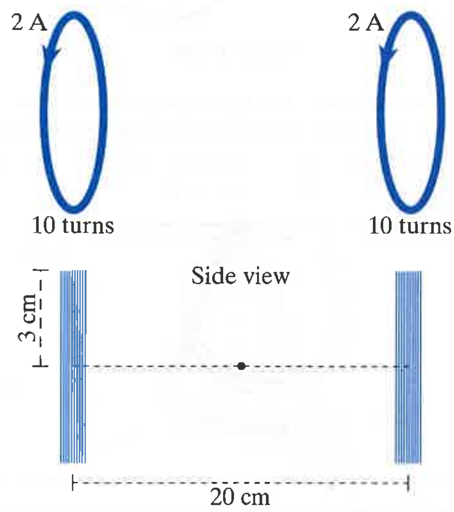

Figure 17.94

(a) What are the magnitude and direction of the magnetic field on the axis, halfway between the two loops, without making the approximation $z \gg r$? (For comparison, remember that the horizontal component of magnetic field in the United States is about 2×10^{-5} T). **(b)** In this situation, the observation location is not very far from either coil. How bad is it to make the $1/z^3$ approximation? That is, what percentage error results if you calculate the magnetic field using the approximate equation for a current loop instead of the exact equation? **(c)** What are the magnitude and direction of the magnetic field midway between the two coils if the current in the right loop is reversed to run clockwise?

••**P51** A conventional current I runs in the direction shown in Figure 17.95. Determine the magnitude and direction of the magnetic field at point C, the center of the circular arcs.

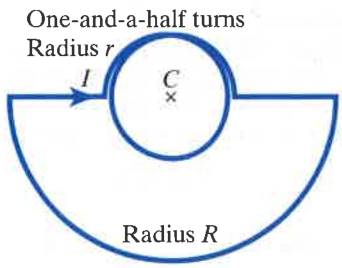

Figure 17.95

••**P52** A square loop of wire with sides of length L and carrying a conventional current I lies in the yz plane with its center at the origin. **(a)** What is the magnitude of the magnetic field due to this loop at a location x on the x axis? **(b)** What is the approximate equation for the magnitude of the magnetic field at a location x that is much greater than L, in terms of the magnetic moment of the loop? **(c)** Is the result of part (b) consistent with our previously derived result for the magnetic field of a magnetic dipole?

Section 17.11

••**P53** A compass originally points north; at this location the horizontal component of the Earth's magnetic field has a magnitude of 2×10^{-5} T. A bar magnet is aligned east–west, pointing at the center of the compass. When the center of the magnet is 0.25 m from the center of the compass, the compass deflects 70°. What is the magnetic dipole moment of the bar magnet?

••**P54** In the region shown in Figure 17.96, the magnitude of the horizontal component of the Earth's magnetic field is about 2×10^{-5} T. Originally a compass placed at location A points north. Then a bar magnet is placed at the location shown in the diagram, with its center 16 cm from location A. With the magnet present, the compass needle points 60° west of north.

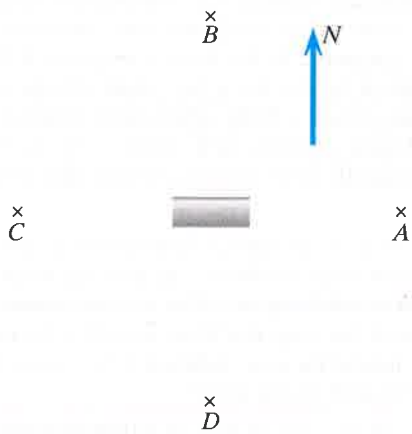

Figure 17.96

(a) Which pole of the magnet is nearer to location A? **(b)** What are the directions of the magnetic field at locations B, C, and D? **(c)** What is the magnetic dipole moment of the bar magnet?

••P55 A bar magnet with magnetic dipole moment $\langle 8,0,0 \rangle$ A·m^2 is located at the origin. A second bar magnet with magnetic dipole moment $\langle \mu,0,0 \rangle$ is located at $\langle 0.4,0.2,0 \rangle$ m. Calculate the value of μ that makes the magnetic field at $\langle 0.4,0,0 \rangle$ m be zero.

••P56 A bar magnet is aligned east–west, with its center 16 cm from the center of a compass (Figure 17.97). The compass is observed to deflect 50° away from north as shown, and the horizontal component of the Earth's magnetic field is known to be 2×10^{-5} T.

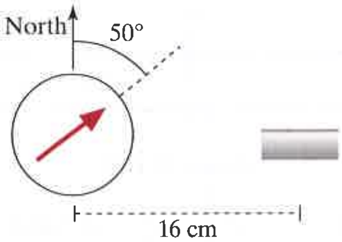

Figure 17.97

(a) Label the N and S poles of the bar magnet and explain your choice. **(b)** Determine the magnetic dipole moment of this bar magnet, including correct units.

••P57 A bar magnet with magnetic dipole moment 0.54 A·m^2 lies on the negative x axis, as shown in Figure 17.98. A compass is located at the origin. Magnetic north is in the negative z direction. Between the bar magnet and the compass is a coil of wire of radius 3.5 cm, connected to batteries not shown. The distance from the center of the coil to the center of the compass is 9.7 cm. The distance from the center of the bar magnet to the center of the compass is 22.5 cm. A steady current of 0.96 A runs through the coil. Conventional current runs clockwise in the coil when viewed from the location of the compass.

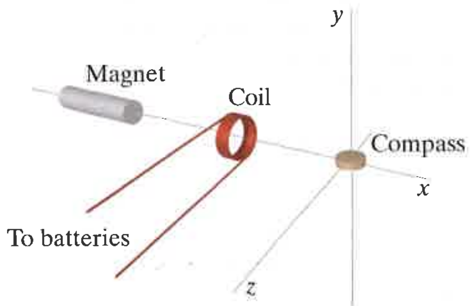

Figure 17.98

Despite the presence of the coil and the bar magnet, the compass points north. **(a)** Which end of the bar magnet is closer to the compass? **(b)** List all of the following statements that are correct: (1) At the location of the compass, the magnetic field due to the magnet is equal in magnitude to the magnetic field due to the coil. (2) It isn't necessary to take the magnetic field of the magnet into account, since the coil is in between the magnet and the compass. (3) Because not all parts of the magnet are the same distance from the compass, treating the magnet as a dipole located at the center of the magnet is an approximation. (4) The magnetic dipole moment of the coil is equal to the magnetic dipole moment of the compass. (5) At the location of the compass, the net magnetic field is equal to the magnetic field of the Earth. **(c)** How many turns of wire are in the coil?

Section 17.12

•P58 A particular alnico (aluminum, cobalt, nickel, and iron) bar magnet (magnet A) has a mass of 10 g. It produces a magnetic field of magnitude 6×10^{-5} T at a location 0.19 m from the center of the magnet, on the axis of the magnet. **(a)** Approximately what is the magnitude of the magnetic field of magnet A a distance of 0.38 m from the center of the magnet, along the same axis? **(b)** If you removed the original magnet and replaced it with a magnet made of the same material but with a mass of 50 g (magnet B), approximately what would be the magnetic field at a location 0.19 m from the center of the magnet, on the axis of the magnet?

••P59 The magnetic field along the axis of a bar magnet can be written like this:

$$B_{\text{axis}} \approx \frac{\mu_0}{4\pi} \frac{2\mu}{r^3}$$

(a) Use your own data from Experiment EXP9 to determine the magnetic dipole moment μ of your bar magnet. If you have mislaid those data, quickly repeat the measurements now. You will use the value of your magnetic dipole moment in later work. The magnetic dipole moment describes how strong a magnet is: the bigger the magnetic dipole moment, the bigger the magnetic field at some distance r. **(b)** Determine the mass of your magnet and thereby determine the number N of atoms in your magnet. Although your magnet is probably made of some alloy such as alnico V (51% iron, 8% aluminum, 14% nickel, 24% cobalt, and 3% copper), for simplicity assume it is made just of iron, which has a density of 8 g/cm^3 and an atomic mass of 56 (that is, 6×10^{23} atoms weigh a total of 56 g). Assuming that each of the atoms has a magnetic dipole moment with a value estimated in Section 17.12, see how well the atomic model for a magnet fits the measured value of the magnetic dipole moment of your bar magnet.

COMPUTATIONAL PROBLEMS

More detailed and extended versions of some computational modeling problems may be found in the lab activities included in the *Matter & Interactions, 4th Edition*, resources for instructors.

••P60 A proton moves with a constant velocity of 4×10^4 m/s in the $+x$ direction, along the x axis, starting at an initial location of $\langle -4 \times 10^{-10},0,0 \rangle$ m. **(a)** Write a program that calculates and displays the magnetic field of the moving proton at four observation locations in the yz plane (two on the y axis and two on the z axis), each a distance of 8×10^{-11} m from the x axis. Use cyan arrows to represent the magnetic field. **(b)** Does the magnetic field at one of your fixed observation locations change or stay constant? **(c)** What do you observe if you change the speed of the proton? **(d)** What do you observe if you change the proton to an antiproton?

••P61 Start with the program you wrote in Problem P60. Modify the program so that there are many observation locations, positioned on a cylindrical surface aligned with the x axis.

••P62 Start with the program you wrote in either Problem P60 or P61. Add to your display the electric field made by the proton at your fixed observation locations. Make the electric field arrows orange. Note that you need to scale the arrows representing electric field differently from the arrows used to represent magnetic field, since these quantities have very different magnitudes and units.

•••P63 Calculate and display (as arrows) the magnetic field made by a square current-carrying loop whose center is at the origin and which lies in the yz plane, with axis in the $+x$ direction. Each side of the square loop is 0.1 m long and the current in the loop is 3 A. Represent the square loop as a curve object with $N = 40$ positions. Show the field at many locations on a circle of radius 1 m in the xy plane centered on the origin, so that you can get a feel for the magnetic field at locations both along the axes and away from the axes. Print the values of the magnetic field where the circle intersects the x and y axes and check that they agree with the analytical expression for the magnetic field of this square loop when far from the loop. When you have the program working properly, determine the approximate minimum value of N that gives good agreement with the analytical solution.

•••P64 This problem is similar to Problem P63 but with a circular loop instead of a square loop, where the radius of the loop is 0.05 m and the current is again 3 A. Represent the circular loop as a curve object with $N = 40$ positions. Show the field at many locations on a circle of radius 1 m in the xy plane centered on the origin, so that you can get a feel for the magnetic field at locations both along the axes and away from the axes. Print the values of the magnetic field where the circle intersects the x and y axes and check that they agree with the analytical expression for the magnetic field of this circular loop when far from the loop. When you have the program working properly, determine the approximate minimum value of N that gives good agreement with the analytical solution.

•••P65 A solenoid of length $L = 0.5$ m and radius $R = 3$ cm is wound with $N = 50$ turns of wire carrying a current $I = 1$ A. Its center line lies on the x axis, with the origin at the center of the solenoid (Figure 17.99). This is a loosely wound solenoid, so it is not clear how uniform will be the magnetic field in its interior. To explore this, do the following:

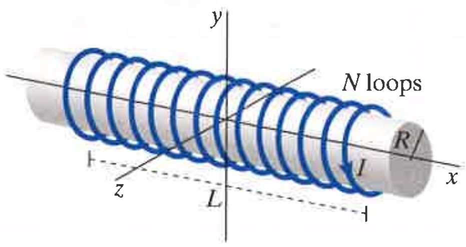

Figure 17.99

(a) Calculate and display magnetic field vectors at the locations in the xy plane, inside and outside of the solenoid, as shown in Figure 17.100. Do the pattern and direction of the magnetic field make sense? **(b)** Display the numerical value of the magnitude of the magnetic field at one location, the center of the solenoid. Also display the theoretical numerical value of the magnetic field, in the approximation that this is a very long solenoid ($B \approx \mu_0 NI/L$). **(c)** What is the minimum number of steps around one turn that are necessary to obtain good agreement between the theoretical value and your numerical integration? What is your criterion for good agreement? **(d)** Vary the number of turns of the helix. What is the minimum number of turns necessary to get an approximately uniform field inside the solenoid? **(e)** How do the magnitude and direction of the magnetic field outside the solenoid compare to the magnitude and direction of the magnetic field inside the solenoid?

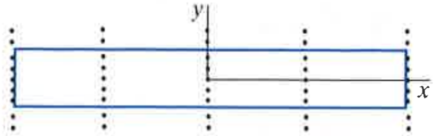

Figure 17.100

The code segment below creates a solenoid-shaped curve, and also creates a list of arrows at the specified observation locations. The arrow at the center of the array of observation locations is given the special name center.

```
from visual import *
scene.width = 800

L = 0.5            ## length of solenoid
R = 0.03           ## radius of solenoid
mzofp = 1e-7       ## mu0/4pi
I = 1.0            ## conventional current
Nturns = 75        ## number of turns
Nsteps = 20        ## number of line segments/turn

## a curve is a list of points
## start with an empty curve (no points)
solenoid = curve(color=color.yellow,
                 radius = 0.001)
dx = L/(Nturns*Nsteps)
omega = 2*pi*Nturns/L
x = -L/2
## add points to the curve
while x < L/2+dx:
    solenoid.append(pos=vector(x,
                    R*sin(x*omega),
                    R*cos(x*omega)))
    x = x + dx

## a list of arrows
## at observation locations with
## arbitrary directions initially
Barrows = []       ## empty list
dx = L/4
## skip y = 0.03 which is inside wire
ylist = [-0.05, -0.04, -0.02, -0.01,
         0., 0.01, 0.02, 0.04, 0.05]
x = -L/2
while x < L/2 + dx:
    i = 0
    while i < len(ylist):
        aa = arrow(pos=vector(x,ylist[i],0),
```

```
                axis=vector(0,0,0.005),
                color=color.cyan,
                shaftwidth=0.003)
        Barrows.append(aa)
        i = i + 1
    x = x + dx

## outer while loop: choose observation location
```

```
## Barrows[i]
## inner while loop: calculate field at
## Barrows[i].pos
## and scale axis of arrow appropriately
## ...
```

ANSWERS TO CHECKPOINTS

1 6×10^{18} electrons/s; 5.4×10^{21} electrons
2 5.4×10^{-6} T
3 **(a)** Figure 17.101; **(b)** Figure 17.102

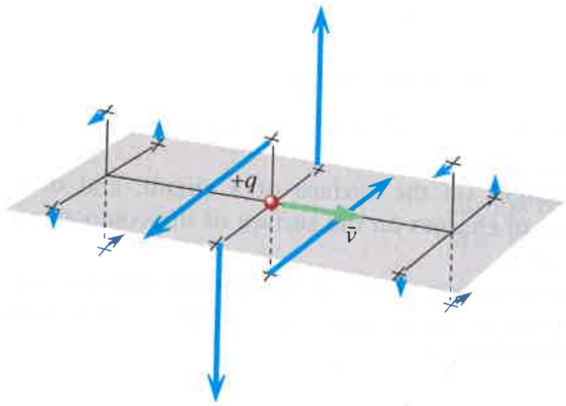

Figure 17.101

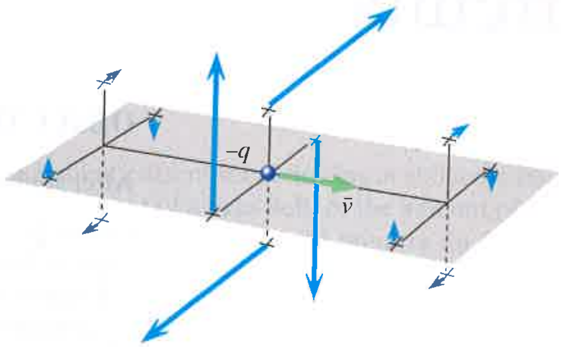

Figure 17.102

4 Electron current flows to the left, conventional current to the right.
5 2.4 A
6 9 $A \cdot m^2$