End-of-Chapter Exercises

Exercises 1 – 12 are primarily conceptual questions, designed to see whether you understand the main concepts of the chapter.

1. A charged particle is moving with a constant velocity directed up the page when it enters a region of uniform magnetic field. (a) If the particle is deflected into a circular path, but it remains in the plane of the page, what does this tells us about the magnetic field? (b) If the particle has a positive charge and it is deflected to the left when it enters the field, what does this tell us about the magnetic field?

2. What is the direction of the magnetic force experienced by the charged particle in each situation shown in Figure 19.31?

3. A negatively charged particle with an initial velocity directed east experiences a magnetic force directed north. (a) If the initial velocity is perpendicular to a uniform magnetic field, in which direction is the field? (b) If the initial velocity and the magnetic field are not necessarily perpendicular, what can you say about the direction of the field?

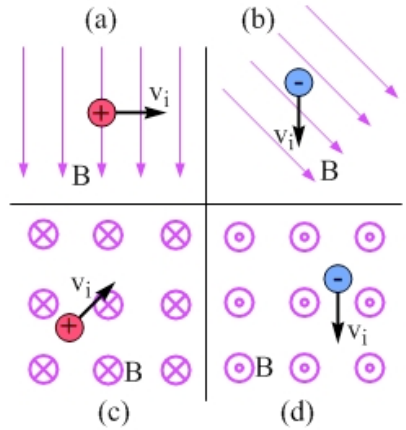

Figure 19.31: Four situations involving a charged particle in a uniform magnetic field, for Exercises 2 and 6.

4. As shown in Figure 19.32, a positively charged particle has an initial velocity directed straight up the page. The initial velocity is perpendicular to a uniform field in the region. (a) If the into-the-page symbol shows the direction of the magnetic force on the particle, in which direction is the magnetic field? (b) If, instead, the into-the-page symbol shows the direction of the magnetic field, in which direction is the force on the particle?

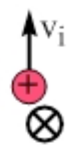

Figure 19.32: A positively charged particle has an initial velocity directed up. Either the magnetic field or the magnetic force is directed into the page. For Exercise 4.

5. Two vectors, which are clearly not perpendicular to one another, are shown in Figure 19.33. (a) Could these two vectors represent the velocity of a negatively charged particle (1) and the direction of a uniform magnetic field (2)? If not, explain why not. If so, in which direction is the magnetic force on the particle? (b) Could the two vectors represent the velocity of a positively charged particle (1), and the direction of the magnetic force acting on the particle (2)? If not, explain why not. If so, in which direction is the magnetic field that exerts the force on the particle?

Figure 19.33: Two vectors, for Exercise 5.

6. Return to the situations shown in Figure 19.31. If the particles have charges of the same magnitude, are in uniform fields of the same magnitude, and have the same initial speed, rank the four situations based on the magnitude of the force experienced by the particle.

7. Figure 19.34 shows the paths followed by three charged particles through a region of uniform magnetic field that is directed perpendicular to the page. If particle 1 has a positive charge, what is the sign of the charge of (a) particle 2? (b) particle 3? (c) In which direction is the magnetic field?

8. Return to the situation described in the previous exercise and shown in Figure 19.34. If the particles have the same mass, and their charges have the same magnitude, rank the particles based on (a) their speed, and (b) the magnitude of the magnetic force they each experience. (c) Which particle spends the most time in this square region? Explain.

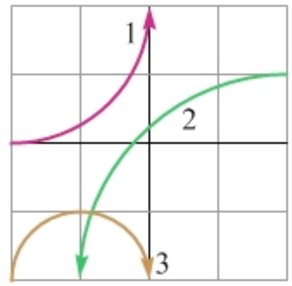

Figure 19.34: The paths followed by three charged particles through a region of uniform magnetic field directed perpendicular to the page, for Exercises 7 and 8.

9. The complete picture of field lines in a particular region is blocked by the square screen in Figure 19.35. (a) Could these field lines be electric field lines? If not, explain. If so, what is behind the screen? (b) Could these field lines be magnetic field lines? If not, explain. If so, what is behind the screen?

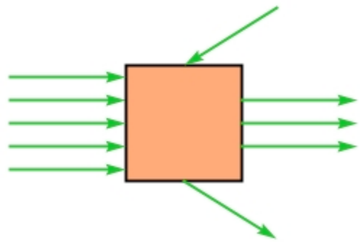

Figure 19.35: Our view of the field lines in a particular region is blocked by a square screen, for Exercise 9.

10. Consider the picture of magnetic field lines in a particular region, shown in Figure 19.36. (a) Points a, b, and c are located on the same field line. Rank these points based on the magnetic field at these points. (b) At which point, a or d, is the magnetic field larger in magnitude? Explain.

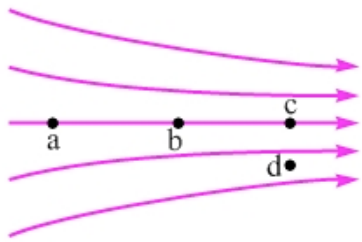

Figure 19.36: The magnetic field in a particular region, for Exercise 10.

11. Two long straight parallel wires are located so that one wire passes through each of the lower corners of an equilateral triangle, as shown in Figure 19.37. The wires carry currents that are directed perpendicular to the page. The net magnetic field at the top vertex of the triangle is also shown in the figure. What is the direction of the current in (a) wire 1? (b) wire 2? (c) Which wire carries more current?

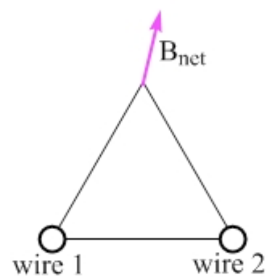

Figure 19.37: Two long straight current-carrying wires pass through the lower corners of an equilateral triangle. For Exercise 11.

12. Four long straight parallel wires pass through the corners of a square, as shown in Figure 19.38. The currents in each wire have the same magnitude, but their directions (either into or out of the page) are unknown. How many possible combinations of current directions are there if the net magnetic field due to these wires at the center of the square is (a) zero? (b) directed to the right? (c) directed toward the top left corner of the square. Draw the various configurations in each case.

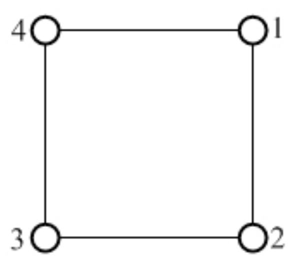

Figure 19.38: Long straight parallel current-carrying wires pass through the corners of a square, for Exercise 12.

Exercises 13 – 16 are designed to give you practice applying the equation for the magnetic force experienced by a charged particle in a magnetic field, $F_M = qvB \sin\theta$ **.**

13. The particle in Figure 19.39 has a charge of 5.0 μC, a speed of 1.4×10^3 m/s, and it is in a uniform magnetic field, directed into the page, of 2.5×10^{-2} T. As the figure shows, the initial velocity of the particle is directed at 30° below the positive *x*-direction, assuming the *x*-direction is toward the right. What is the magnitude and direction of the magnetic force acting on the particle?

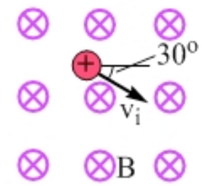

Figure 19.39: A particle with a positive charge has a velocity directed at 30° below the positive *x*-direction, in a magnetic field directed into the page. For Exercise 13.

14. A charged particle is in a region in which the only force acting on it comes from a uniform magnetic field. When the particle's initial velocity is directed in the positive *x*-direction (to the right), the particle experiences no magnetic force. When the particle's initial velocity is directed in the positive *y*-direction (up the page), the particle experiences a magnetic force in the positive *z*-direction (out of the page). (a) If the particle has a negative charge, in which direction is the magnetic field? In which direction is the magnetic force on the particle if the particle's initial velocity is directed in the (b) +*z*-direction? (c) –*z*-direction? (d) –*x*-direction? (e) –*y*-direction?

15. In a particular region, there is a uniform magnetic field with a magnitude of $B = 2.0$ T. You take a particle with a charge of +5.0 μC and give it an initial speed of 4.0×10^5 m/s in this field. (a) Under these conditions, what is the magnitude of the maximum magnetic force experienced by the particle? (b) What is the magnitude of the minimum magnetic force experienced by the particle? (c) If the particle experiences a force with a magnitude that is 25% of the magnitude of the maximum force, what is the angle between the particle's velocity and the magnetic field?

16. A particle with a charge of –5.0 μC travels in a circular path of radius 30 m at a speed of 15 m/s. The particle's path is circular because it is traveling in a region of uniform magnetic field. If the particle's mass is 25 μg, what is the magnitude of the magnetic field acting on the particle?

Exercises 17 – 19 involve charged particles moving in circular paths in uniform magnetic fields.

17. Figure 19.40 shows the paths followed by three charged particles through a region of uniform magnetic field that is directed perpendicular to the page. If the particles have the same speed, and their charges have the same magnitude, rank the particles based on (a) their mass, and (b) the magnitude of the magnetic force they each experience.

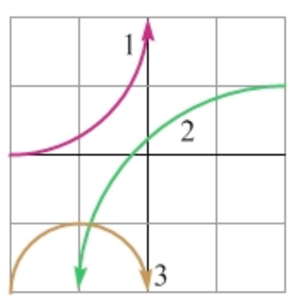

Figure 19.40: The paths followed by three charged particles through a region of uniform magnetic field directed perpendicular to the page, for Exercise 17.

18. Figure 19.41 shows the paths followed by three charged particles through a region of uniform magnetic field that is directed out of the page. The particles have the same magnitude charge. Complete table 19.3, filling in the six pieces of missing data.

Particle	Sign of Charge	Mass	Speed	Path taken
1		$2m$	$4v$	
2		$4m$		
3		m	$2v$	L

Table 19.3: The charge, mass, and speed for three particles passing through a magnetic field.

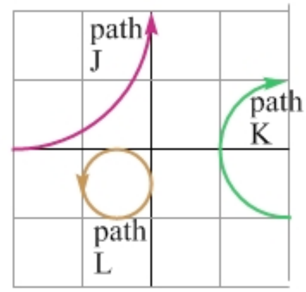

Figure 19.41: The paths of the three particles.

19. A particle with a charge of $-8.0\ \mu C$ and a mass of 9.0×10^{-9} kg is given an initial velocity of 5.0×10^4 m/s in the positive x-direction. The particle is in a uniform magnetic field, with $B = 2.0$ T, that is directed in the negative z-direction, and the particle starts from the origin. Assume the particle is affected only by the magnetic field. (a) How long after leaving the origin does the particle first return to the origin? (b) What is the maximum distance the particle gets from the origin? (c) Where is the particle when it achieves its maximum distance from the origin?

Exercises 20 – 24 deal with long straight wires in situations that are analogous to situations involving masses, from Chapter 8, and charged particles, from Chapter 16.

20. Figure 19.42 shows three long straight parallel wires that are carrying currents perpendicular to the page. Wire 1 experiences a force per unit length of 4 N/m to the left because of the combined effects of wires 2 and 3. Wire 2 experiences a force per unit length of 12 N/m to the right because of the combined effects of wires 1 and 3. Is there enough information given to find the force per unit length experienced by wire 3 because of the combined effects of wires 1 and 2? If so, find it. If not, explain why not.

Figure 19.42: Three long straight wires carry currents perpendicular to the page. The net forces per unit length on two of the wires are shown. For Exercise 20.

21. Figure 19.43 shows two long straight parallel wires that are separated by 12 cm. Wire 1, on the left, has a current of 3.0 A directed out of the page. Wire 2, on the right, has a current of 2.0 A directed into the page. (a) What is the magnitude and direction of the net magnetic field from these two wires at the point midway between them? (b) Are there any points a finite distance from the wires at which the net magnetic field from the wires is zero? If not, explain why not. If so, state the location of all such points.

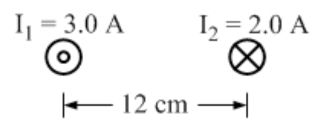

Figure 19.43: Two long straight parallel wires carry currents perpendicular to the page. For Exercise 21.

22. Three long straight parallel wires pass through three corners of a square measuring 20 cm on each side, as shown in Figure 19.44. Find the magnitude and direction of the net magnetic field at (a) the center of the square. (b) the top left corner of the square.

23. Three long straight parallel wires pass through three corners of a square measuring 20 cm on each side, as shown in Figure 19.44. Find the magnitude and direction of the magnetic force per unit length experienced by wire 2, in the bottom right corner, due to the other two wires.

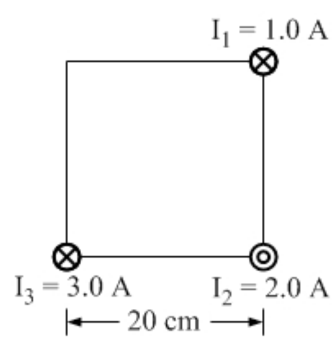

Figure 19.44: Three long straight current-carrying wires pass through three corners of a square. For Exercises 22 and 23.

Exercises 21 – 25 involve adding magnetic fields as vectors.

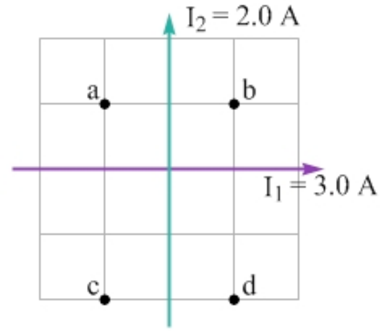

Figure 19.45: Two long straight perpendicular wires carry currents in the plane of the page. For Exercises 24 and 25.

24. Two long straight wires are in the plane of the page, and are perpendicular to one another. As shown in Figure 19.45, wire 2 is placed on top of wire 1, but the wires are electrically insulated from one another. Wire 1 carries a current of 3.0 A to the right, while wire 2 carries a current of 2.0 A up. Rank the four labeled points based on the magnitude of the net magnetic field due to the wires, from largest to smallest.

25. Return to the situation described in Exercise 24, and shown in Figure 19.45. Each of the four points is 20 cm from wire 2. Points a and b are also 20 cm from wire 1, while points c and d are 40 cm from wire 1. Determine the magnitude and direction of the net magnetic field, due to the two wires, at (a) point a, (b) point b, (c) point c, and (d) point d.

26. Two long straight parallel wires pass through two corners of a right-angled triangle, as shown in Figure 19.46. The currents in the wires are directed in opposite directions. Wire 1 produces a magnetic field of 4.0×10^{-5} T at the unoccupied corner of the triangle, which is 20 cm from wire 1. If the current in wire 2 has the same magnitude as that in wire 1, determine the magnitude and direction of the net magnetic field from the two wires at the unoccupied corner of the triangle.

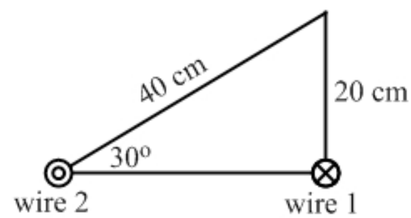

Figure 19.46: Two long straight parallel wires, carrying currents in opposite directions, pass through two corners of a right-angled triangle, for Exercises 26 and 27.

27. Return to the situation described in Exercise 26, and shown in Figure 19.46. Now the magnitude of the current in wire 2 is adjusted so that the net magnetic field at the unoccupied corner of the square, due to the wires, is directed straight up. Find the ratio of the magnitude of the current in wire 2 to that in wire 1.

Exercises 25 – 30 deal with current-carrying loops and solenoids.

28. Figure 19.47 shows three concentric current-carrying loops. The inner loop, with a radius of 20 cm, carries a current of 2.0 A counterclockwise. The middle loop, with a radius of 30 cm, carries a current of 3.0 A clockwise. The outer loop, with a radius of 40 cm, carries a current of 4.0 A counterclockwise. Determine the magnitude and direction of the net magnetic field at point c, the center of each loop, due to the loops.

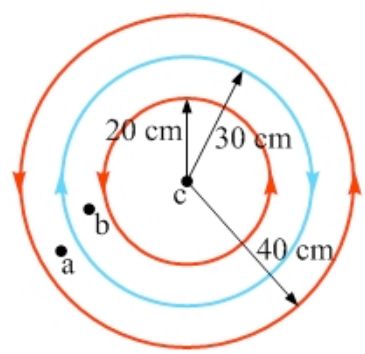

Figure 19.47: Three concentric loops, for Exercise 28, or a cross-section through three concentric solenoids, for Exercise 29.

29. Return to the situation described in Exercise 28, but now Figure 19.47 represents a cross-sectional slice through a set of three long current-carrying solenoids. (a) Assuming the solenoids are ideal and have the same number of turns per unit length, and using the currents specified in the previous exercise, rank points a, b, and c based on the magnitude of the net magnetic field at their location. (b) Determine the magnitude and direction of the net magnetic field at point b, if each solenoid has 800 turns/m.

30. As shown in Figure 19.48, a long straight wire, carrying a current I up the page, lies in the plane of a loop. The long straight wire is 40 cm from the center of the loop, which has a radius of 20 cm. Initially, the magnetic field at the center of the loop is due only to the current in the long straight wire. When a current in the loop is turned on, however, the net field at the center of the loop has a magnitude two times larger than the field at that point from the long straight wire. What is the magnitude (in terms of I) and direction of the current in the loop? Find all possible solutions.

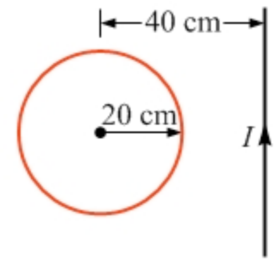

Figure 19.48: A long straight current-carrying wire passes 40 cm from the center of a loop that has a radius of 20 cm, for Exercise 30.

31. A particular ideal solenoid has 1200 turns/m, a radius of 10 cm, and a current of 4.0 A. An electron is fired from the axis of the solenoid in a direction perpendicular to the axis. What is the maximum speed the electron can have if it is not to run into the side of the solenoid?

32. A very strong neodymium-iron-boron (NdFeB) magnet with a magnetic field of around 0.1 T can be purchased for a few dollars. (a) Compare this magnetic field to the field you can get by making your own electromagnet, assuming that you wind some wire at 800 turns/m around an aluminum nail, and the current in the coil is 1.0 A. (b) If you wind the wire around an iron or steel nail instead, you can amplify the magnetic field by a factor of several hundred. How does this field compare to the field from the NdFeB magnet? (c) Name a key advantage that your electromagnet offers over the NdFeB magnet.

General problems and conceptual questions

33. Consider the photograph of two magnets, shown on the opening page of this chapter. (a) Are the magnets attracting one another or repelling? Explain. (b) Can you say which end of the magnet on the right is a north pole and which end is a south pole? Explain.

34. The SI unit of the tesla is named after a very interesting person. Do some research on this individual, and write two or three paragraphs describing his/her contributions to science.

35. We know quite a lot about the historical behavior of the Earth's magnetic field, through a field of study called **paleomagnetism**. Investigate the methods used by researchers in this field, and write 2-3 paragraphs about these methods.

36. What is the predominant direction of the Earth's magnetic field if you are standing on the surface of the Earth (a) at a point on the Earth's equator? (b) in northern Canada, directly above one of the Earth's magnetic poles?

37. The northern lights (*aurora borealis*) and southern lights (*aurora australis*) are colorful displays of light associated with fast-moving charged particles entering the Earth's atmosphere. (a) Recalling that moving charges tend to spiral around magnetic field lines, explain why these light shows are generally confined to Earth's polar regions. (b) In the event that a positively charged particle enters Earth's atmosphere above the equator, with a velocity directed straight down toward the ground, in which direction is the particle initially deflected by the Earth's magnetic field?

38. A charged particle is passing through a particular region of space at constant velocity. One possible explanation for the fact that the particle is undeflected while it is in this region is that there is neither an electric field nor a magnetic field present. Let's consider other possibilities. Explain your answers to the following. (a) Could there be a uniform electric field in the region, but no magnetic field? (b) Could there be a uniform magnetic field in the region, but no electric field? (c) Could there be both a uniform electric field and a uniform magnetic field present?

39. An electron is in a uniform magnetic field. Assume that the electron interacts only with the magnetic field, and that all other interactions, including gravity, can be neglected. 2.0 s after being released, what is the electron's speed if it is (a) released from rest? (b) released with a velocity of 800 m/s in a direction parallel to the magnetic field? (c) released with a velocity of 800 m/s in a direction perpendicular to the magnetic field.

40. Figure 19.49 shows, to scale, the initial velocities of four identical charged particles in a uniform magnetic field. Rank the particles based on the magnitude of the magnetic force they experience from the field if the field is directed (a) up the page (b) to the right (c) out of the page.

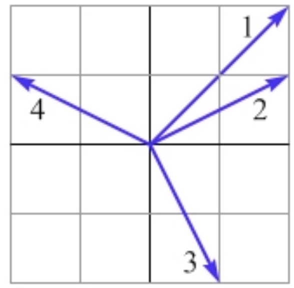

Figure 19.49: The initial velocities of four identical charged particles in a uniform magnetic field, for Exercise 40.

41. When a particle with a charge of +3.0 μC and a mass of 5.0×10^{-8} kg passes through the origin, its velocity components are $\vec{v}_x = +3.0\times10^4$ m/s in the *x*-direction and $\vec{v}_y = +4.0\times10^4$ m/s in the *y*-direction. The particle is traveling through a region of uniform magnetic field which is directed in the negative *x*-direction, with a magnitude of 2.0×10^{-2} T. The particle follows a spiral path in the field. (a) What is the radius of the spiral path, and in which direction does the axis of the spiral point? (b) How long does it take the particle to make one complete loop on the spiral? (c) How far from the origin is the particle when it has made one complete loop on the spiral?

42. Return to the situation described in Exercise 42, but now we will add a uniform electric field of 1000 N/C in the +*x*-direction, parallel to the magnetic field. (a) With the addition of the electric field, which of the answers to the previous exercise would change and which would stay the same? Explain. (b) Re-calculate all the answers to the previous exercises that are changed by the addition of the electric field.

43. Four particles pass through a square region of uniform magnetic field, as shown in Figure 19.50. The magnetic field inside the square region is perpendicular to the page, and the field outside the region is zero. The paths followed by particles 1 and 2 are shown; while for particles 3 and 4 the direction of their velocities and the points at which they enter the region are shown. The paths of all particles lie in the plane of the paper. Particle 1 has a mass *m*, a speed *v*, and a positive charge +*q*. Assume that the only thing acting on the particles as they move through the magnetic field is the field. (a) In which direction is the uniform magnetic field in the square region? (b) As particle 1 moves through the field, does its kinetic energy increase, decrease, or stay the same? Explain. (c) What is the sign of particle 2's charge? (d) If particle 2's mass is *m* and its charge has a magnitude of *q*, what is its speed? (e) Particle 3 has a mass 2*m*, a speed 2*v*, and a charge –2*q*. Re-draw Figure 19.50, and sketch on this diagram, as precisely as you can, the path followed by particle 3 through the region of magnetic field. (f) Particle 4 has a mass 2*m*, a speed 2*v*, and no charge. Sketch its path through the region of magnetic field. (g) Which particle feels the largest magnitude force as it passes through the field?

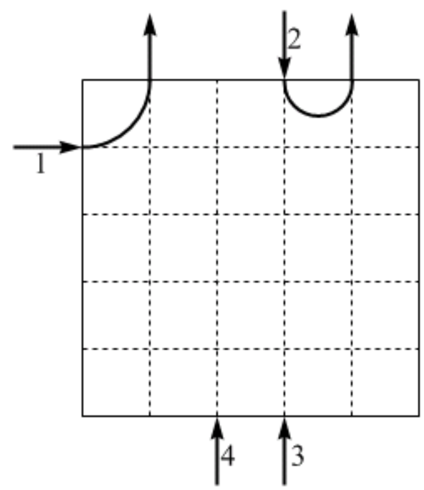

Figure 19.50: Four particles pass through a square region of uniform magnetic field directed perpendicular to the page. Only the paths followed by particles 1 and 2 are shown. For Exercise 43.

44. Two particles are sent into a square region in which there is a uniform magnetic field directed into the page, as shown in Figure 19.51. There is no magnetic field outside of the region. The velocity of the particles is perpendicular to the magnetic field at all times. Particle 1 is sent through the field twice, entering at the same point both times. The first time it has an initial speed v and the second time it has an initial speed of $2v$. (a) Which path, P or Q, corresponds to when the initial speed of particle 1 is $2v$? (b) For which path is the magnitude of the force experienced by particle 1 larger? (c) Is the charge on particle 1 positive or negative? (d) Particle 2 has the same mass and the same magnitude charge as particle 1, but the sign of its charge is opposite to that of particle 1. Particle 2 has an initial speed of v when it enters the field. Re-draw the diagram and sketch the path followed by particle 2.

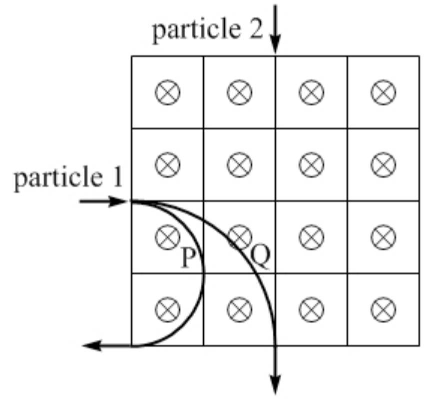

Figure 19.51: Two particles pass through a square region of uniform magnetic field directed into the page. Particle 1 is sent through the field twice, following path *P* on one occasion and path *Q* on the other. For Exercise 44.

45. The velocity of the electrons in an electron beam is 1.0×10^5 m/s directed right. The electrons pass through a velocity selector without being deflected in any way, as shown in Figure 19.52. The velocity selector consists of a set of parallel plates with a uniform electric field with $\vec{E} = 2000\ V/m$ directed down, and a uniform magnetic field directed perpendicular to the velocity of the electrons. (a) In which direction is the magnetic field? (b) What is the magnitude of the magnetic field inside the velocity selector? (c) What will happen to electrons traveling faster than those that are undeflected?

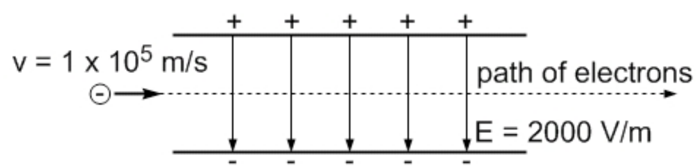

Figure 19.52: Electrons with just the right speed pass undeflected through a velocity selector, for Exercise 45.

46. A charged particle enters a velocity selector with a speed of 2.0×10^4 m/s. A graph of the net force acting on the particle when it enters the velocity selector, as a function of the magnetic field in the velocity selector, is shown in Figure 19.53. A positive net force means that the particle is deflected up, while a negative net force means that it is deflected down. The geometry of the velocity selector is similar to that shown in Figure 19.52, with the initial velocity of the particle directed parallel to the plates of the velocity selector, and perpendicular to both the electric field and the magnetic field, which are perpendicular to one another. Using the graph, determine (a) the magnitude of the electric field in the velocity selector, and (b) the magnitude of the charge on the particle.

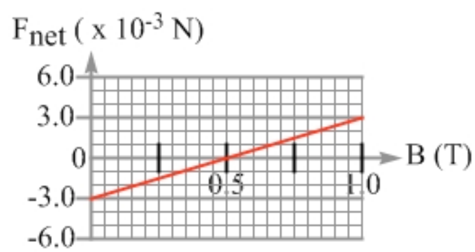

Figure 19.53: A graph of the net force acting on a charged particle when it enters a velocity selector, as a function of the magnetic field in the velocity selector, for Exercise 46.

47. You have a sample of chlorine, and you are trying to determine what fraction of your sample consists of chlorine-35 atoms (with an atomic mass of about 35 atomic mass units) and what fraction is made up of chlorine-37 atoms (with an atomic mass of about 37 atomic mass units). To do this, you use a mass spectrometer, as described in section 19–4, ionizing the atoms so that each atom is singly-ionized, with a charge of $+e$. (a) In

the velocity selector, you use a uniform electric field of 2000 N/C, and a uniform magnetic field of 5.0×10^{-2} T. These two fields are mutually perpendicular, and are each perpendicular to the velocity of the chlorine ions when they enter the velocity selector. What is the speed of chlorine ions that pass undeflected through the velocity selector? (b) The undeflected ions continue to the uniform magnetic field in the mass separator. If you want the ions of different mass to be separated by 1.0 mm after going through a half-circle in the mass separator, to what value should you set the magnitude of the magnetic field in the mass separator?

48. A graph of the magnetic field from a long straight wire, as a function of the inverse of the distance from the wire, is shown in Figure 19.54. What is the magnitude of the current in the wire?

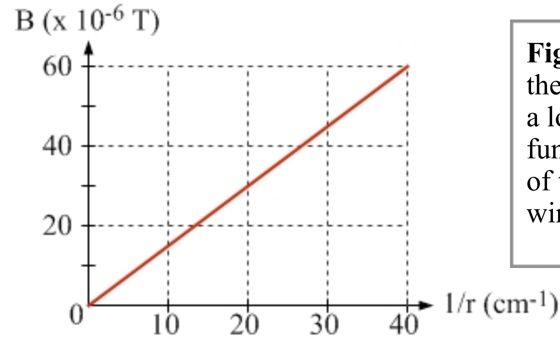

Figure 19.54: A graph of the magnetic field from a long straight wire, as a function of the inverse of the distance from the wire, for Exercise 48.

49. Three long straight parallel wires are placed in a line, with 40 cm between neighboring wires, as shown in Figure 19.53. Wires 1 and 2 carry currents directed into the page, while wire 3 carries a current directed out of the page. The currents all have the same magnitude. (a) Rank the three wires based on the magnitude of the net force per unit length experienced by each wire because of the other two. (b) If the current in each wire is 4.0 A, confirm your ranking from part (a) by determining the magnitude and direction of the force experienced by each wire.

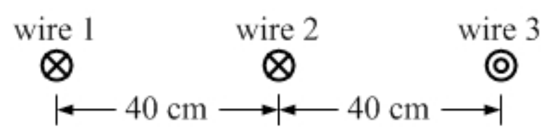

Figure 19.55: Three long straight parallel current-carrying wires, for Exercises 49 and 50.

50. Three long straight parallel wires are placed in a line, with 40 cm between neighboring wires, as shown in Figure 19.55. Wires 1 and 2 carry currents directed into the page, while wire 3 carries a current directed out of the page. Wire 1 experiences no net force due to the other two wires. (a) How does the magnitude of the current in wire 3 compare to that in wire 2? (b) How does the net force per unit length experienced by wire 3 compare to that of wire 2?

51. Two points, a and b, are 5.0 m apart. There is a uniform magnetic field of 2.0 T present that is directed parallel to the line connecting a and b. How much force does the field exert on a wire carrying 3.0 A of current from a to b, if the wire is (a) 5 m long? (b) 10 m long, and follows a circuitous path from a to b?

52. Repeat Exercise 51, but now the magnetic field is directed perpendicular to the line connecting a and b.

53. A rectangular loop with a current of 2.0 A directed clockwise measures 30 cm long by 10 cm wide, as shown in Figure 19.56. The loop is placed 10 cm from a long straight wire that carries a current of 3.0 A to the right. The goal of this exercise is to determine the magnitude and direction of the net magnetic force exerted on the loop by the long straight wire. (a) In section 19-5, we discussed the fact that a current-carrying loop in a uniform magnetic field experiences no net force. Why does the loop in this situation experience a non-zero net force? (b) Draw a diagram showing the force experienced by

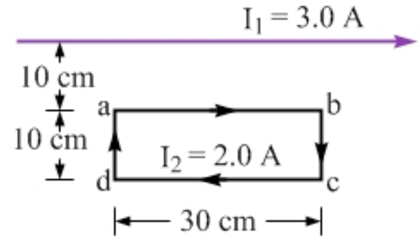

Figure 19.56: A current-carrying loop near a current-carrying long straight wire, for Exercises 53 and 54.

each side of the loop. (c) Explain why the forces on the left and right sides of the loop are difficult to calculate, but why we do not need to calculate them to find the net force on the loop. (d) Find the force exerted on the upper side of the loop by the long straight wire. (e) Find the force exerted on the lower side of the loop by the long straight wire. (f) Combine your previous results to find the net force acting on the loop.

54. Return to the situation described in Exercise 53, and shown in Figure 19.56. Does the rectangular loop experience a net torque, about an axis that passes through the center of the loop, because of the magnetic field from the long straight wire? Explain.

55. Two very long straight wires carry currents perpendicular to the page, as shown in Figure 19.57. The x-axis is in the plane of the page. Wire 1, which carries a current I_1 into the page, passes through the x-axis at $x = +a$. Wire 2, located at $x = -2a$, carries an unknown current. The net field at the origin ($x = 0$), due to the current-carrying wires, has a magnitude of $B = 2\mu_0 I_1 /(2\pi a)$. What is the magnitude and direction of the current in wire 2? Find all possible solutions.

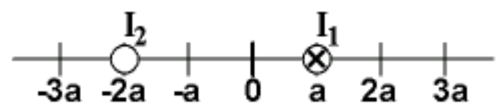

Figure 19.57: Two long straight parallel wires pass through $x = +a$. and $x = -2a$, respectively. For Exercise 55.

56. Two long straight wires, that are parallel to the y-axis, pass through the x-axis. One wire carries a current of $2I$ in the $+y$-direction, and passes through the x-axis at the point $x = -d$. The second wire carries an unknown current, and passes through an unknown location on the positive x-axis. The net magnetic field at all points on the y-axis is zero due to the wires, and the force per unit length experienced by each wire has a magnitude of $3\mu_0 I^2 /(2\pi d)$. Find the current in the second wire, and determine at which point it passes through the x-axis.

57. Three equally spaced long straight wires are arranged in a line, as shown in Figure 19.58. The currents in the wires are as follows: wire 1 carries a current I into the page; wire 2 carries a current of $2I$ into the page; wire 3 carries a current of $3I$ out of the page. (a) Rank the three wires based on the magnitude of the net force per unit length they experience, from largest to smallest. (b) In which direction is the net force experienced by wire 1 due to the other two wires?

Figure 19.58: Three long straight parallel wires carry currents perpendicular to the page, for Exercise 57.

58. As shown in Figure 19.59, a long straight wire, supported by light strings tied to the wire at regular intervals, hangs at equilibrium at 30° from the vertical in a uniform magnetic field directed down. The current is directed perpendicular to the page. The wire has a mass per unit length of 0.12 kg/m, and the magnetic field has a magnitude of 0.36 T. What is the magnitude and direction of the current in the wire?

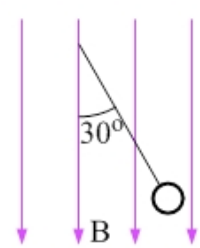

Figure 19.59: A long straight current-carrying wire, supported by strings, is in equilibrium at an angle of 30° from the vertical. For Exercise 58.

59. A rectangular wire loop measures 4.0 cm wide by 8.0 cm long. The loop carries a current of 5.0 A. The loop is in a uniform magnetic field with $B = 2.5 \times 10^{-3}$ T. What is the magnitude of the torque exerted by the field on the loop if the direction of the magnetic field is (a) parallel to the short sides of the loop? (b) parallel to the long sides of the loop? (c) perpendicular to the plane of the loop? In each case, take torques about an axis that maximizes the torque from the field.

60. Return to the situation described in Exercise 59. Rank the three cases, (a), (b), and (c), based on the magnitude of the angular acceleration experienced by the loop, assuming the loop is made from a uniform wire.

61. Return to the situation described in Exercise 59. If each centimeter of the wire loop has a mass of 5.0 grams, determine the angular acceleration of the loop in the situation when the magnetic field is parallel to the short sides of the loop.

62. An electron with a speed of 4.0×10^5 m/s travels in a circular path in the Earth's magnetic field. (a) Assuming that the magnitude of the Earth's field is 5.0×10^{-5} T, what is the radius of the electron's path? (b) Is it reasonable to neglect the force of gravity acting on the electron in this situation? Justify your answer. (c) An electron moving in a circle acts like a current loop, producing a magnetic field of its own. How large is the magnetic field at the center of the circular path, arising from the electron's motion?

63. Comment on each statement made by two students, who are discussing a situation in which a charged object experiences uniform circular motion because it is moving in a uniform magnetic field.

Kailey: The problem says that the object travels at constant speed in a circular path – the motion is confined to a plane. That tells us that the field must be directed perpendicular to that plane, right?

Isaac: I agree with you. Then it says, how does the radius of the path followed by the first object compare to that followed by the second object. Everything about the two objects is the same except that the second one has twice the speed as the first. Well, the force is proportional to the speed, so, if you increase the force, the radius must decrease.

Kailey: I'm not sure about that. Even if the force was the same on the two particles, if you change the speed the faster one is going to travel in a larger circle. That, by itself, would suggest that the radius goes up. Which effect wins, or do they balance?