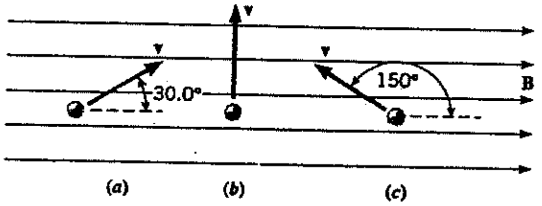
Magnetism
and
Electromagnetic Induction

Advanced Placement Physics B
Mr. DiBucci

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

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

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 4.50×10^{3} m/s perpendicular to a uniform magnetic field. The charge experiences a magnetic force of 7.31×10^{-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 1.90×10^{-3}-N force. Determine (a) the magnitude of the magnetic field and (b) the speed of q_2.

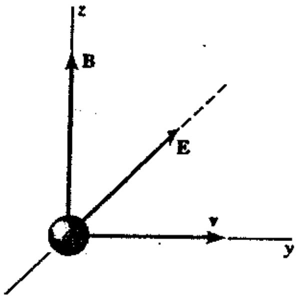
4. A charged body, moving with a velocity of 8.0×10^{4} m/s at an angle of 30.0° with respect to a magnetic field of strength 5.6×10^{-5} T, experiences a force of 2.0×10^{-4} N. What is the magnitude of the charge?

5. **ssm** At a certain location, the horizontal component of the earth's magnetic field is 2.5×10^{-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. An electron is moving through a magnetic field whose magnitude is 8.70×10^{-4} T. The electron experiences only a magnetic force and has an acceleration of magnitude 3.50×10^{14} m/s². At a certain instant, it has a speed of 6.80×10^{6} m/s. Determine the angle θ (less than 90°) between the electron's velocity and the magnetic field.

7. A charged particle is projected perpendicularly into a magnetic field at a speed of 1400 m/s and experiences a force of magnitude F. If the speed of the particle were 1800 m/s, at what angle θ (less than 90°) with respect to the field would the particle experience the same force magnitude F?

***8.** The drawing shows a charged particle ($q = +2.80 \times 10^{-6}$ C) moving along the $+y$ axis with a speed of 4.80×10^{6} m/s. A magnetic field of magnitude 3.35×10^{-5} T is directed along the $+z$ axis, and an electric field of magnitude 123 N/C points along the $-x$ axis. Determine the (a) magnitude and (b) direction of the net force that acts on the particle.



***9.** **ssm** **www** The electrons in the beam of a television tube have a kinetic energy of 2.40×10^{-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 2.00×10^{-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)?

***10.** 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 6.50×10^{-5} C experiences a maximum force of 0.455 N when traveling at a speed of 2.00×10^{4} m/s through the region where the fields are. Find the magnitude of the unknown field.

21.1 → 21.2 magnetic Fields

1) 75.1°, 105°

2) 5.7×10^{-5} into paper
1.1×10^{-4} N into PAPER
5.7×10^{-5} N into paper

3) 6.5×10^{-2} T
9.10×10^{3} m/s

4) 8.5×10^{-5} C

5) 4.1×10^{-3} m/s

6) 14.7°

7) 51°

8) 1.06×10^{-4} N
+x direction

9) 2.55×10^{14} m/s²

10) 0.287T

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

11. An electron moves at a speed of 6.0×10^6 m/s perpendicular to a constant magnetic field. The path is a circle of radius 1.3×10^{-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.

12. An ionized helium atom has a mass of 6.6×10^{-27} kg and a speed of 4.4×10^5 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 $+2e$.

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. An α-particle has a charge of $+2e$ and a mass of 6.64×10^{-27} kg. It is accelerated from rest through a potential difference of 1.20×10^6 V and then enters a uniform magnetic field whose magnitude is 2.20 T. The α-particle moves perpendicular to the magnetic field at all times. What is (a) the speed of the α-particle, (b) the magnitude of the magnetic force exerted on it, and (c) the radius of its circular path?

15. 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 9.0×10^6 m/s encounters the earth's magnetic field at an altitude where the field has a magnitude of 1.2×10^{-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.

16. 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 2.00×10^3 V, after which it enters a 0.600-T magnetic field. Find the radius of its circular path.

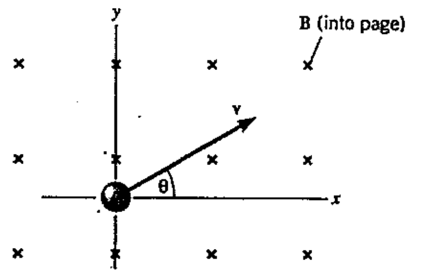
17. **ssm** **www** A charged particle with a charge-to-mass ratio of $q/m = 5.7 \times 10^8$ C/kg travels on a circular path that is perpendicular to a magnetic field whose magnitude is 0.72 T. How much time does it take for the particle to complete one revolution?

18. 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.

19. Suppose that an ion source in a mass spectrometer produces *doubly* ionized gold ions (Au^{2+}), each with a mass of 3.27×10^{-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.

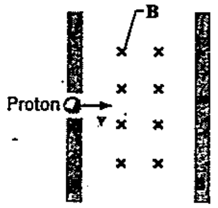
***20.** A proton and a deuteron are accelerated from rest through the same potential difference. (A deuteron consists of a proton and a neutron bound together). They then enter the bending region of the mass spectrometer shown in Figure 21.15. The horizontal distance between where the proton enters the magnetic field and the detector is 1.10 cm. How far must the detector be moved to the right to detect the deuteron?

***21.** **ssm** A particle of charge $+7.3\ \mu C$ and mass 3.8×10^{-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 θ, 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.



***22.** 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 3.80×10^3 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.

***23.** A proton with a speed of 2.2×10^6 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?



***24.** 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.

***25.** **ssm** **www** A particle of mass 6.0×10^{-8} kg and charge $+7.2\ \mu C$ is traveling due east. It enters perpendicular to 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?

***26.** An α-particle is the nucleus of a helium atom; the orbiting electrons are missing. The α-particle contains two protons and two neutrons, and has a mass of 6.64×10^{-27} kg. Suppose an α-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 ω does the α-particle move on its circular path?

7. 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.

WORKSHEET PHYSICS

Section 30–2 Magnetic Field

30–1 In a magnetic field directed vertically upward a particle initially moving north is deflected toward the east. What is the sign of the charge of the particle?

30–2 A particle with a mass of 5.00×10^{-3} kg and a charge of 3.50×10^{-8} C has at a given instant a velocity with a magnitude of 2.00×10^{5} m·s^{-1} in the $+y$-direction. What are the magnitude and direction of the acceleration of the particle that is produced by a uniform magnetic field that has magnitude 0.8 T and is in the $-x$-direction?

30–3 A particle having a mass of 0.500 g carries a charge of 4.60×10^{-8} C. The particle is given an initial horizontal velocity that is due east and has a magnitude of 6.00×10^{4} m·s^{-1}. What are the magnitude and direction of the magnetic field that will keep the particle moving in the earth's gravitational field in the same horizontal, eastward direction?

30–4 A particle with a charge of -2.50×10^{-8} C is moving with an instantaneous velocity of magnitude $v = 4.00 \times 10^{4}$ m·s^{-1} in the xy-plane at an angle of 50° counterclockwise from the $+x$-axis. What are the magnitude and direction of the force exerted on this particle by a magnetic field with magnitude 2.00 T in the

a) $-x$-direction?

b) $+z$-direction?

30–5 Each of the lettered circles at the corners of the cube in Fig. 30–19 represents a positive charge q moving with a velocity of magnitude v in the direction indicated. The region in the figure is a uniform magnetic field B, parallel to the x-axis and directed toward the right. Copy the figure, find the magnitude and direction of the force on each charge, and show the force in your diagram.

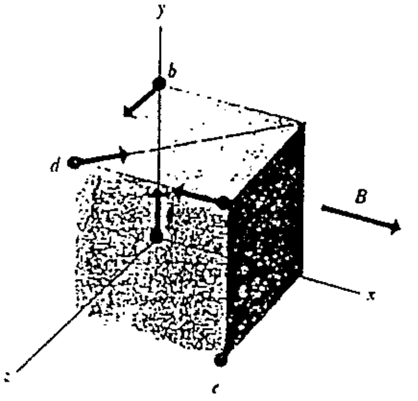


FIGURE 30–19

Section 30–5 Thomson's Measurement of e/m

Section 30–6 Isotopes and Mass Spectroscopy

30–13 In the Bainbridge mass spectrometer (Fig. 30–12), suppose the magnetic field magnitude B in the velocity selector is 1.30 T, and ions having a speed of 4.00×10^{6} m·s^{-1} pass through undeflected.

a) What is the electric field between the plates P and P'?

b) If the separation of the plates is 0.500 cm, what is the potential difference between the plates?

30–14

a) What is the speed of a beam of electrons when the simultaneous influence of an electric field of 3.40×10^{5} V·m^{-1} and a magnetic field of 8.00×10^{-2} T, with both fields normal to the beam and to each other, produces no deflection of the electrons?

b) Show in a diagram the relative orientation of the vectors v, E, and B.

c) What is the radius of the electron path when the electric field is removed?

30–15 The electric field between the plates of the velocity selector in a Bainbridge mass spectrometer is 1.20×10^{5} V·m^{-1}, and the magnetic field in both regions is 0.600 T. A stream of singly charged neon atoms moves in a circular path of 0.728-m radius in the magnetic field. Determine the mass of one neon atom and the mass number of this neon isotope.

30–46 A particle with mass m and charge $+q$ starts from rest at the origin in Fig. 30–29. There is a uniform electric field E in the positive y-direction and a uniform magnetic field B directed toward the reader. It is shown in more advanced books that the path is a *cycloid* whose radius of curvature at the top points is twice the y-coordinate at that level.

a) Explain why the path has this general shape and why it is repetitive.

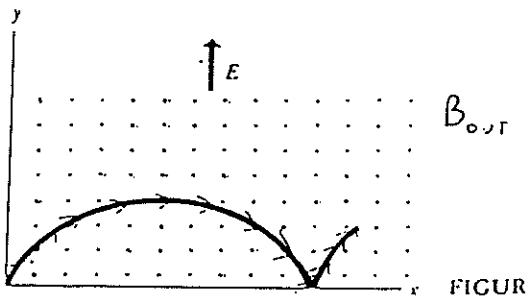
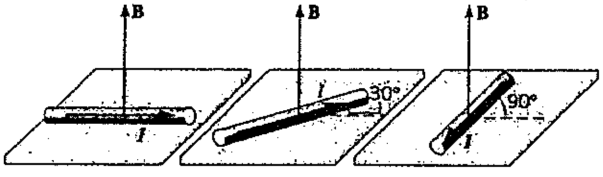


FIGURE 30–24

Section 21.5 The Force on a Current in a Magnetic Field

28. The drawing shows wires of length L and current I, lying in a plane that is perpendicular to a magnetic field **B**. In all cases $B = 0.25$ T, $L = 0.60$ m, and $I = 15$ A. Find the magnitude and direction of the magnetic force on each wire.

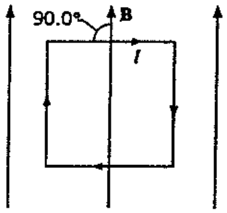


(a) (b) (c)

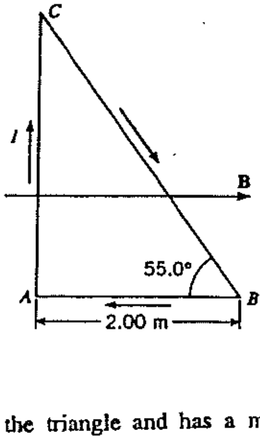
29. **ssm** An electric power line carries a current of 1400 A in a location where the earth's magnetic field is 5.0×10^{-5} T. The line makes an angle of 75° with respect to the field. Determine the magnitude of the magnetic force on a 120-m length of line.

30. Near the equator in South America the earth's magnetic field has a strength of 3.2×10^{-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?

31. 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.



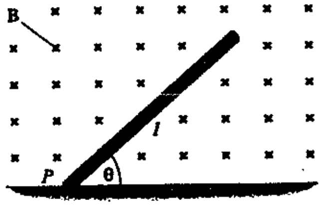
32. The triangular loop of wire shown in the drawing carries a current of $I = 4.70$ A. A uniform magnetic field is directed parallel to side AB of the triangle and has a magnitude of 1.80 T. (a) Find the magnitude and direction of the magnetic force exerted on each side of the triangle. (b) Determine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



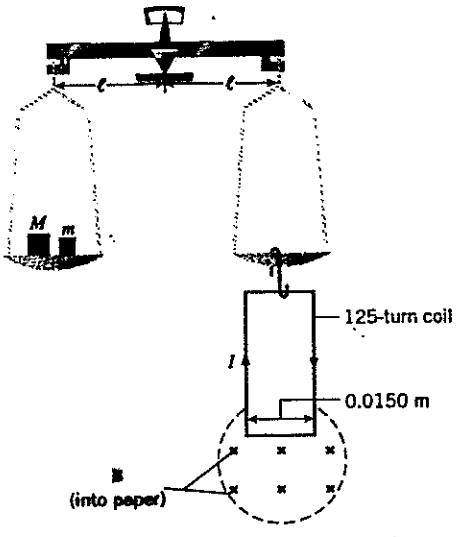
33. **ssm** A wire of length 0.655 m carries a current of 21.0 A. In the presence of a 0.470-T magnetic field, the wire experiences a force of 5.46 N. What is the angle (less than 90°) between the wire and the magnetic field?

34. At New York City, the earth's magnetic field has a vertical (downward) component of 5.2×10^{-5} T and a horizontal component of 1.8×10^{-5} T that is directed toward geographic north. What is the magnitude of the magnetic force on a long, straight wire, 6.0 m in length, that carries a 28-A current due east?

***35.** 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 counter-clockwise. Find the angle θ. *(Hint: The magnetic force may be taken to act at the center of gravity.)*



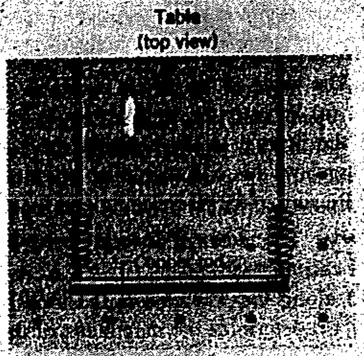
***36.** A 125-turn rectangular coil of wire is hung from one arm of a balance, as the drawing shows. With the magnetic field turned off, a mass M is added to the pan on the other arm to balance the mass of the coil. When a constant magnetic field of magnitude 0.200 T is turned on and there is a current of 8.50 A in the coil, how much *additional* mass m must be added to regain the balance?



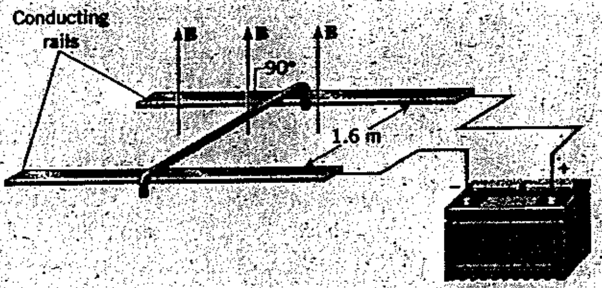
28) 2.39
29) 8.1N
30) east → west, 39A
31) 0.96N, 0.96N, 0N
32) 0N, 24.2N, 24.2N, 0N
out of paper into paper

33) 57.6°
34) 9.2×10^{-3} N
35) 57°
36) 0.325 kg

***37.** **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?



****38.** A 0.20-kg aluminum rod is lying on top of two conducting rails that are separated by 1.6 m. A 0.050-T magnetic field has the direction shown in the drawing. The coefficient of static friction between the rod and a rail is $\mu_s = 0.45$. (a) How much current must be sent through the rod before the rod begins to move? (b) In what direction will the rod move, toward the battery or away from it? Explain.



****39.** Suppose the two conducting rails in problem 38 are tilted upward so they each make an angle of 30.0° with respect to the horizontal. The 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?

37) left → Right
1.1×10^{-2} m

38) 11 A
39) 14A

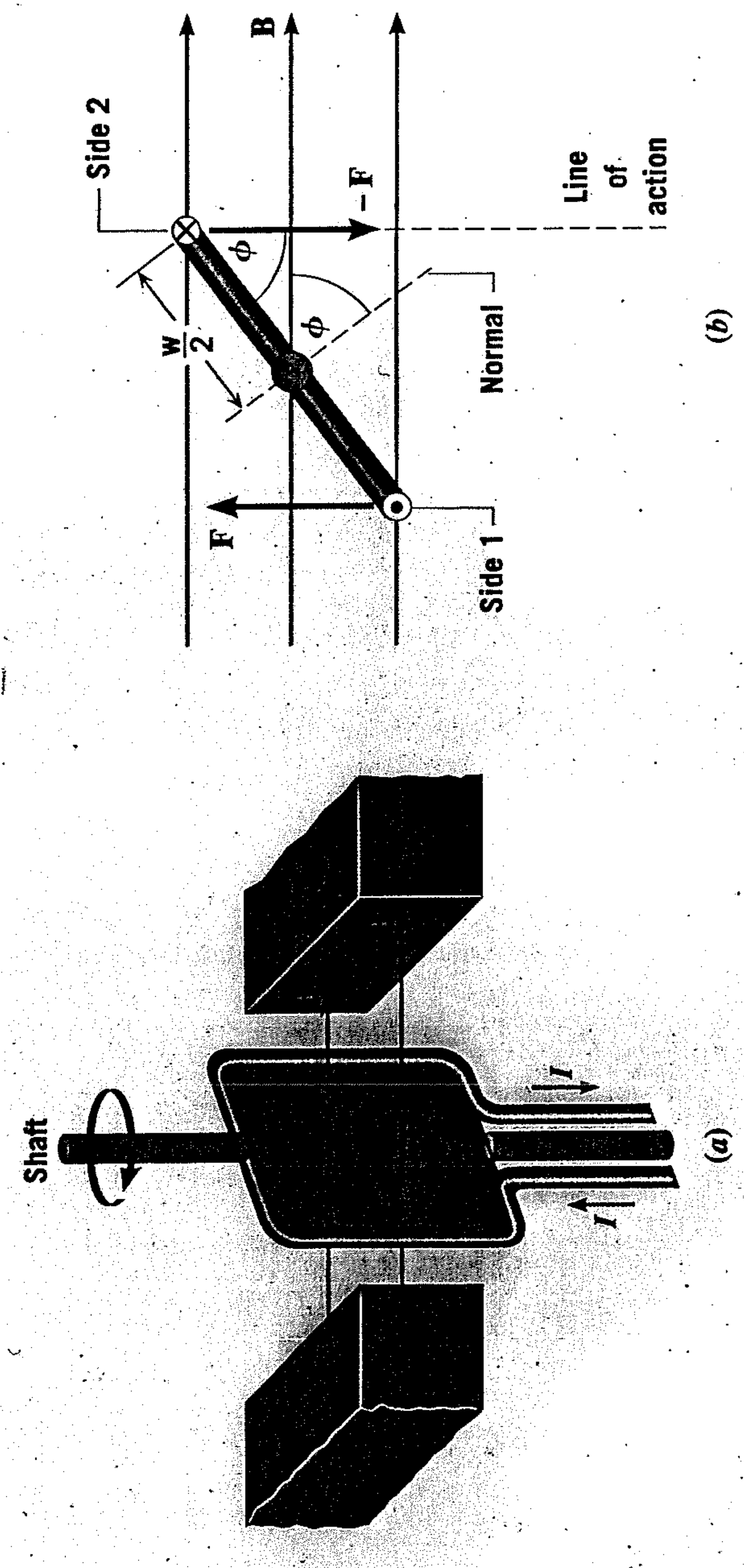

Shaft
I
I
(a)
Side 2
$\frac{w}{2}$
ϕ
ϕ
−F
B
F
Side 1
Normal
Line of action
(b)

FIGURE 21-22

Section 21.6 The Torque on a Current-Carrying Coil

40. A circular coil of one turn is made from a wire of length 7.00×10^{-2} m. There is a current of 4.30 A in the wire. In the presence of a 2.50-T magnetic field, what is the largest torque that this loop can experience?

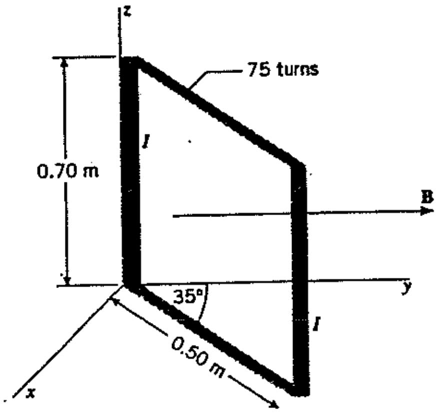
41. **ssm** A circular coil of wire has a radius of 0.10 m. The coil has 50 turns and a current of 15 A, and is placed in a magnetic field whose magnitude is 0.20 T. (a) Determine the magnetic moment of the coil. (b) What is the maximum torque the coil can experience in this field?

42. Suppose the current-carrying triangle in problem 32 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.

43. 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 21.23*a*. What is the maximum torque that the loop can experience?

44. 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.

45. **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. If 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.



46. Review Conceptual Example 7 as background for this problem. A square coil of *N* turns carries a current *I* in a magnetic field *B*. The coil is made from a length *L* of wire. Derive an expression for the maximum torque that this coil experiences. Aside from numerical factors, the expression contains the variables *N*, *I*, *B*, and *L*.

***47.** The coil in Figure 21.23*a* contains 380 turns and has an area per turn of 2.5×10^{-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. If 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?

***48.** 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 $\tau_{\text{square}}/\tau_{\text{rectangle}}$ of the maximum torques that these coils experience in the same magnetic field when they contain the same current.

****49.** **ssm** A charge of 4.0×10^{-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.)*

40) 4.19×10^{-3} N·m

41) 24 A·m^2
4.8 N·m

42) 13.4 Am^2
24.1 N·M

43) 0.023 N·m

44) 53.1°

45) 170 N·m
35° Angle increases

46) $\frac{IL^2B}{16N}$

47) 2.6 N

48) 1.13 N

49) 1.2×10^{-5} A·m^2

WORK SHEET

PHYSICS

30–17 A horizontal rod 0.200 m long is mounted on a balance and carries a current. At the location of the rod there is a uniform horizontal magnetic field with magnitude 0.0800 T and direction perpendicular to the rod. The magnetic force on the rod is measured by the balance and is found to be 0.240 N. What is the current?

30–18 In Exercise 30–17, suppose the magnetic field is horizontal but makes an angle of 30.0° with the rod. What is the current in the rod?

30–19 A wire along the x-axis carries a current of 6.00 A in the $+x$-direction. Calculate the force (magnitude and direction) on a 1.00-cm section of the wire exerted by the following uniform magnetic fields:

a) $B = 0.600$ T, in the $-y$-direction;
b) $B = 0.500$ T, in the $+z$-direction;
c) $B = 0.300$ T, in the $-x$-direction;
d) $B = 0.200$ T, in the xz-plane at an angle of 60.0° from the $+x$-axis and 30.0° from the $+z$-axis.

30–20 A straight, vertical wire carries a current of 8.00 A upward in a region between the poles of a large superconducting electromagnet, where the magnetic field has magnitude $B = 3.00$ T and is horizontal. What are the magnitude and direction of the magnetic force on a 1.00-cm section of the wire if the magnetic field direction is

a) east? b) south? c) 30.0° south of west?

Section 30–8 Force and Torque on a Current Loop

30–21 What is the maximum torque on a rectangular coil 5.00 cm × 12.0 cm and of 600 turns when carrying a current of 4.00×10^{-5} A in a uniform field with magnitude 0.300 T?

30–22 The plane of a rectangular loop of wire 5.00 cm × 8.00 cm is parallel to a magnetic field with magnitude 0.150 T. The loop carries a current of 8.00 A.

a) What torque acts on the loop?
b) What is the magnetic moment of the loop?

30–23 A circular coil of wire 8.00 cm in diameter has 12 turns and carries a current of 4.00 A. The coil is in a region where the magnetic field is 0.600 T.

a) What is the maximum torque on the coil?
b) In what position would the torque be one-half as great as in part (a)?

30–24 A coil with magnetic moment $m = 2.80\ \text{A}\cdot\text{m}^2$ is oriented initially with its magnetic moment parallel to a uniform magnetic field with $B = 0.750$ T. What is the change in potential energy of the coil when it is rotated 180° so that its magnetic moment is antiparallel to the field?

30–25 A circular coil with area A and N turns is free to rotate about a diameter that coincides with the x-axis. Current I is circulating in the coil. There is a uniform magnetic field B in the positive y-direction. Calculate the magnitude of the torque τ when the coil is oriented as shown in parts (a) through (d) of Fig. 30–22.

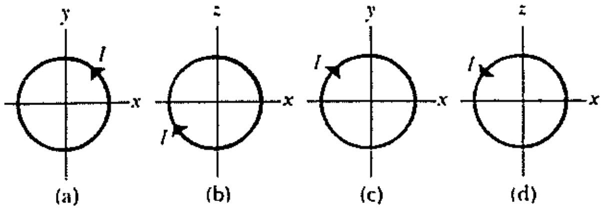


FIGURE 30–22

ANSWERS

17) 15.0 A   18) 30.0 A

19) A) 0.0360 N ; −z
B) 0.0300 N ; −y
c) 0
d) 0.0104 N ; −y

20) A) 0.240 N; North
B) 0.240 N; East
c) 0.240 N; 30° East of South

21) 4.32×10^{-5} N·m   22) a) 4.8×10^{-3} N·m
B) 0.0320 A·m^2

23) A) 0.145 N·m   B) Plane of coil at 60° to the field.

24) +4.20 J

25) A) +NIBA   B) −NIBA
c) +NIBA   d) +NIBA

Section 21.7 Magnetic Fields Produced by Currents

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

51. In a lightning bolt, 15 C of charge flows in a time of 1.5×10^{-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?

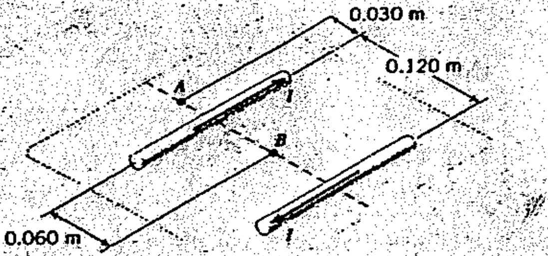
52. What must be the radius of a circular loop of wire so the magnetic field at its center is 1.8×10^{-4} T when the loop carries a current of 12 A?

53. **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 1.2×10^{-3} m^2, and carries a current of 0.50 A. Find the torque exerted on the coil.

54. A long, straight wire is oriented in the north–south direction, and the current in the wire is directed to the north. The horizontal component of the earth's magnetic field is 4.5×10^{-5} T and points due north. A small horizontal compass needle is located directly below the wire, 1.9 cm from it. The compass needle points 35° north of west. What is the current in the wire?

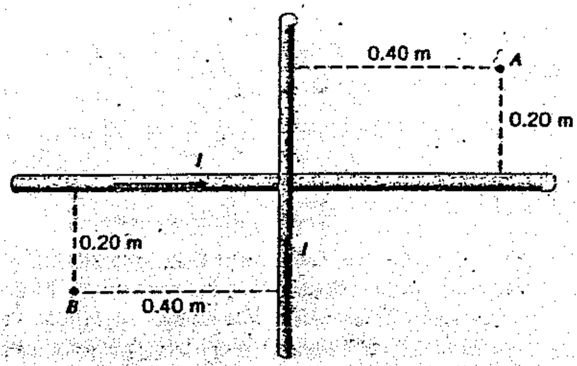
55. Suppose in Figure 21.31*a* that $I_1 = I_2 = 25$ A and that the separation between the wires is 0.016 m. By applying an external magnetic field (created by a source other than the wires) it is possible to cancel the mutual repulsion of the wires. This external field must point along the vertical direction. (a) Does the external field point up or down? Explain. (b) What is the magnitude of the external field?

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



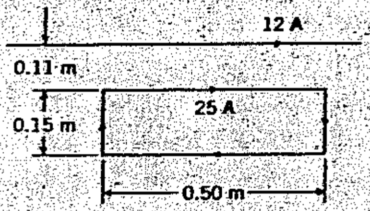
57 **ssm** Two rigid rods are oriented parallel to each other and the ground. The rods carry the same current in the same direcon. The length of each rod is 0.85 m, while the mass of each is 0.073 kg. One rod is held in place above the ground, and the other ests beneath it at a distance of 8.2×10^{-3}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

58. The drawing shows two perpendicular wires that lie in the plane of the paper. Each wire carries a current of 5.6 A. Determine the magnitude and direction of the net magnetic field at points (a) *A* and (b) *B*.



59. 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?

60. As background for this problem, review Conceptual Example 10. 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.



61. **ssm** A piece of copper wire has a resistance per unit length of 5.90×10^{-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.

62. A charge of $+5.7 \times 10^{-5}$ C is distributed uniformly around a thin ring of insulating material. The ring has a radius of 0.38 m and rotates with an angular speed of $\omega = 7400$ rad/s about an axis perpendicular to the plane of the ring and passing through its center. Determine the magnitude of the magnetic field produced at the center of the ring.

50) 0.12 M
51) 8×10^{-5} T
52) 4.2×10^{-2} m
53) 1.9×10^{-4} N·m
54) 6.1 A
55) 3.1×10^{-4} T
56) 4.3×10^{-5} T
5.3×10^{-5} T

57) 190 A
58) $+2.8 \times 10^{-6}$ T OUT OF PAGE
-2.8×10^{-6} T INTO PAGE
59) 6.8 A OPPOSITE DIR.
60) 1.5×10^{-4} N

Solutions from the AP Physics B magnetism packet, sections:
21.6 Torque on a current carrying wire : 40-43,45
21.7 Magnetic Fields produced by currents: 50-54,56,60

40. ***REASONING AND SOLUTION*** We know that the torque is $\tau = NIAB \sin \phi$. For the maximum torque, $\phi = 90.0°$. To find the area A, note that the length of the wire is $L = 2\pi r$, where r is the radius of the circle. Thus,

$$r = L/(2\pi) = (7.00 \times 10^{-2}\ \text{m})/(2\pi) = 1.114 \times 10^{-2}\ \text{m}$$

The area of the circle is, therefore,

$$A = \pi r^2 = \pi(1.114 \times 10^{-2}\ \text{m})^2 = 3.899 \times 10^{-4}\ \text{m}^2$$

The maximum torque is

$$\tau = NIAB \sin 90.0° = (1)(4.30\ \text{A})(3.899 \times 10^{-4}\ \text{m}^2)(2.50\ \text{T}) = \boxed{4.19 \times 10^{-3}\ \text{N} \cdot \text{m}}$$

41. SSM ***REASONING AND SOLUTION***

a. The magnetic moment of the coil is

$$\textit{Magnetic moment} = NIA = (50)(15\ \text{A})\left[\pi(0.10\ \text{m})^2\right] = \boxed{24\ \text{A} \cdot \text{m}^2}$$

where we have used the fact that the area of the circular loop is $A = \pi r^2 = \pi(0.10\ \text{m})^2$.

b. According to Equation 21.4, the torque is the product of the magnetic moment NIA and $B \sin \phi$. However, the maximum torque occurs when $\phi = 90.0°$, so we have

$$\tau = (\textit{Magnetic moment})(B \sin 90.0°) = (24\ \text{A} \cdot \text{m}^2)(0.20\ \text{T}) = \boxed{4.8\ \text{N} \cdot \text{m}}$$

42. ***REASONING*** The magnetic moment of the current-carrying triangle is the product of the current I and the area A of the triangle. The magnitude τ of the torque exerted on the triangle by the magnetic field is equal to the product of the magnetic moment, the magnitude B of the magnetic field, and the sine of the angle ϕ between the magnetic field and the normal to the plane of the triangle, $\tau = (\textit{Magnetic moment})\ B \sin \phi$.

SOLUTION

a. The area of a triangle is equal to one-half the base times the height,

$$A = \tfrac{1}{2}(2.00\ \text{m})\left[(2.00\ \text{m})\tan 55.0°\right] = 2.86\ \text{m}^2$$

The magnetic moment is

$$\textit{Magnetic moment} = IA = (4.70\ \text{A})(2.86\ \text{m}^2) = \boxed{13.4\ \text{A} \cdot \text{m}^2}$$

b. The magnitude of the net torque exerted on the triangle is

$$\begin{aligned} \tau &= (\textit{Magnetic moment})B \sin \phi & (21.4) \\ &= (13.4\ \text{A} \cdot \text{m}^2)(1.80\ \text{T})\sin 90.0° = \boxed{24.1\ \text{N} \cdot \text{m}} \end{aligned}$$

43. ***REASONING AND SOLUTION*** The maximum torque occurs when $\phi = 90.0°$ so that $\tau = NIAB$. For a square loop, $A = (L/4)^2 = (0.50\ \text{m}/4)^2 = 1.6 \times 10^{-2}\ \text{m}^2$. So,

$$\tau = NIAB = (1)(12\ A)(1.6 \times 10^{-2}\ \text{m}^2)(0.12\ \text{T}) = \boxed{0.023\ \text{N} \cdot \text{m}}$$

44. ***REASONING AND SOLUTION*** The torque is given by $\tau = NIAB \sin \phi$

a. The maximum torque occurs when $\phi = 90.0°$ ($\sin \phi = 1$). In this case we want the torque to be 80.0% of the maximum value, so

$$NIAB \sin \phi = 0.800(NIAB \sin 90.0°) \quad \text{so that} \quad \phi = \sin^{-1}(0.800) = \boxed{53.1°}$$

45. SSM WWW ***REASONING*** The torque on the loop is given by Equation 21.4, $\tau = NIAB\sin\phi$. From the drawing in the text, we see that the angle ϕ between the normal to the plane of the loop and the magnetic field is $90° - 35° = 55°$. The area of the loop is $0.70\ \text{m} \times 0.50\ \text{m} = 0.35\ \text{m}^2$.

SOLUTION

a. The magnitude of the net torque exerted on the loop is

$$\tau = NIAB \sin \phi = (75)(4.4\ \text{A})(0.35\ \text{m}^2)(1.8\ \text{T}) \sin 55° = \boxed{170\ \text{N} \cdot \text{m}}$$

b. As discussed in the text, when a current-carrying loop is placed in a magnetic field, the loop tends to rotate such that its normal becomes aligned with the magnetic field. The normal to the loop makes an angle of 55° with respect to the magnetic field. Since this angle decreases as the loop rotates, the $\boxed{35° \text{ angle increases}}$.

46. ***REASONING AND SOLUTION*** According to Equation 21.4, the maximum torque is $\tau_{\text{max}} = NIAB \sin 90.0° = NIAB$. The area A of a square is $A = d^2$, where d is the length of one of the sides. Since the total length L of the wire is used to create $4N$ sides, the length of one side is $d = L/(4N)$. Thus, the area is $A = [L/(4N)]^2$. Using this expression for the area, we find that the maximum torque is

$$\tau_{\text{max}} = NIAB = NI\left(\frac{L}{4N}\right)^2 B = \boxed{\frac{IL^2 B}{16N}}$$

47. ***REASONING AND SOLUTION*** In Figure 21.23a the magnetic torque is a maximum. Equation 21.4 gives this maximum torque as $\tau_{\text{max}} = NIAB$. The torque from the brake balances this magnetic torque. The brake torque is $\tau_{\text{brake}} = F_{\text{brake}} r$, where F_{brake} is the brake force, and r is the radius of the shaft and also the lever arm. The maximum value for the brake force available from static friction is $F_{\text{brake}} = \mu_s F_{\text{N}}$, where F_{N} is the normal force pressing the brake shoe against the shaft. The brake torque, then, is $\tau_{\text{brake}} = \mu_s F_{\text{N}} r$. Therefore, we can obtain the magnitude of the minimum normal force as follows:

$$\tau_{\text{brake}} = \tau_{\text{max}} \quad \text{or} \quad \mu_s F_{\text{N}} r = NIAB$$

$$F_{\text{N}} = \frac{NIAB}{\mu_s r} = \frac{(380)(0.16\ A)(2.5 \times 10^{-3}\ \text{m}^2)(0.12\ \text{T})}{(0.70)(0.010\ \text{m})} = \boxed{2.6\ \text{N}}$$

48. ***REASONING AND SOLUTION*** According to Equation 21.4, the maximum torque for a single turn is $\tau_{\text{max}} = IAB$. When the length L of the wire is used to make the square, each side of the square has a length $L/4$. The area of the square is $A_{\text{square}} = (L/4)^2$. For the rectangle, since two sides have a length d, while the other two sides have a length $2d$, it follows that $L = 6d$, or $d = L/6$. The area is $A_{\text{rectangle}} = 2d^2 = 2(L/6)^2$. Using Equation 21.4 for the square and the rectangle, we obtain

$$\frac{\tau_{\text{square}}}{\tau_{\text{rectangle}}} = \frac{IA_{\text{square}}B}{IA_{\text{rectangle}}B} = \frac{A_{\text{square}}}{A_{\text{rectangle}}} = \frac{(L/4)^2}{2(L/6)^2} = \boxed{1.13}$$

49. SSM ***REASONING*** The magnetic moment of the rotating charge can be found from the expression $\textit{Magnetic moment} = NIA$. For this situation, $N = 1$. Thus, we need to find the current and the area for the rotating charge. This can be done by resorting to first principles.

SOLUTION The current for the rotating charge is, by definition (see Equation 20.1), $I = \Delta q / \Delta t$, where Δq is the amount of charge that passes by a given point during a time interval Δt. Since the charge passes by once per revolution, we can find the current by dividing the total rotating charge by the period T of revolution.

$$I = \frac{\Delta q}{T} = \frac{\Delta q}{2\pi / \omega} = \frac{\omega \Delta q}{2\pi} = \frac{(150\ \text{rad/s})(4.0 \times 10^{-6}\ \text{C})}{2\pi} = 9.5 \times 10^{-5}\ \text{A}$$

The area of the rotating charge is $A = \pi r^2 = \pi(0.20\ \text{m})^2 = 0.13\ \text{m}^2$

Therefore, the magnetic moment is

$$\textit{Magnetic moment} = NIA = (1)(9.5 \times 10^{-5}\ \text{A})(0.13\ \text{m}^2) = \boxed{1.2 \times 10^{-5}\ \text{A} \cdot \text{m}^2}$$

50. ***REASONING AND SOLUTION*** The magnitude B of the magnetic field at a distance r from a long straight wire carrying a current I is $B = \mu_0 I/(2\pi r)$. Thus, the distance is

$$r = \frac{\mu_0 I}{2\pi B} = \frac{(4\pi \times 10^{-7}\ \text{T} \cdot \text{m/A})(48\ \text{A})}{2\pi(8.0 \times 10^{-5}\ \text{T})} = \boxed{0.12\ \text{m}} \qquad (21.5)$$

51. ***REASONING AND SOLUTION*** The current associated with the lightning bolt is

$$I = \frac{\Delta q}{\Delta t} = \frac{15\ \text{C}}{1.5 \times 10^{-3}\ \text{s}} = 1.0 \times 10^4\ \text{A}$$

The magnetic field near this current is given by

$$B = \frac{\mu_0 I}{2\pi r} = \frac{(4\pi \times 10^{-7}\ \text{T} \cdot \text{m/A})(1.0 \times 10^4\ \text{A})}{2\pi(25\ \text{m})} = \boxed{8.0 \times 10^{-5}\ \text{T}}$$

52. ***REASONING AND SOLUTION*** The magnetic field at the center of a current loop of radius R is given by $B = \mu_0 I/(2R)$, so that

$$R = \frac{\mu_0 I}{2B} = \frac{(4\pi \times 10^{-7}\ \text{T} \cdot \text{m/A})(12\ \text{A})}{2(1.8 \times 10^{-4}\ \text{T})} = \boxed{4.2 \times 10^{-2}\ \text{m}}$$

53. SSM ***REASONING*** The coil carries a current and experiences a torque when it is placed in an external magnetic field. Thus, when the coil is placed in the magnetic field due to the solenoid, it will experience a torque given by Equation 21.4: $\tau = NIAB\sin\phi$, where N is the number of turns in the coil, A is the area of the coil, B is the magnetic field inside the solenoid, and ϕ is the angle between the normal to the plane of the coil and the magnetic field. The magnetic field in the solenoid can be found from Equation 21.7, $B = \mu_0 nI$, where n is the number of turns per unit length of the solenoid and I is the current through the solenoid.

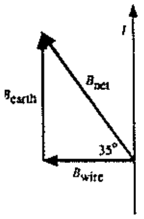
SOLUTION The magnetic field inside the solenoid is

$$B = \mu_0 nI = (4\pi \times 10^{-7}\ \text{T} \cdot \text{m/A})(1400\ \text{turns/m})(3.5\ \text{A}) = 6.2 \times 10^{-3}\ \text{T}$$

The torque exerted on the coil is

$$\tau = NIAB\sin\phi = (50)(0.50\ \text{A})(1.2 \times 10^{-3}\ \text{m}^2)(6.2 \times 10^{-3}\ \text{T})(\sin 90.0°) = \boxed{1.9 \times 10^{-4}\ \text{N} \cdot \text{m}}$$

54. ***REASONING*** The drawing below shows a top view of the current-carrying wire. The magnetic field that it produces at a distance r below the wire is labeled as B_{wire} and points to the left (the direction is determined by using Right-Hand Rule No. 2). The magnitude of B_{wire} is $B_{\text{wire}} = \mu_0 I/2\pi r$. The diagram also shows the earth's magnetic field, B_{earth}, and the net magnetic field, B_{net}, as sensed by the compass. By using these results with the aid of trigonometry, we can determine the current in the wire.



SOLUTION From the right triangle in the drawing, we see that $B_{\text{earth}} = B_{\text{wire}} \tan 35°$. Substituting in the value of B_{wire} from above and solving for the current I, we find that

$$I = \frac{2\pi r B_{\text{earth}}}{\mu_0 \tan 35°} = \frac{2\pi\left(1.9\times10^{-2}\ \text{m}\right)\left(4.5\times10^{-5}\ \text{T}\right)}{\left(4\pi\times10^{-7}\ \text{T}\cdot\text{m/A}\right)\tan 35°} = \boxed{6.1\ \text{A}}$$

---

55. ***REASONING AND SOLUTION***

a. In Figure 21.31a the magnetic field that exists at the location of each wire points upward. Since the current in each wire is the same, the fields at the locations of the wires also have the same magnitudes. Therefore, a single external field that points $\boxed{\text{downward}}$ will cancel the mutual repulsion of the wires, if this external field has a magnitude that equals that of the field produced by either wire.

b. Equation 21.5 gives the magnitude of the field produced by a long straight wire. The external field must have this magnitude:

$$B = \frac{\mu_0 I}{2\pi r} = \frac{\left(4\pi\times10^{-7}\ \text{T}\cdot\text{m/A}\right)\left(25\ \text{A}\right)}{2\pi(0.016\ \text{m})} = \boxed{3.1\times10^{-4}\ \text{T}}$$

---

56. ***REASONING AND SOLUTION*** Let the current in the left-hand wire be labeled I_1 and that in the right-hand wire I_2.

a. At point A: B_1 is *up* and B_2 is *down*, so we subtract them to get the net field. We have

$$B_1 = \mu_0 I_1/2\pi d_1 = \mu_0\,(8.0\ \text{A})/[2\pi(0.030\ \text{m})]$$
$$B_2 = \mu_0 I_2/2\pi d_2 = \mu_0\,(8.0\ \text{A})/[2\pi(0.150\ \text{m})]$$

So the net field at point A is

$$B_A = B_1 - B_2 = \boxed{4.3\times10^{-5}\ \text{T}}$$

b. At point B: B_1 and B_2 are both *down* so we add the two. We have

$$B_1 = \mu_0(8.0\ \text{A})/[2\pi(0.060\ \text{m})]$$
$$B_2 = \mu_0\,(8.0\ \text{A})/[2\pi(0.060\ \text{m})]$$

So the net field at point B is

$$B_B = B_1 + B_2 = \boxed{5.3\times10^{-5}\ \text{T}}$$

---

57. SSM ***REASONING*** The two rods attract each other because they each carry a current I in the same direction. The bottom rod floats because it is in equilibrium. The two forces that act on the bottom rod are the downward force of gravity mg and the upward magnetic force of attraction to the upper rod. If the two rods are a distance s apart, the magnetic field generated by the top rod at the location of the bottom rod is (see Equation 21.5) $B = \mu_0 I/(2\pi s)$. According to Equation 21.3, the magnetic force exerted on the bottom rod is $F = ILB\sin\theta = \mu_0 I^2 L\sin\theta/(2\pi s)$, where θ is the angle between the magnetic field at the location of the bottom rod and the direction of the current in the bottom rod. Since the rods are parallel, the magnetic field is perpendicular to the direction of the current (RHR-2), and $\theta = 90.0°$, so that $\sin\theta = 1.0$.

SOLUTION Taking upward as the positive direction, the net force on the bottom rod is

$$\frac{\mu_0 I^2 L\sin\theta}{2\pi s} - mg = 0$$

Solving for I, we find

$$I = \sqrt{\frac{2\pi mgs}{\mu_0 L}} = \sqrt{\frac{2\pi(0.073\ \text{kg})(9.80\ \text{m/s}^2)(8.2\times10^{-3}\ \text{m})}{(4\pi\times10^{-7}\ \text{T}\cdot\text{m/A})(0.85\ \text{m})}} = \boxed{190\ \text{A}}$$

---

58. ***REASONING*** The magnitude B of the magnetic field produced by a long straight wire is given by Equation 21.5 as $B = \mu_0 I/2\pi r$. The net magnetic field produced at any spot due to the two wires is the vector sum of the magnetic fields produced by the wires. To find the directions of the magnetic fields, we will use Right-Hand Rule No. 2.

SOLUTION

a. The magnitude B_{H} of the magnetic field at point A due to the horizontal wire is

$$B_{\text{H}} = \frac{\mu_0 I}{2\pi r} = \frac{\left(4\pi\times10^{-7}\ \text{T}\cdot\text{m/A}\right)\left(5.6\text{A}\right)}{2\pi\left(0.20\text{m}\right)} = 5.6\times10^{-6}\ \text{T}$$

According to Right-Hand Rule No. 2, the direction of B_{H} is perpendicular to the plane of the paper and directed out of the page, toward the reader.

The magnitude B_{V} of the magnetic field at point A due to the vertical wire is

$$B_{\text{V}} = \frac{\mu_0 I}{2\pi r} = \frac{\left(4\pi\times10^{-7}\ \text{T}\cdot\text{m/A}\right)\left(5.6\text{A}\right)}{2\pi\left(0.40\text{m}\right)} = 2.8\times10^{-6}\ \text{T}$$

According to Right-Hand Rule No. 2, the direction of B_{V} is perpendicular to the plane of the paper and directed into the page, away from the reader. Taking "out of the page" as the positive direction, the net magnetic field at point A is

$$B_{\text{net}} = B_{\text{H}} - B_{\text{V}} = 5.6\times10^{-6}\ \text{T} - 2.8\times10^{-6}\ \text{T} = \boxed{+2.8\times10^{-6}\ \text{T}}$$

where the plus sign indicated that

$$\boxed{\text{the direction of } B_{\text{net}} \text{ is out of the page, toward the reader}}.$$

b. The magnitude of the magnetic field at point B due to the horizontal wire is

$$B_{\text{H}} = \frac{\mu_0 I}{2\pi r} = \frac{\left(4\pi\times10^{-7}\ \text{T}\cdot\text{m/A}\right)\left(5.6\text{A}\right)}{2\pi\left(0.20\text{m}\right)} = 5.6\times10^{-6}\ \text{T}$$

According to Right-Hand Rule No. 2, the direction of B_{H} is perpendicular to the plane of the page and directed into the page, away the reader.

The magnitude of the magnetic field at point B due to the vertical wire is

$$B_{\text{V}} = \frac{\mu_0 I}{2\pi r} = \frac{\left(4\pi\times10^{-7}\ \text{T}\cdot\text{m/A}\right)\left(5.6\text{A}\right)}{2\pi\left(0.40\text{m}\right)} = 2.8\times10^{-6}\ \text{T}$$

According to Right-Hand Rule No. 2, the direction of B_{V} is perpendicular to the plane of the page and directed out of the page, toward the reader. Taking "out of the page" as the positive direction, the net magnetic field at point A is

$$B_{\text{net}} = -B_{\text{H}} + B_{\text{V}} = -5.6\times10^{-6}\ \text{T} + 2.8\times10^{-6}\ \text{T} = -2.8\times10^{-6}\ \text{T}$$

The magnitude of the magnetic field is $B_{\text{net}} = \boxed{2.8\times10^{-6}\ \text{T}}$, and the minus sign indicated that

$$\boxed{\text{the direction of } B_{\text{net}} \text{ is into the page, away from the reader}}.$$

---

59. ***REASONING AND SOLUTION*** The magnitude B_{i} of the magnetic field due to the inner coil is

$$B_{\text{i}} = \mu_0 I_{\text{i}} N_{\text{i}}/2\pi r_{\text{i}}$$

The magnetic field B_0 due to the outer coil must cancel that due to the inner coil. We have

$$B_0 = \mu_0 I_0 N_0/2\pi r_0$$

and this must equal B_{i}. Therefore,

$$\mu_0 I_{\text{i}} N_{\text{i}}/2\pi r_{\text{i}} = \mu_0 I_0 N_0/2\pi r_0$$

so that

$$I_0 = I_{\text{i}}\left(\frac{N_{\text{i}}}{N_0}\right)\left(\frac{r_0}{r_{\text{i}}}\right) = (6.0\ \text{A})\left(\frac{120\ \text{turns}}{150\ \text{turns}}\right)\left(\frac{0.017\ \text{m}}{0.012\ \text{m}}\right) = \boxed{6.8\ \text{A}}$$

In order for the two fields to be equal in magnitude but opposite in direction, the current in the outer coil must flow in the $\boxed{\text{opposite direction}}$ as the inner coil current.

---

60. ***REASONING AND SOLUTION*** The net force on the wire loop is a sum of the forces on each segment of the loop. The forces on the two segments perpendicular to the long straight wire cancel each other out. The net force on the loop is therefore the sum of the forces on the parallel segments (near and far). These are

$$F_{\text{n}} = \mu_0 I_1 I_2 L/2\pi d_{\text{n}} = \mu_0(12\ \text{A})(25\ \text{A})(0.50\ \text{m})/[2\pi(0.11\ \text{m})] = 2.7\times10^{-4}\ \text{N}$$

$$F_{\text{f}} = \mu_0 I_1 I_2 L/2\pi d_{\text{f}} = \mu_0(12\ \text{A})(25\ \text{A})(0.50\ \text{m})/[2\pi(0.26\ \text{m})] = 1.2\times10^{-4}\ \text{N}$$

Note: F_{n} is a force of attraction, while F_{f} is a repulsive one. The magnitude of the net force is, therefore,

$$F = F_{\text{n}} - F_{\text{f}} = 2.7\times10^{-4}\ \text{N} - 1.2\times10^{-4}\ \text{N} = \boxed{1.5\times10^{-4}\ \text{N}}$$

DiBucci

PRACTICE PROBLEMS

1. The electrons in the beam of a television tube have an energy of 15 keV. The tube is oriented so that the electrons move horizontally from east to west. The earth's magnetic field points down and has a magnitude $B = 4.5 \times 10^{-5}$ T. (a) In what direction will the beam deflect? (b) What is the acceleration of a given electron?

$5.8 X 10^{14} m/s^2$

2. Protons in a magnetic field of 0.80 T follow a circular trajectory of 75-cm radius. (a) What is the speed of the protons? (b) If electrons traveled at the same speed in this field, what would the radius of their trajectory be?

$5.7 X 10^{7} m/s$

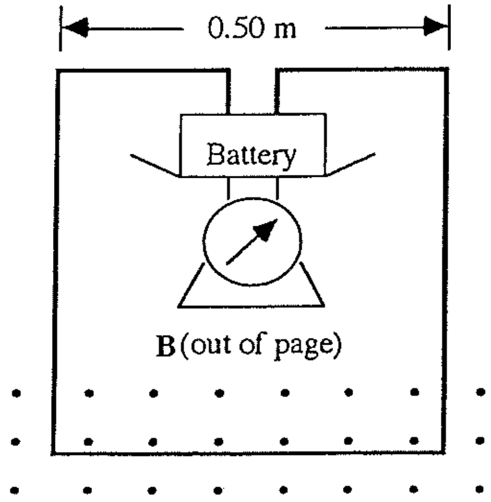
$4.1 X 10^{-4} m$

3. Two isotopes of carbon, carbon-12 and carbon-13, have masses of 19.92×10^{-27} kg and 21.59×10^{-27} kg, respectively. These two isotopes are singly ionized and each is given a speed of 6.667×10^{5} m/s. The ions then enter the bending region of a mass spectrometer where the magnetic field is 0.8500 T. Determine the spatial separation between the two isotopes after they have traveled through a half-circle.

$1.6 X 10^{-2} m$

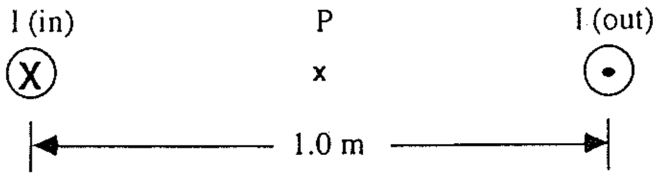
4. A weighing scale supports a battery, to which a rigid wire loop is attached, as shown in the figure. The lower part of the loop is in a magnetic field of 0.20 T. If the combined mass of the battery and wire loop is 0.25 kg, what current in the wire is necessary for the scale to indicate zero weight? Which pole of the battery is positive?

25A



5. Two wires parallel to one another are separated by 1.0 m, as shown in the figure. Each carries a current of 3.0 A, but in opposite directions. Find the magnitude and direction of the magnetic field at a point P midway between the wires.

2.4×10^{-6} T
Down



6. Two parallel straight wires are separated by a distance Of 0.75 m and carry currents $I_1 = 25$ A and $I_2 = 35$ A. Find the force (magnitude and direction) that each wire exerts on a 2.5 m length of the other wire if the currents are (a) in the same direction and (b) in the opposite directions.

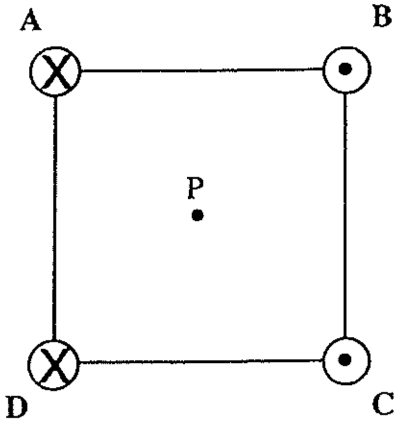
5.8×10^{-4} N

7. You are given 251 m of copper wire that can carry a current of 0.500 A without excessive heating. This wire is used to make a solenoid of 25.0 cm length and 3.00 cm diameter. Determine the magnetic field that can be achieved at the center of the solenoid.

6.66×10^{-3} T

8. Four long, parallel conductors all carry currents of 5.0 A. An end view of the conductors is shown in the figure below. The current directions for wires A and D are into the page (indicated by crosses) while the current directions for B and C are out of the page (indicated by dots). Calculate the magnitude and direction of the magnetic field at point P, located at the center of the square of edge length 0.40 m.

1.0×10^{-5} T
Down



SOLUTIONS AND ANSWERS

Practice Problems

---

1. (a) The direction of the beam is obtained using RHR-1. With B down (fingers point down), and the velocity to the west (thumb to the west), the palm of the hand (F) is facing south. For an electron, force is directed **north**.
(b) The kinetic energy is

$$KE = (1/2)mv^2 = (15\,000 \text{ eV})(1.6 \times 10^{-19} \text{ J}/1 \text{ eV}) = 2.4 \times 10^{-15} \text{ J}.$$

Solving for v yields,

$$v^2 = 2KE/m = 2(2.4 \times 10^{-15} \text{ J})/(9.11 \times 10^{-31} \text{ kg}) \Rightarrow v = 7.3 \times 10^7 \text{ m/s}.$$

The force is $F = qvB \sin\theta$ ($\theta = 90°$). The acceleration can therefore be obtained using

$$a = F/m = qvB \sin 90°/m = (1.6 \times 10^{-19} \text{ C})(7.3 \times 10^7 \text{ m/s})(4.5 \times 10^{-5} \text{ T})/(9.11 \times 10^{-31} \text{ kg}) = \mathbf{5.8 \times 10^{14} \text{ m/s}^2}.$$

---

2. (a) Solving equation (21.2) for the velocity yields

$$v = qrB/m = (1.6 \times 10^{-19} \text{ C})(0.75 \text{ m})(0.80 \text{ T})/(1.67 \times 10^{-27} \text{ kg}) = \mathbf{5.7 \times 10^7 \text{ m/s}}.$$

(b) For an electron,

$$r = mv/qB = (9.11 \times 10^{-31} \text{ kg})(5.7 \times 10^7 \text{ m/s})/[(1.6 \times 10^{-19} \text{ C})(0.80 \text{ T})] = \mathbf{4.1 \times 10^{-4} \text{ m}}.$$

---

3. The spatial separation of the two isotopes is the difference between the diameter of their trajectories. Therefore,

$$r_{12} = m_{12}v/qB = (19.92 \times 10^{-27} \text{ kg})(6.667 \times 10^5 \text{ m/s})/[(1.602 \times 10^{-19} \text{ C})(0.8500 \text{ T})] = 9.753 \times 10^{-2} \text{ m}.$$

$$r_{13} = m_{13}v/qB = (21.59 \times 10^{-27} \text{ kg})(6.667 \times 10^5 \text{ m/s})/[(1.602 \times 10^{-19} \text{ C})(0.8500 \text{ T})] = 10.57 \times 10^{-2} \text{ m}.$$

The spatial separation is therefore, $s = 2(r_{13} - r_{12}) = \mathbf{1.6 \times 10^{-2} \text{ m}}$.

---

4. To support the weight of the battery, the magnetic force on the wire must equal the weight of the battery. That is $F = ILB \sin\theta = mg$. Using $\theta = 90°$ we can solve for the current to obtain,

$$I = mg/LB = (0.25 \text{ kg})(9.80 \text{ m/s}^2)/[(0.50 \text{ m})(0.20 \text{ T})] = \mathbf{25 \text{ A}}.$$

In order to balance the weight, the magnetic force must be directed UP. Since the field is OUT of the page, and the force is up, RHR-1 tells us I is to the left. Therefore, the **right-hand terminal is positive.**

---

5. At point P, the field due to each wire is pointing DOWN, as determined from RHR-2. Since each wire carries the same current and is at the same distance from P, the total field is

$$B_{TOT} = 2B = 2(\mu_0 I/2\pi r) = \mu_0 I/\pi r = (4\pi \times 10^{-7} \text{ T m/A})(3.0 \text{ A})/\pi(0.50 \text{ m}) = \mathbf{2.4 \times 10^{-6} \text{ T, DOWN}}.$$

---

6. The magnitude of the force between the wires (see example 9 in the text) is

$$F = \mu_0 I_1 I_2 L/2\pi r = (4\pi \times 10^{-7}\ \text{T m/A})(25\ \text{A})(35\ \text{A})(2.5\ \text{m})/2\pi(0.75\ \text{m}) = \mathbf{5.8 \times 10^{-4}\ N}.$$

(a) If the currents are in the same direction, by RHR-2 and RHR-1, the force is one of **attraction.**
(b) If the currents flow in opposite directions through each wire, the force is one of **repulsion.**

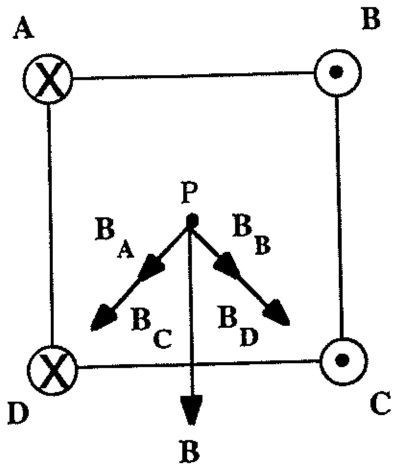
---

7. To find the number of turns of wire, divide the total length of the wire (251 m) by the length per turn, which is just $l = 2\pi r = 2\pi(1.50 \times 10^{-2}\ \text{m}) = 0.0942$ m per turn. Thus, N = (251 m)/(0.0942 m/turn) = 2660 turns. Since the solenoid is 25.0 cm in length, n = 2660 turns/0.250 m = 10 600 turns/m. The magnetic field at the center is

$$B = \mu_0 n I = (4\pi \times 10^{-7}\ \text{T m/A})(10\ 600\ \text{m}^{-1})(0.500\ \text{A}) = \mathbf{6.66 \times 10^{-3}\ T}.$$

---

8. The diagram showing the directions of the fields due to each wire is shown below.



Since each wire carries the same current, and each is equidistant from the center, $r^2 = (0.20\ \text{m})^2 + (0.20\ \text{m})^2$, so r = 0.28 m. The field due to each wire is

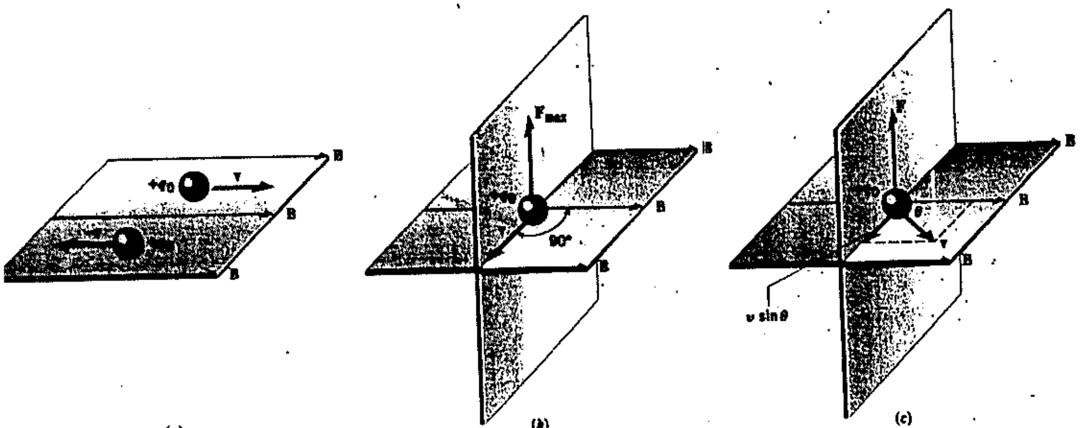
$$B = \mu_0 I/2\pi r = (4\pi \times 10^{-7}\ \text{T m/A})(5.0\ \text{A})/2\pi(0.28\ \text{m}) = 3.6 \times 10^{-6}\ \text{T}.$$

Note that the x-components of the fields vanish, while the y-components add together. The total field is thus,

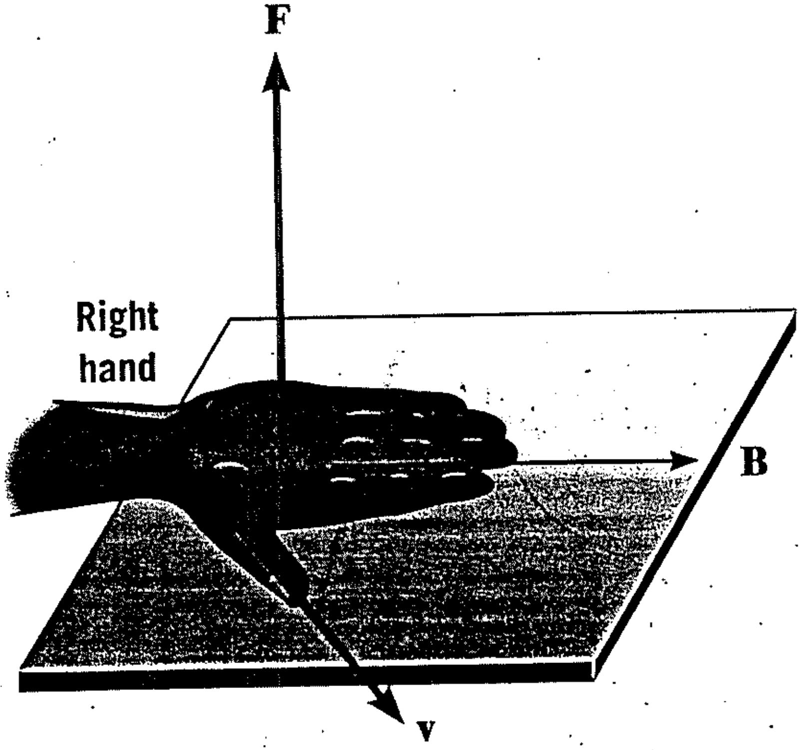
$$B_{tot} = 4B \sin 45° = 4(3.6 \times 10^{-6}\ \text{T}) \sin 45° = \mathbf{1.0 \times 10^{-5}\ T,\ DOWN}.$$

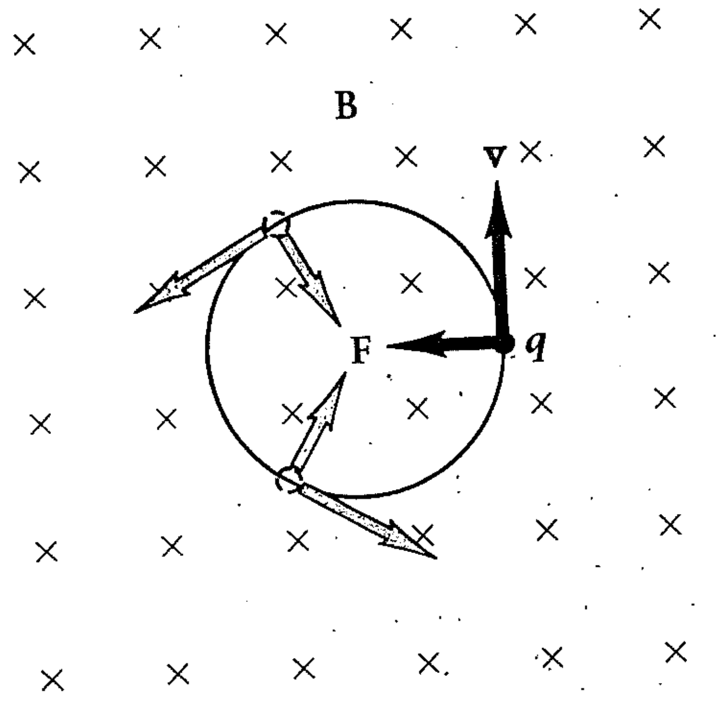
Quiz answers

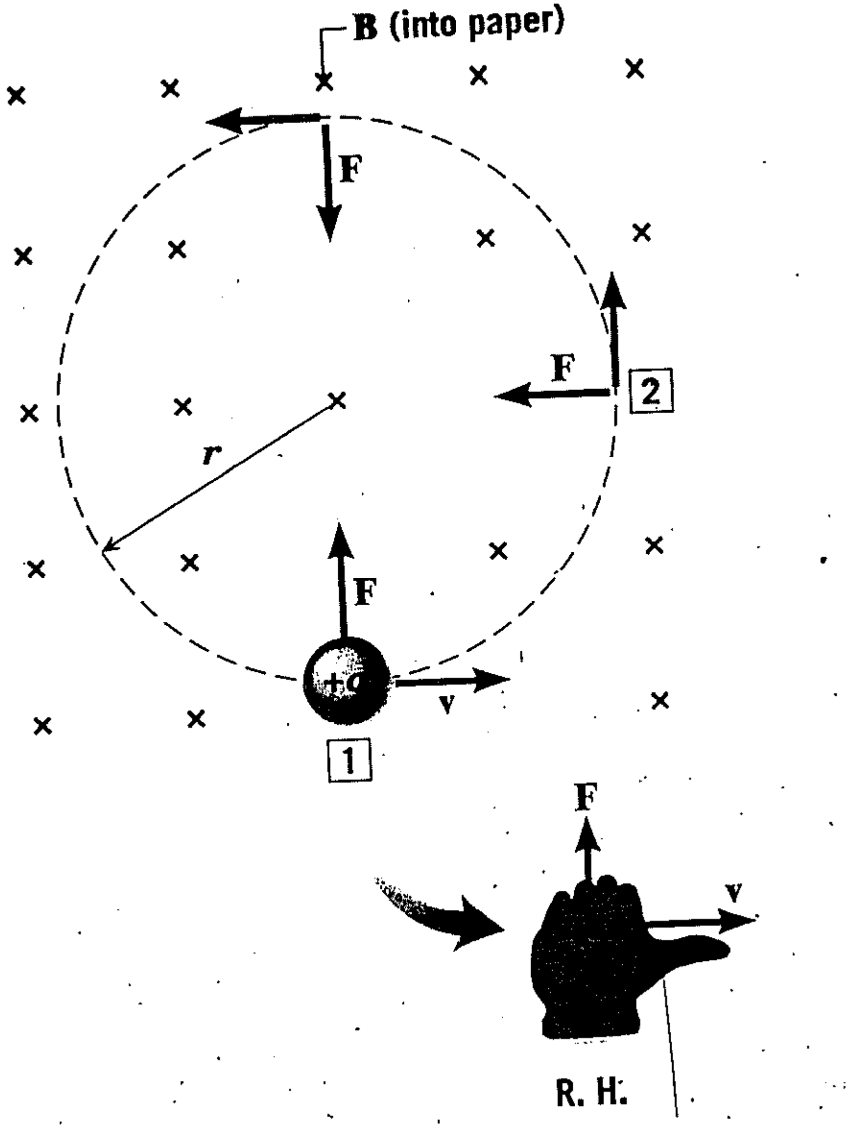
1. d
2. a
3. c
4. c
5. b
6. c
7. d
8. d
9. a
10. b

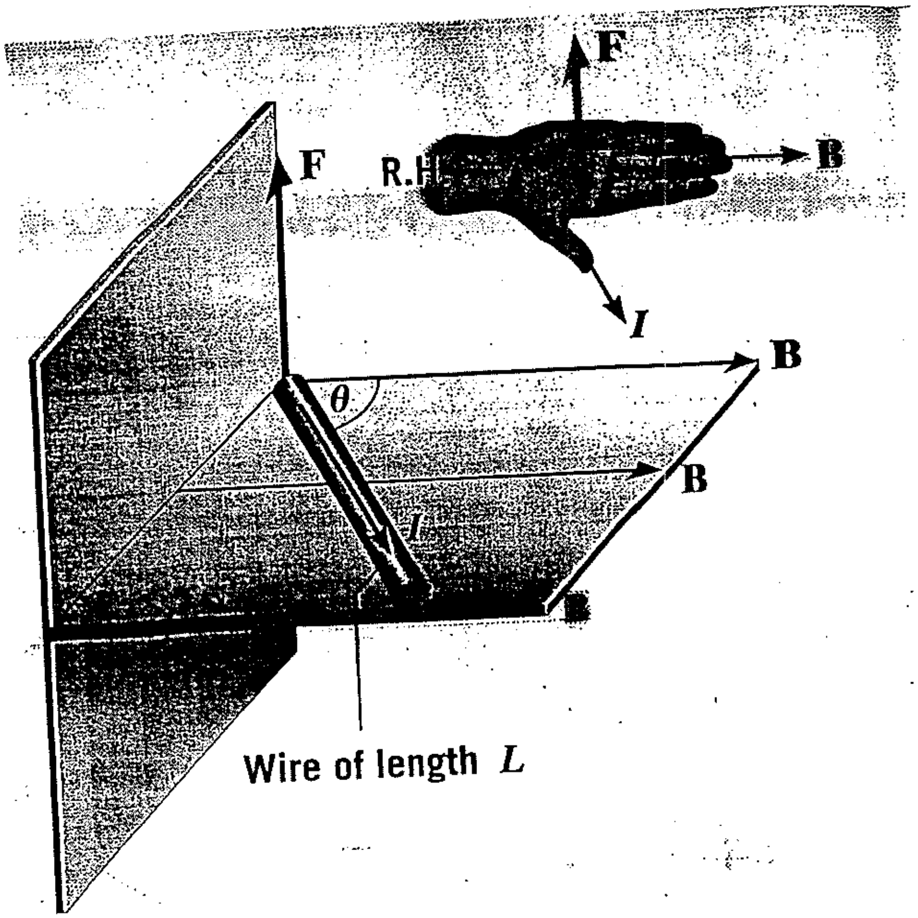


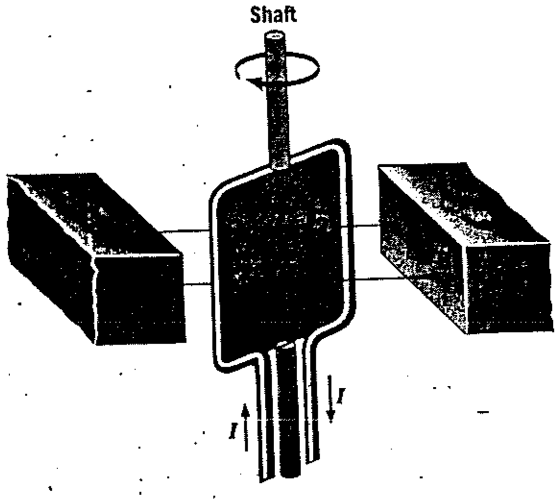
(a) (b) (c)



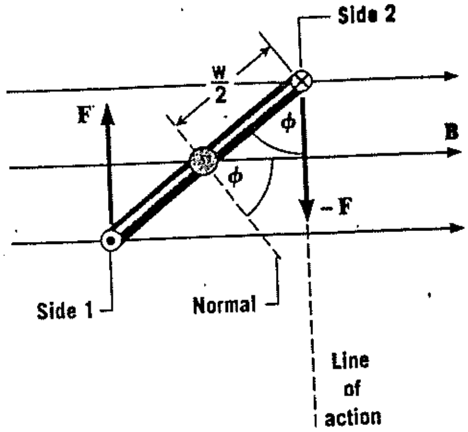

B
v
F
q


B (into paper)
F
F
2
r
F
+q
v
1
F
v
R. H.

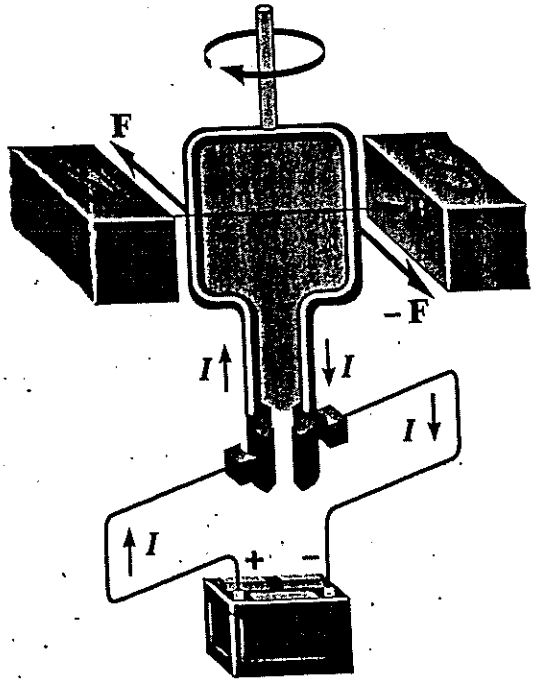

F
F
R.H.
B
I
B
θ
B
I
Wire of length L



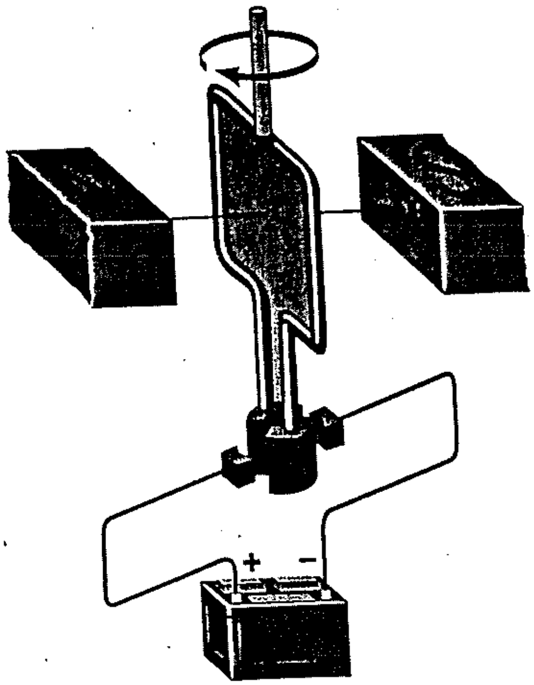
(a)



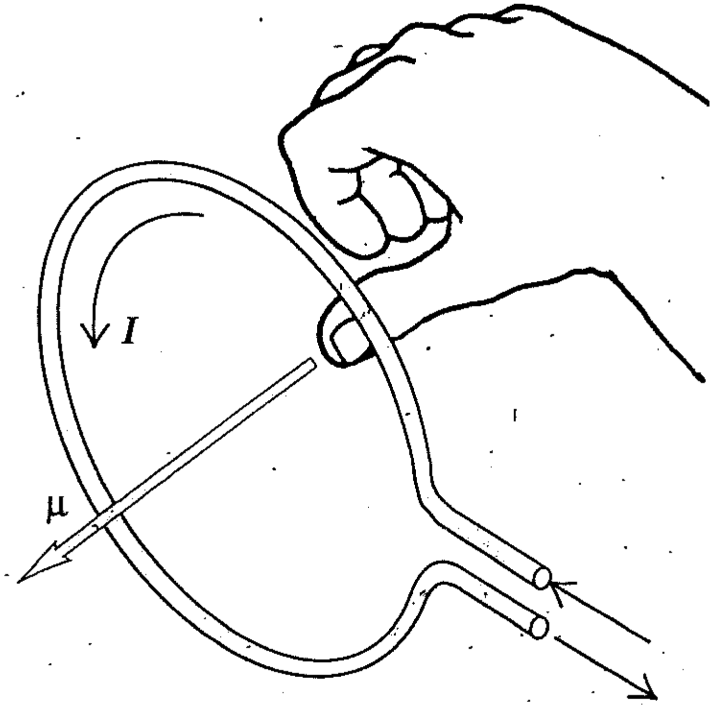
(b)

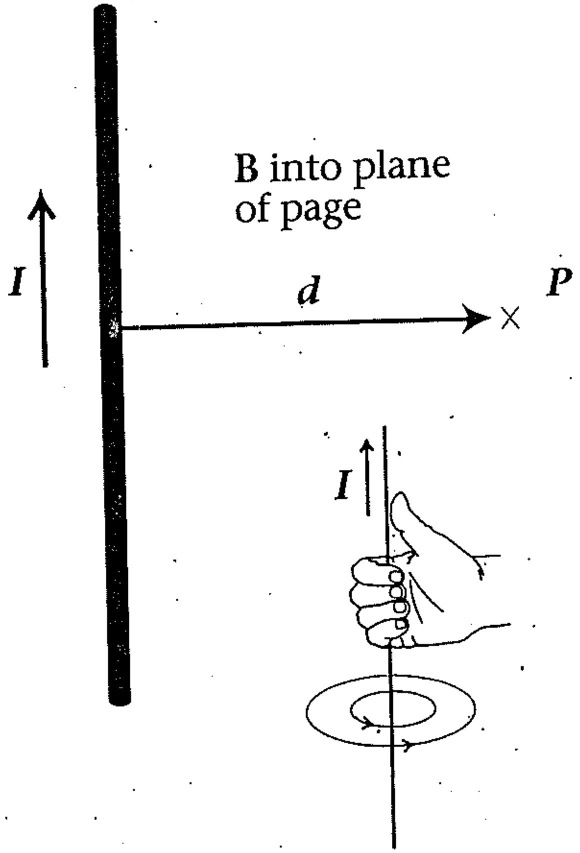


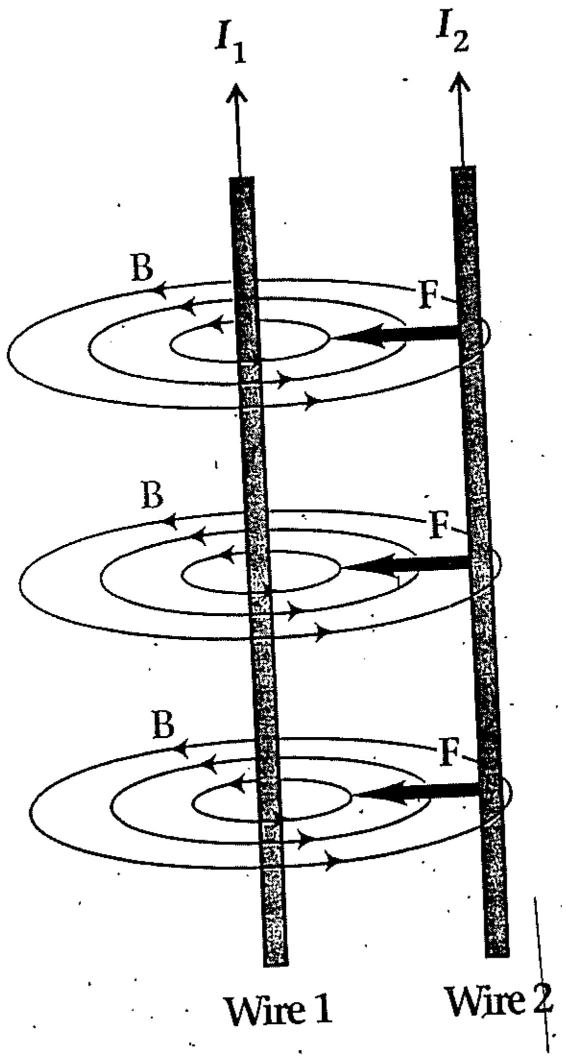
(a)

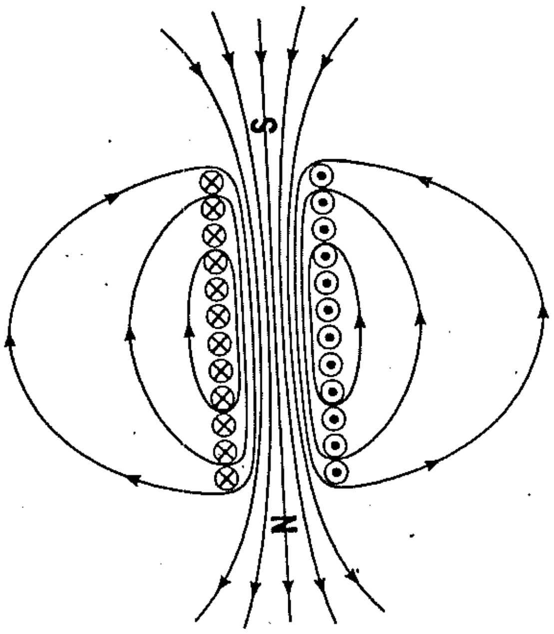


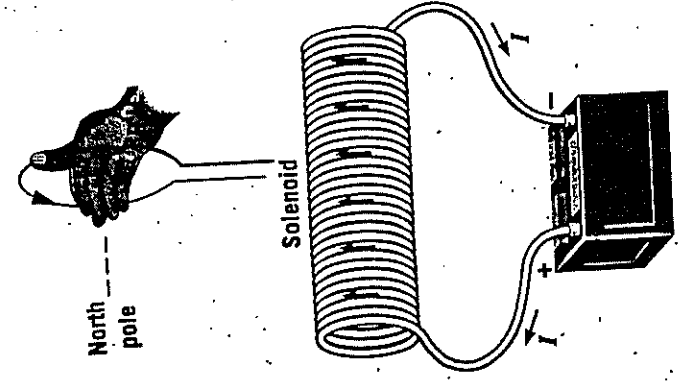
(b)


I
μ


B into plane
of page
I
d
P
I


I_1
I_2
B
F
B
F
B
F
Wire 1
Wire 2


S
N


I
–
+
I
Solenoid
North pole

Electromagnetic Induction

Electromagnetic Induction

PREVIEW

Whenever the magnetic flux changes through a loop, an emf is generated in the loop. This observation is given substance in the form of Faraday's Law of Electromagnetic Induction which is presented in this chapter. Electromagnetic induction is used to explain the operation of electric generators and useful circuit devices called inductors along with the operation of the common transformer.

QUICK REFERENCE

Important Terms

Induced current
The current produced in a conducting coil when it is exposed to a changing magnetic field or its area or orientation changes relative to a magnetic field.

Induced emf
The emf in a coil or loop when it is exposed to a changing magnetic field or its area or its orientation changes in a magnetic field. The induced emf MAY produce an induced current if the coil or loop is a conductor.

Motional emf
The emf produced across a conductor due to its motion through a magnetic field.

Magnetic flux
The product of the area of a loop, the magnetic field through the loop and the cosine of the angle that the magnetic field makes with a line drawn normal to the plane of the loop. It is the change of magnetic flux through a loop which produces the induced emf.

Induced magnetic field
The magnetic field which is produced by an induced current.

Back emf
The induced emf produced in the rotating coils of a motor whose polarity is opposite the polarity of the emf applied to the motor.

Mutual induction
The process by which a changing current in one circuit produces a changing magnetic field which induces a current in another circuit.

Self-induction
The process by which a changing current in a circuit induces an emf in the same circuit.

Inductors
Coils which are used as circuit elements to exploit their property of self-induction.

Transformer
A device which uses mutual inductance between primary and secondary coils to increase or decrease an ac voltage.

Induced emfs

The emf induced in a rod moving perpendicularly with respect to a magnetic field is

$$\text{emf} = vBL \qquad (22.1)$$

The emf induced in a **coil of N loops** (Faraday's Law)

$$\text{emf} = -N\frac{\Delta\Phi}{\Delta t} \qquad (22.3)$$

The emf produced by a **generator**

$$\text{emf} = NAB\omega \sin \omega t \qquad (22.4)$$

The emf due to **mutual induction**

$$(\text{emf})_2 = -M\frac{\Delta I_1}{\Delta t} \qquad (22.7)$$

The emf due to **self-induction**

$$\text{emf} = -L\frac{\Delta I}{\Delta t} \qquad (22.9)$$

Magnetic Flux

The magnetic flux through a **plane area or coil**

$$\Phi = BA \cos \phi \qquad (22.2)$$

Inductance

Mutual inductance of **two coils**

$$M = \frac{N_2\Phi_2}{I_1} \qquad (22.6)$$

Self-induction of a coil

$$L = \frac{N\Phi}{I} \qquad (22.8)$$

Motors

The **current** drawn by a motor (emf is the "back emf" of the motor)

$$I = \frac{V - \text{emf}}{R} \qquad (22.5)$$

Energy in Inductors

The **energy** stored in an inductor due to **self inductance** is

$$\text{Energy} = \frac{1}{2}LI^2 \qquad (22.10)$$

The **energy density** in a **magnetic field**

$$\text{Energy density} = \frac{1}{2\mu_0}B^2 \qquad (22.11)$$

Transformers

The **transformer equation**

$$\frac{V_s}{V_p} = \frac{N_s}{N_p} \qquad (22.12)$$

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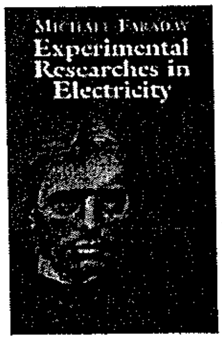
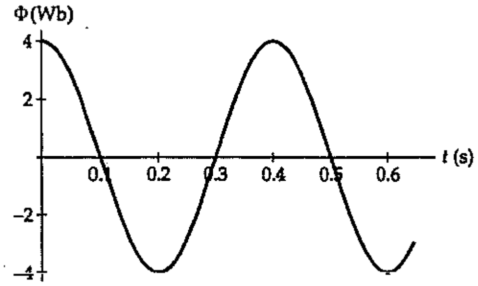
Faraday's Law of Induction

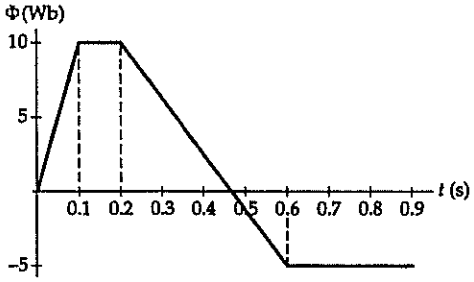


10. • **Figure 23–32** shows the magnetic flux through a coil as a function of time. At what times shown in this plot do (a) the magnetic flux and (b) the induced emf have the greatest magnitude?



▲ **FIGURE 23–32** Problems 10 and 13

11. • **Figure 23–33** shows the magnetic flux through a single-loop coil as a function of time. What is the induced emf in the coil at (a) $t = 0.050$ s, (b) $t = 0.15$ s, and (c) $t = 0.50$ s?



▲ **FIGURE 23–33** Problems 11 and 12

12. •• **IP** The magnetic flux through a single-loop coil is given by Figure 23–33. (a) Is the magnetic flux at $t = 0.25$ s greater than, less than, or the same as the magnetic flux at $t = 0.55$ s? Explain. (b) Is the induced emf at $t = 0.25$ s greater than, less than, or the same as the induced emf at $t = 0.55$ s? Explain. (c) Calculate the induced emf at the times $t = 0.25$ s and $t = 0.55$ s.

13. •• **IP** Consider a single-loop coil whose magnetic flux is given by Figure 23–32. (a) Is the magnitude of the induced emf in this coil greater near $t = 0.4$ s or near $t = 0.5$ s? Explain. (b) At what times in this plot do you expect the induced emf in the coil to have a maximum magnitude? Explain. (c) Estimate the induced emf in the coil at times near $t = 0.3$ s, $t = 0.4$ s and $t = 0.5$ s.

14. •• A single conducting loop of wire has an area of 7.4×10^{-2} m^2 and a resistance of 110 Ω. Perpendicular to the plane of the loop is a magnetic field of strength 0.28 T. At what rate (in T/s) must this field change if the induced current in the loop is to be 0.32 A?

15. •• The area of a 120-turn coil oriented with its plane perpendicular to a 0.20-T magnetic field is 0.050 m^2. Find the average induced emf in this coil if the magnetic field reverses its direction in 0.34 s.

10.) 0s, .2s, .4s, 0.6s
.1s, .3s, .5s

11) − 0.1 kV, 0V, 0.04 kV

12) greater, same, −37.5 wb/s
0.04 kV

13) 0.5s,
0.1, 0.3, 0.5 sec
− 0.06 kV
0V
+0.06 kV

14) 32.5V, 4.8×10^{2} T

15) 7.1V

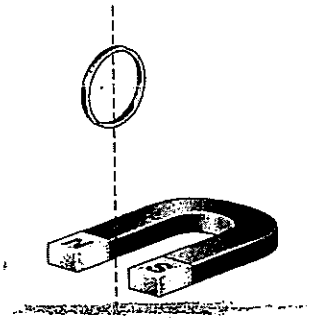
Name______________________________ Per. ___ Date __________

Lenz's Law

Section 23–4 Lenz's Law

18\. • A bar magnet with its north pole pointing downward is falling toward the center of a horizontal conducting ring. As viewed from above, is the direction of the induced current in the ring clockwise or counterclockwise? Explain.

19\. • **A Wire Loop and a Magnet** A loop of wire is dropped and allowed to fall between the poles of a horseshoe magnet, as shown in **Figure 23–34**. State whether the induced current in the loop is clockwise or counterclockwise when (a) the loop is above the magnet and (b) the loop is below the magnet.

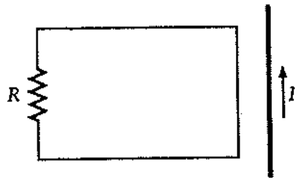


▲ **FIGURE 23–34** Problems 19, 20, and 21

20\. •• Suppose we change the situation shown in Figure 23–34 as follows: Instead of allowing the loop to fall on its own, we attach a string to it and lower it with constant speed along the path indicated by the dashed line. Is the tension in the string greater than, less than, or equal to the weight of the loop? Give specific answers for times when (a) the loop is above the magnet and (b) the loop is below the magnet. Explain in each case.

21\. •• Rather than letting the loop fall downward in Figure 23–34, suppose we attach a string to it and raise it upward with constant speed along the path indicated by the dashed line. Is the tension in the string greater than, less than, or equal to the weight of the loop? Give specific answers for times when (a) the loop is below the magnet and (b) the loop is above the magnet. Explain in each case.

22\. •• **Figure 23–35** shows a current-carrying wire and a circuit containing a resistor R. (a) If the current in the wire is constant, is the induced current in the circuit clockwise, counterclockwise, or zero? Explain. (b) If the current in the wire increases, is the induced current in the circuit clockwise, counterclockwise, or zero? Explain.

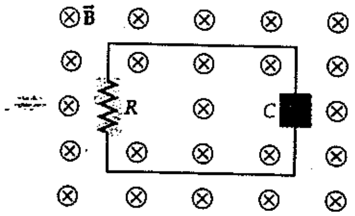


▲ **FIGURE 23–35** Problems 22 and 23

23\. •• Consider the physical system shown in Figure 23–35. If the current in the wire changes direction, is the induced current in the circuit clockwise, counterclockwise, or zero? Explain.

24\. •• A long, straight, current-carrying wire passes through the center of a circular coil. The wire is perpendicular to the plane of the coil. (a) If the current in the wire is constant, is the induced emf in the coil zero or nonzero? Explain. (b) If the current in the wire increases, is the induced emf in the coil zero or nonzero? Explain. (c) Does your answer to part (b) change if the wire no longer passes through the center of the coil but is still perpendicular to its plane? Explain.

25\. •• **Figure 23–36** shows a circuit containing a resistor and an uncharged capacitor. Pointing into the plane of the circuit is a uniform magnetic field $\vec{B}$. If the magnetic field reverses direction in a short period of time, which plate of the capacitor (top or bottom) becomes positively charged? Explain.



▲ **FIGURE 23–36** Problems 25 and 26

26\. •• Referring to Problem 25, which plate of the capacitor (top or bottom) becomes positively charged if the magnetic field increases in magnitude with time? Explain.

18) ccw
19) cw, ccw
20) less, less
21) greater, greater
22) zero, cw
23) ccw
24) zero, zero, No change
25) Top,
26) Bottom

Sample Problem

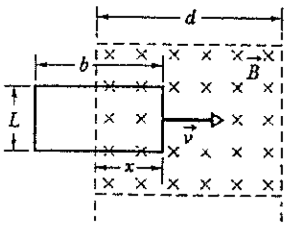
Figure 31-63*a* shows a rectangular conducting loop of resistance R, width L, and length b being pulled at constant speed v through a region of width d in which a uniform magnetic field $\vec{B}$ is produced by an electromagnet. Let $L = 40$ mm, $b = 10$ cm, $d = 15$ cm, $R = 1.6\ \Omega$, $B = 2.0$ T, and $v = 1.0$ m/s.

(a) Plot the magnetic flux Φ_B through the loop as a function of the position x of the right side of the loop.

(b) Plot the induced emf as a function of the position of the loop. Indicate the directions of the induced emf.

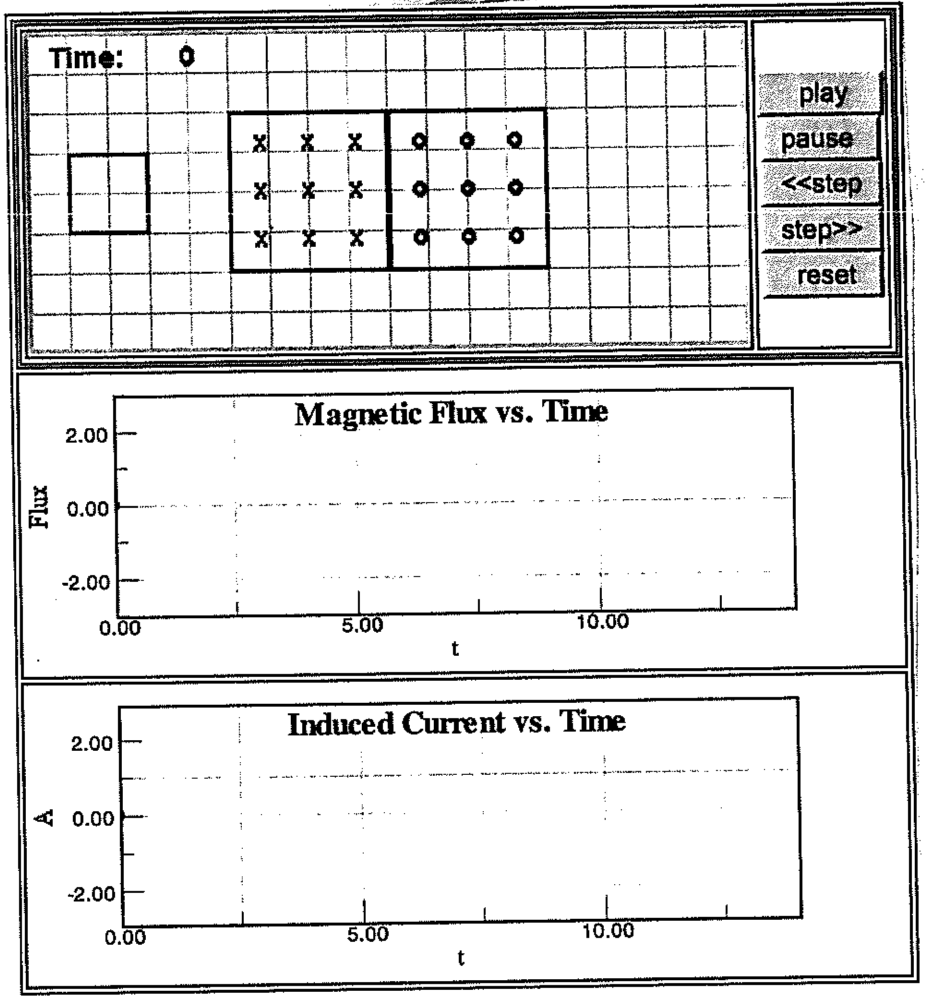
(c) Plot the rate of production of thermal energy in the loop as a function of the position of the loop.

(*a*)



Name ______________________________ per. ___ date _________

Faraday's law of Electromagnetic Induction



A square loop moves at a constant velocity of 1 m/s to the right across two regions of uniform magnetic field. One region extends from x = -4 to x = 0, and has a uniform field directed into the page. The second region extends from x = 0 to x = 4, with a uniform magnetic field directed out of the page. The magnitudes of the fields are equal.

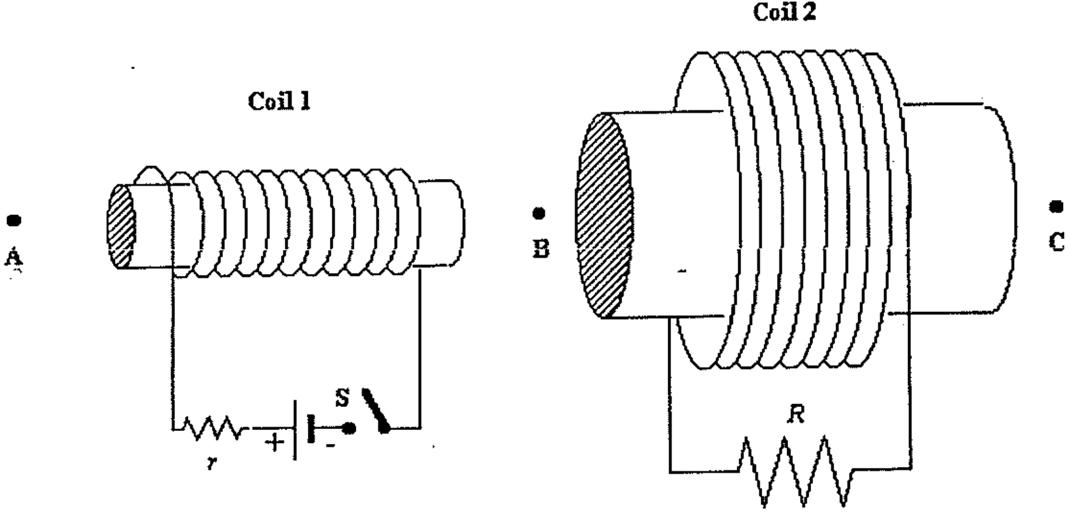
Plot the magnetic flux through the loop, and the induced current, as a function of time. Take the flux to be positive if the field is into the page, and take clockwise to be positive for induced current.

Given:

R = 1.0 Ohms
B = 0.5 Tesla

Name ____ per. __ Date _____
AP Physics B DiBucci
Electromagnetic induction and Lenz's Law

Two coils, **1** and **2,** with iron cores are positioned as shown in the figure. Coil **1** is part of a circuit with a battery and a switch.



1. Immediately after the switch (S) is closed, in which direction does the magnetic field point inside **coil 1**? In what direction does the **induced magnetic field** point in **coil 2**?

2. Immediately after the switch (S) is closed, in which direction will the **induced current** flow through resistor **R in coil 2**?

3. After the switch (S) has been closed for a long time, in which direction will the current flow in **resistor r in coil 1 and resistor R in coil 2**?

4. Assume the switch (S) has been closed for a long time. If **coil 1 is moved towards coil 2,** in which direction will the **induced magnetic field** point in coil 2? **And in which direction will the induced current flow through the resistor R in coil 2?**

5. If switch (S) has been closed for a long time and **coil 1 is suddenly moved away from coil 2, in which direction will the induced magnetic field point inside coil 2? In which direction will the induced current flow through resistor R in coil 2?**

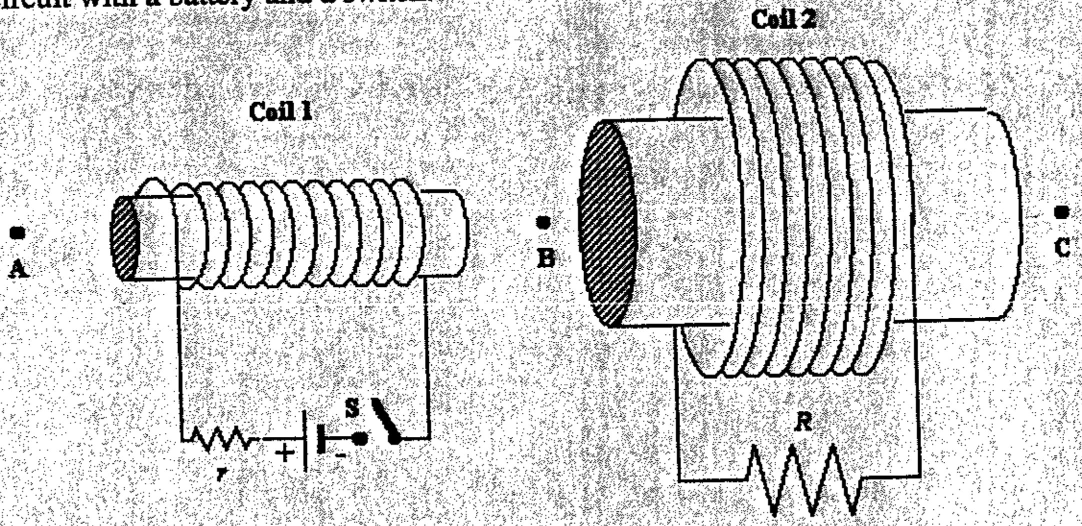
6. Suppose again that switch (S) has been closed for a long time, **and then the switch is suddenly opened.** In which direction will the **induced magnetic field point in coil 2**? In which direction will the **induced current flow through R in coil 2**?

Name ______________________________ per. __ Date _____

AP Physics B *DiBucci*

Electromagnetic induction and Lenz's Law- Worksheet 2

Two coils, 1 and 2, with iron cores are positioned as shown in the figure. Coil 1 is part of a circuit with a battery and a switch.



For each question explain the reasoning you used to arrive at your conclusion.

1. Assume the switch in coil 1 has been closed for a long time. If coil 2 is suddenly moved towards coil 1, in which direction will current flow through resistor R?

2. Assume the switch in coil 1 has been closed for a long time. If coil 2 is moved away from coil 1, in which direction will current flow in resistor R?

3. Assume the switch is initially open and there is no current in either coil. If the polarity of the battery were switch in coil 1, and the switch is closed, in which direction will current flow through the resistor R in coil 2?

4. Answer the following question based on the situation described in number 3. Assume you are looking directly into coil 2 from the point of view at point C. Sketch the direction of the circulating induced current and the direction of the induced magnetic field in the space below.

ection 22.2 Motional Emf

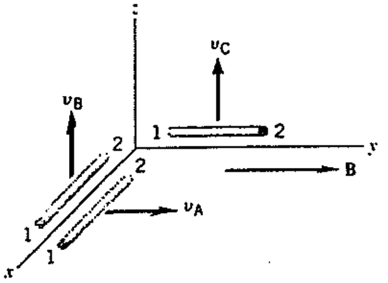
ssm A spark can jump between two nontouching conductors the potential difference between them is sufficiently large. A po- ential difference of approximately 940 V is required to produce a k in an air gap of 1.0 × 10^{-4} m. Suppose the light bulb in Fig- .4*b* is replaced by such a gap. How fast would a 1.3-m rod ve to be moving in a magnetic field of 4.8 T to cause a spark to mp across the gap?

The wingspan (tip-to-tip) of a Boeing 747 jetliner is 59 m. he plane is flying horizontally at a speed of 220 m/s. The vertical omponent of the earth's magnetic field is 5.0 × 10^{-6} T. Find the mf induced between the wing tips.

Near San Francisco, where the vertically downward compo- ent of the earth's magnetic field is 4.8 × 10^{-5} T, a car is travel- forward at 25 m/s. An emf of 2.4 × 10^{-3} V is induced be- een the sides of the car. (a) Which side of the car is positive, the ver's side or the passenger's side? (b) What is the width of car?

Two metal bars have the same length. Each is pushed through magnetic field as in Figure 22.4*a*. The emf generated between e ends of each bar is the same. Bar 1 moves through a field of 13 T at a speed of 5.8 m/s. Bar 2 moves through a field of 33 T. What is the speed of bar 2?

ssm www The drawing shows three identical rods (A, B, and C) moving in different planes. A constant magnetic field of magnitude 0.45 T is directed along the +*y* axis. The length of each rod is L = 1.3 m, and the speeds are the same, $v_A = v_B = v_C$ = 2.7 m/s. For each rod, find the magnitude of the motional emf, and indicate which end (1 or 2) of the rod is positive.



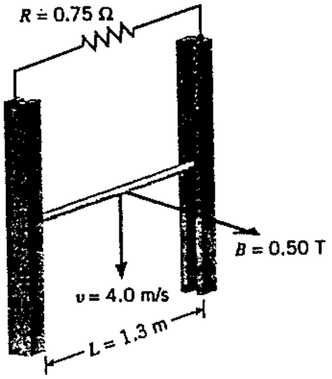
6. A metal rod (length = 0.75 m) moves perpendicular to a magnetic field of 0.15 T. An emf of 0.24 V exists between the ends of the rod. How far does the rod move in 7.0 s?

*7. Suppose the light bulb in Figure 22.4*b* is replaced with a short wire of zero resistance, and the resistance of the rails is negligible. The only resistance is from the moving rod, which is iron (resistivity = 9.7 × 10^{-8} Ω·m). The rod has a cross-sectional area of 3.1 × 10^{-6} m^2 and moves with a speed of 2.0 m/s. The magnetic field has a magnitude of 0.050 T. What is the current in the rod?

*8. Refer to the drawing that accompanies conceptual question 6 (not problem 6). Suppose that the voltage of the battery in the circuit is 3.0 V, the magnitude of the magnetic field (directed perpendicularly into the plane of the paper) is 0.60 T, and the length of the rod between the rails is 0.20 m. Assuming that the rails are very long and have negligible resistance, find the maximum speed attained by the rod after the switch is closed.

*9. **ssm** Suppose the light bulb in Figure 22.4*b* is replaced by a 6.0-Ω electric heater that consumes 15 W of power. The conducting bar moves to the right at a constant speed, the field strength is 2.4 T, and the length of the bar between the rails is 1.2 m. (a) How fast is the bar moving? (b) What force must be applied to the bar to keep it moving to the right at the constant speed found in part (a)?

**10. Review Conceptual Example 3 as an aid in solving this problem. A conducting rod slides down between two frictionless vertical copper tracks at a constant speed of 4.0 m/s perpendicular to a 0.50-T magnetic field (see the drawing). The resistance of the rod and tracks is negligible. The rod maintains electrical contact with the tracks at all times and has a length of 1.3 m. A 0.75-Ω resistor is attached between the tops of the tracks. (a) What is the mass of the rod? (b) Find the change in the gravitational potential energy that occurs in a time of 0.20 s. (c) Find the electrical energy dissipated in the resistor in 0.20 s.



Section 22.3 Magnetic Flux

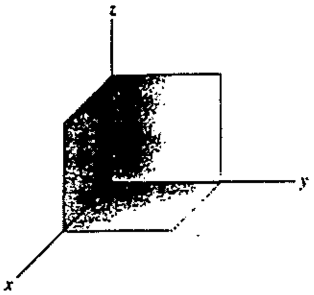
For problems in this set, assume that the magnetic flux is a positive quantity.

11. A hand is held flat and placed in a uniform magnetic field of magnitude 0.35 T. The hand has an area of 0.0160 m^2 and negligible thickness. Determine the magnetic flux that passes through the hand when the normal to the hand is (a) parallel and (b) perpendicular to the magnetic field.

12. A magnetic field has a magnitude of 0.078 T and is uniform over a circular surface that has a radius of 0.10 m. The field is oriented at an angle of $\phi = 25°$ with respect to the normal to the surface. What is the flux through the surface?

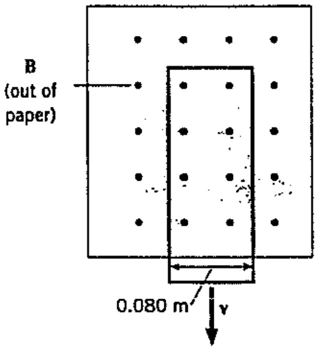
13. **ssm** A standard door into a house rotates about a vertical axis through one side, as defined by the door's hinges. A uniform magnetic field is parallel to the ground and perpendicular to this axis. Through what angle must the door rotate so that the magnetic flux that passes through it decreases from its maximum value to one-third of its maximum value?

14. The drawing shows three square surfaces, one lying in the *xy* plane, one in the *xz* plane, and one in the *yz* plane. The sides of each square have lengths of 2.0×10^{-2} m. A uniform magnetic field exists in this region, and its components are: $B_x = 0.50$ T, $B_y = 0.80$ T, and $B_z = 0.30$ T. Determine the magnetic flux that passes through the surface that lies in (a) the *xy* plane, (b) the *xz* plane, and (c) the *yz* plane.

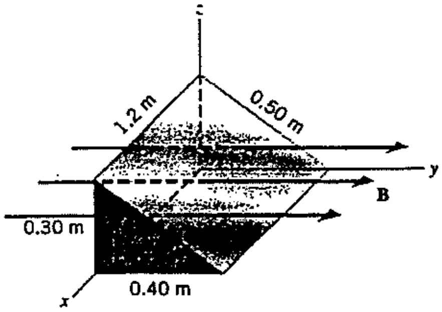


15. A house has a floor area of 112 m^2 and an outside wall that has an area of 28 m^2. The earth's magnetic field here has a horizontal component of 2.6×10^{-5} T that points due north and a vertical component of 4.2×10^{-5} T that points straight down, toward the earth. Determine the magnetic flux through the wall if the wall faces (a) north and (b) east. (c) Calculate the magnetic flux that passes through the floor.

***16.** A rectangular loop of wire is moving toward the bottom of the page with a speed of 0.020 m/s (see the drawing). The loop is leaving a region in which a 2.4-T magnetic field exists; the magnetic field outside this region is zero. During a time of 2.0 s, what is the magnitude of the *change* in the magnetic flux?



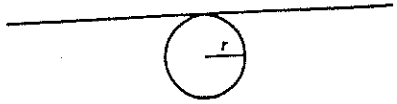
***17.** **ssm** **www** A five-sided object, whose dimensions are shown in the drawing, is placed in a uniform magnetic field. The magnetic field has a magnitude of 0.25 T and points along the positive *y* direction. Determine the magnetic flux through each of the five sides.



Section 22.4 Faraday's Law of Electromagnetic Induction

18. A magnetic field is perpendicular to a 0.040-m × 0.060 rectangular coil of wire that has one hundred turns. In a time 0.050 s, an average emf of magnitude 1.5 V is induced in the co What is the magnitude of the change in the magnetic field?

19. The drawing shows a straight wire, a part of which is be into the shape of a circle. The radius of the circle is 2.0 cm. A co stant magnetic field of magnitude 0.55 T is directed perpendicu to the plane of the paper. Someone grabs the ends of the wire and pulls it taut, so the radius of the circle shrinks to zero in a time of 0.25 s. Find the magnitude of the average induced emf between the ends of the wire.



20. A planar coil of wire has a single turn. The normal to this coil is parallel to a uniform and constant (in time) magnetic field of 1.7 T. An emf that has a magnitude of 2.6 V is induced in this coil, because the coil's area A is shrinking. What is the magnitude of $\Delta A/\Delta t$, which is the rate (in m^2/s) at which the area changes?

21. **ssm** A circular coil (950 turns, radius = 0.060 m) is rotating in a uniform magnetic field. At $t = 0$, the normal to the coil is perpendicular to the magnetic field. At $t = 0.010$ s, the normal makes an angle of $\phi = 45°$ with the field, because the coil has made one-eighth of a revolution. An average emf of magnitude 0.065 V is induced in the coil. Find the magnitude of the magnetic field at the location of the coil.

22. A 75-turn conducting coil has an area of 8.5×10^{-3} m^2 and the normal to the coil is parallel to a magnetic field **B**. The coil has a resistance of 14 Ω. At what rate (in T/s) must the magnitude of **B** change for an induced current of 7.0 mA to exist in the coil?

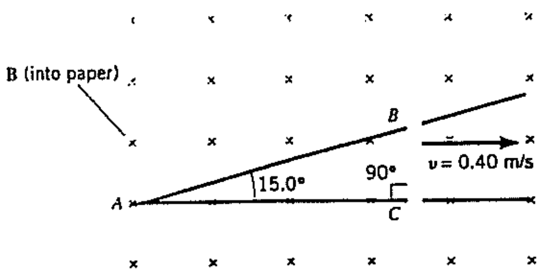
23. Magnetic resonance imaging (MRI) is a medical technique for producing "pictures" of the interior of the body. The patient is placed within a strong magnetic field. One safety concern is what would happen to the positively and negatively charged particles in the body fluids if an equipment failure caused the magnetic field to be shut off suddenly. An induced emf could cause these particles to flow, producing an electric current within the body. Suppose the largest surface of the body through which flux passes has an area of 0.032 m^2 and a normal that is parallel to a magnetic field of 1.5 T. Determine the smallest time period during which the field can be allowed to vanish if the magnitude of the average induced emf is to be kept less than 0.010 V.

24. A 1.5-m-long aluminum rod is rotating about an axis that is perpendicular to one end. A 0.16-T magnetic field is directed parallel to the axis. The rod rotates through one-fourth of a circle in 0.66 s. What is the magnitude of the average emf generated between the ends of the rod during this time?

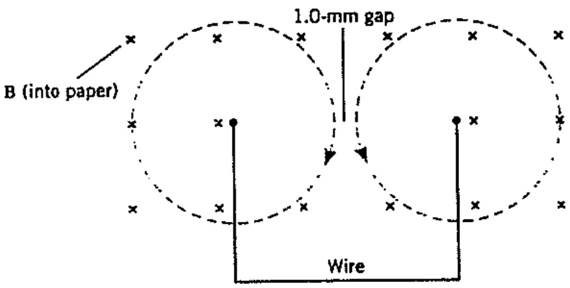
***25.** **ssm www** A conducting coil of 1850 turns is connected to a galvanometer, and the total resistance of the circuit is 45.0 Ω. The area of each turn is 4.70×10^{-4} m^2. This coil is moved from a region where the magnetic field is zero into a region where it is nonzero, the normal to the coil being kept parallel to the magnetic field. The amount of charge that is induced to flow around the circuit is measured to be 8.87×10^{-3} C. Find the magnitude of the magnetic field. (Such a device can be used to measure the magnetic field strength and is called a *flux meter.*)

***26.** A uniform and constant (in time) magnetic field has a magnitude of 0.15 T and is perpendicular to a circular loop of wire (one turn) that has a radius of 0.30 m. This circle, without changing its orientation relative to the field, changes into a square in a time interval of 0.22 s. Find the magnitude of the emf induced in the wire.

27. A copper rod is sliding on two conducting rails that make an angle of 15° with respect to each other, as in the drawing. The rod is moving to the right with a constant speed of 0.40 m/s. A 0.42-T uniform magnetic field is perpendicular to the plane of the paper. Determine the magnitude of the average emf induced in the triangle ABC during the 5.0-s period after the rod has passed point A.



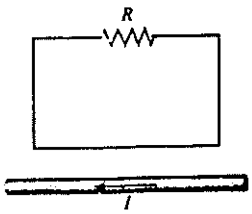
****28.** Two 0.68-m-long conducting rods are rotating at the same speed in opposite directions, and both are perpendicular to a 4.7-T magnetic field. As the drawing shows, the ends of these rods come to within 1.0 mm of each other as they rotate. Moreover, the fixed ends about which the rods are rotating are connected by a wire, so these ends are at the same electric potential. If a potential difference of 4.5×10^3 V is required to cause a 1.0-mm spark in air, what is the angular speed (in rad/s) of the rods when a spark jumps across the gap?



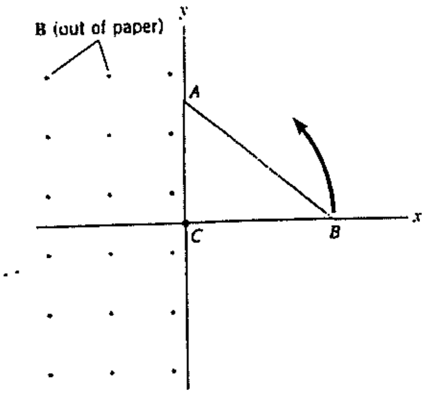
Section 22.5 Lenz's Law

29. **ssm** In Figure 22.1, suppose the north and south poles of the magnet were interchanged. Determine the direction of the current through the ammeter in parts *b* and *c* of the picture (left-to-right or right-to-left). Give your rationale.

30. What is the direction of the induced current through *R* in the [illegible]ing as the current *I* increases? Provide a reason for your answer.

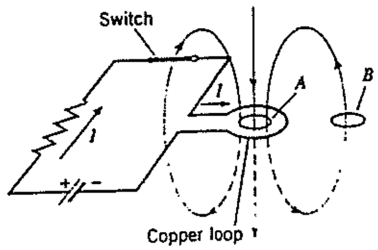


31. The drawing shows that a uniform magnetic field is directed perpendicularly out of the plane of the paper and fills the entire region to the left of the *y* axis. There is no magnetic field to the right of the *y* axis. A rigid right triangle *ABC* is made of copper wire.

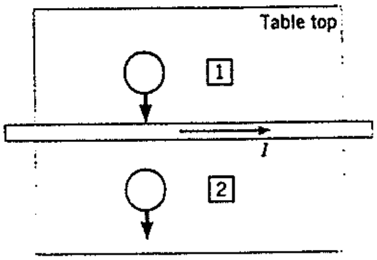


The triangle rotates counterclockwise about the origin at point *C*. What is the direction (clockwise or counterclockwise) of the induced current when the triangle is crossing (a) the +*y* axis, (b) the −*x* axis, (c) the −*y* axis, and (d) the +*x* axis? For each case, justify your answer.

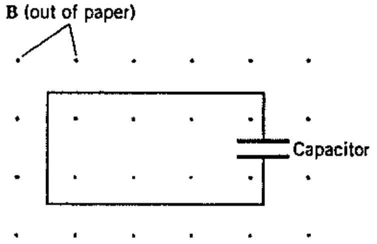
32. As the picture shows, a loop of copper wire is lying flat on a table and is attached to a battery via a switch. The current *I* in the loop establishes the magnetic field lines shown in color. There are also two smaller conducting loops *A* and *B* lying flat on the table, but not connected to batteries. Determine the direction of the induced current in loops *A* and *B* when the switch is (a) opened and (b) closed again. Specify the direction of the currents to be clockwise or counterclockwise when viewed from above the table. Account for your answer.



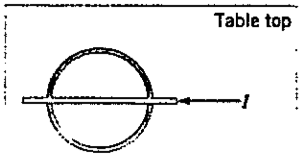
33. **ssm** Review Conceptual Example 9 as an aid in understanding this problem. A long, straight wire lies on a table and carries a current *I*. As the drawing shows, a small circular loop of wire is pushed across the top of the table from position 1 to position 2. Determine the direction of the induced current, clockwise or counterclockwise, as the loop moves past (a) position 1 and (b) position 2. Justify your answers.



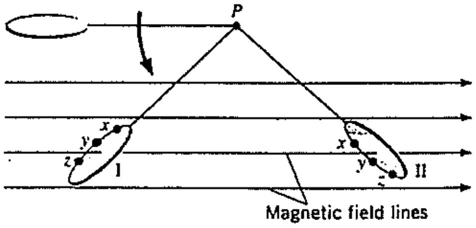
*34. Indicate the direction of the electric field between the plates of the parallel plate capacitor shown in the drawing if the magnetic field is decreasing in time. Give your reasoning.



*35. A circular loop of wire rests on a table. A long, straight wire lies on this loop, directly over its center, as the drawing illustrates. The current *I* in the straight wire is increasing. In what direction is the induced current, if any, in the loop? Give your reasoning.



**36. A wire loop is suspended from a string that is attached to point *P* in the drawing. When released, the loop swings downward, from left to right, through a uniform magnetic field, with the plane of the loop remaining perpendicular to the plane of the paper at all times. (a) Determine the direction of the current induced in the loop as it swings past the locations labeled I and II. Specify the [illegible]rection of the current in terms of the points *x*, *y*, and *z* on the loop (e.g., $x \rightarrow y \rightarrow z$ or $z \rightarrow y \rightarrow x$). The points *x*, *y*, and *z* lie behind the plane of the paper. (b) What is the direction of the induced current at the locations II and I when the loop swings back, from right to left? Provide reasons for your answers.



MAGNETIC FIELDS Produced By WIRES

50) 0.12 m
51) 8×10^{-5} T
52) 4.2×10^{-2} m
53) 1.9×10^{-4} N·m
54) 6.1 A
55) 3.1×10^{-4} T
56) 4.3×10^{-5} T
5.3×10^{-5} T

57) 190 A
58) $+2.8 \times 10^{-6}$ T OUT OF PAGE
-2.8×10^{-6} T INTO PAGE
59) 6.8 A OPPOSITE Dir.
60) 1.5×10^{-4} N

MOTIONAL EMF

1) 150 m/s
2) 0.065 v
3) Driver's side
2.0 m
4) 2.3 m/s

5) 0, 1.6 v, end 2, 0
6) 15 m
7) 3.2 A
8) 25 m/s
9) 3.3 m/s, 4.6 N

MAGNETIC FLUX

11) 5.6×10^{-3} wb, 0 wb
12) 2.2×10^{-3} wb
13) 70.5°
14) 1.2×10^{-4} Wb
3.2×10^{-4} wb
20×10^{-4} wb

15) 2.3×10^{-4} wb, 0 wb
4.7×10^{-3} wb
16) 7.7×10^{-3} wb
17) 0, 0.090 wb
53°, 0.090 wb

FARADAY'S LAW OF INDUCTION

18) 0.31 T
19) 2.8×10^{-3} V
20) 1.5 m^2/s
21) 8.6×10^{-5} T
22) 0.15 T/s
23) 4.8 s
24) 0.43 V
25) 0.459 T
26) 0.041 V
27) 0.045 V
28) 2100 rad/s

Lenz's Law

31) CW
NO Induced current
CCW
NO current

32) A) CW For A
CCW For B
B) CCW For A
CW For B

33) A) CW
B) CW

34) upward

35) No Induced current

36)
X → Y → Z
Z → Y → X
Z → Y → X
X → Y → Z

AP Physics B **Mr. DiBucci**
Solutions to problems Sections 22.2 – 22.5
Assigned problems:
22.2: 6-10 skip 8 **22.3: 12,14,16,17** **22.4: 18-22, 25**
22.5: 30-35

1. $\boxed{\text{SSM}}$ ***REASONING AND SOLUTION*** According to Equation 22.1, the motional emf when the velocity v, the magnetic field B, and the length L are mutually perpendicular is given by $\text{emf} = vBL$. Therefore in order for a spark to jump across the gap, the rod would have to be moving in the magnetic field with speed

$$v = \frac{\text{emf}}{BL} = \frac{940\ \text{V}}{(4.8\ \text{T})(1.3\ \text{m})} = \boxed{150\ \text{m/s}}$$

2. ***REASONING AND SOLUTION*** Using Equation 20.1, we find

$$\text{emf} = vBL = (220\ \text{m/s})(5.0 \times 10^{-6}\ \text{T})(59\ \text{m}) = \boxed{0.065\ \text{V}}$$

3. ***REASONING AND SOLUTION***

a. The right-hand rule shows that positive charge would be forced to the $\boxed{\text{driver's side}}$.

b. According to Equation 22.1, the width of the car is

$$L = \frac{\text{emf}}{vB} = \frac{2.4 \times 10^{-3}\ \text{V}}{(25\ \text{m/s})\left(4.8 \times 10^{-5}\ \text{T}\right)} = \boxed{2.0\ \text{m}}$$

4. ***REASONING*** According to Equation 22.1, the emf is given by emf = *vBL* for each bar. The fact that the emf is the same for each bar is the starting point for our solution.

SOLUTION Using Equation 22.1 and the fact the emf is the same for each bar, we have

$$v_1 B_1 L = v_2 B_2 L$$

In this expression the length *L* of each bar is the same and can be eliminated algebraically. As a result, we find

$$v_2 = \frac{v_1 B_1}{B_2} = \frac{(5.8\ \text{m/s})(0.13\ \text{T})}{0.33\ \text{T}} = \boxed{2.3\ \text{m/s}}$$

5. $\boxed{\text{SSM}}$ $\boxed{\text{WWW}}$ ***REASONING AND SOLUTION*** For each of the three rods in the drawing, we have the following:

Rod A: The motional emf is $\boxed{\text{zero}}$, because the velocity of the rod is parallel to the direction of the magnetic field, and the charges do not experience a magnetic force.

Rod B: The motional emf is, according to Equation 22.1,

$$\text{emf} = vBL = (2.7\ \text{m/s})(0.45\ \text{T})(1.3\ \text{m}) = \boxed{1.6\ \text{V}}$$

The positive end of Rod 2 is $\boxed{\text{end 2}}$

Rod C: The motional emf is $\boxed{\text{zero}}$, because the magnetic force *F* on each charge is directed perpendicular to the length of the rod. For the ends of the rod to become charged, the magnetic force must be directed parallel to the length of the rod.

6. ***REASONING AND SOLUTION*** The distance traveled in time *t* is *x* = *vt*. Using Equation 20.1 to express the speed of the rod in this expression gives

$$x = \left(\frac{\text{emf}}{BL}\right)t = \left[\frac{0.24\ \text{V}}{(0.15\ \text{T})(0.75\ \text{m})}\right](7.0\ \text{s}) = \boxed{15\ \text{m}}$$

7. ***REASONING AND SOLUTION*** Ohm's law requires *I* = emf/*R*, where emf = *vBL* and *R* = *ρL/A*. Hence,

$$I = \frac{BvA}{\rho} = \frac{(2.0\ \text{m/s})(0.050\ \text{T})(3.1 \times 10^{-6}\ \text{m}^2)}{9.7 \times 10^{-8}\ \Omega \cdot \text{m}} = \boxed{3.2\ \text{A}}$$

8. ***REASONING*** Once the switch is closed, there is a current in the rod. The magnetic field applies a force to this current and accelerates the rod to the right. As the rod begins to move, however, a motional emf appears between the ends of the rod. This motional emf depends on the speed of the rod and increases as the speed increases. Equally important is the fact that the motional emf opposes the emf of the battery. The net emf causing the current in the rod is the algebraic sum of the two emf contributions. Thus, as the speed of the rod increases and the motional emf increases, the net emf decreases. As the net emf decreases, the current in the rod decreases and so does the force that field applies to the current. Eventually, the speed reaches the point when the motional emf has the same magnitude as the battery emf, and the net emf becomes zero. At this point, there is no longer a net force acting on the rod and the speed remains constant from this point onward, according to Newton's second law. This maximum speed can be determined by using Equation 20.1 for the motional emf, with a value of the motional emf that equals the battery emf.

SOLUTION Using Equation 20.1 (emf = *vBL*) and a value of 3.0 V for the emf, we find that the maximum speed of the rod is

$$v = \frac{\text{emf}}{BL} = \frac{3.0\ \text{V}}{(0.60\ \text{T})(0.20\ \text{m})} = \boxed{25\ \text{m/s}}$$

9. $\boxed{\text{SSM}}$ ***REASONING*** The moving rod acts as a battery does in supplying an emf or voltage in the circuit. The speed of the rod is related to the emf by Equation 22.1, $\text{emf} = vBL$. From Equation 20.6c, we have $P = (\text{emf})^2/R$, where *P* is the power consumed by the circuit and *R* is the resistance in the circuit.

SOLUTION

a. Solving Equation 20.6c for the emf, we have

$$\text{emf} = \sqrt{PR} = \sqrt{(15\ \text{W})(6.0\ \Omega)} = 9.5\ \text{V}$$

The speed of the rod is

$$v = \frac{\text{emf}}{LB} = \frac{9.5\ \text{V}}{(2.4\ \text{T})(1.2\ \text{m})} = \boxed{3.3\ \text{m/s}}$$

b. The force exerted on the rod by the magnetic field is given by Equation 21.3 with $\theta = 90°$, and $I = \text{emf}/R$. Therefore

$$F = ILB\,(\sin\ 90°) = \left(\frac{\text{emf}}{R}\right)LB = \left(\frac{9.5\ \text{V}}{6.0\ \Omega}\right)(1.2\ \text{m})(2.4\ \text{T}) = \boxed{4.6\ \text{N}}$$

10. ***REASONING AND SOLUTION***

a. Newton's second law gives the magnetic retarding force to be

$$F = mg = IBL$$

Now the current, *I*, is

$$I = V/R = vBL/R$$

so

$$m = \frac{v(BL)^2}{Rg} = \frac{(4.0\ \text{m/s})(0.50\ \text{T})^2\,(1.3\ \text{m})^2}{(0.75\ \Omega)(9.80\ \text{m/s}^2)} = \boxed{0.23\ \text{kg}}$$

b. The change in height in a time, Δ*t*, is

$$\Delta h = -v\Delta t$$

The change in gravitational PE is

$$\Delta\text{PE} = mg\Delta h = -mgv\Delta t = -(0.23\ \text{kg})(9.80\ \text{m/s}^2)(4.0\ \text{m/s})(0.20\ \text{s}) = \boxed{-1.8\ \text{J}}$$

c. The energy dissipated in the resistor is the amount by which the gravitational potential energy decreases or $\boxed{1.8\ \text{J}}$.

11. ***REASONING AND SOLUTION*** The magnetic flux is Φ = BA cos ϕ.

a. Since ϕ = 0.0°, we have

$$\Phi = (0.35\ \text{T})(0.0160\ \text{m}^2)\cos 0.0° = \boxed{5.6 \times 10^{-3}\ \text{Wb}}$$

b. Since ϕ = 90°, we have

$$\Phi = (0.35\ \text{T})(0.0160\ \text{m}^2)\cos 90° = \boxed{0\ \text{Wb}}$$

12. ***REASONING AND SOLUTION*** The flux through the circular surface is

$$\Phi = \text{BA}\cos\phi = \text{B}\pi r^2\cos\phi = (0.078\ \text{T})(\pi)(0.10\ \text{m})^2\cos 25° = \boxed{2.2 \times 10^{-3}\ \text{Wb}}$$

13. $\boxed{\text{SSM}}$ ***REASONING*** The general expression for the magnetic flux through an area *A* is given by Equation 22.2: $\Phi = BA\cos\phi$ where *B* is the magnitude of the magnetic field and ϕ is the angle of inclination of the magnetic field B with respect to the normal to the area.

The magnetic flux through the door is a maximum when the magnetic field lines are perpendicular to the door and $\phi_1 = 0.0°$ so that $\Phi_1 = \Phi_{\text{max}} = BA(\cos 0.0°) = BA$.

SOLUTION When the door rotates through an angle ϕ_2, the magnetic flux that passes through the door decreases from its maximum value to one-third of its maximum value. Therefore $\Phi_2 = \frac{1}{3}\Phi_{\text{max}}$, and we have

$$\Phi_2 = BA\cos\phi_2 = \tfrac{1}{3}BA \qquad \text{or} \qquad \cos\phi_2 = \tfrac{1}{3} \qquad \text{or} \qquad \phi_2 = \cos^{-1}\left(\tfrac{1}{3}\right) = \boxed{70.5°}$$

14. ***REASONING AND SOLUTION*** When computing the magnetic flux, we multiply the component of the magnetic field that is parallel to the normal to the surface by the area of the surface.

a. For the surface that lies in the xy plane, the normal is parallel to the z axis, so

$$\Phi = \text{B}_z\text{A} = (0.30\ \text{T})(2.0 \times 10^{-2}\ \text{m})^2 = \boxed{1.2 \times 10^{-4}\ \text{Wb}}$$

b. For the surface that lies in the xz plane, the normal is parallel to the y axis, so

$$\Phi = \text{B}_y\text{A} = (0.80\ \text{T})(2.0 \times 10^{-2}\ \text{m})^2 = \boxed{3.2 \times 10^{-4}\ \text{Wb}}$$

c. For the surface that lies in the yz plane, the normal is parallel to the x axis, so

$$\Phi = \text{B}_x\text{A} = (0.50\ \text{T})(2.0 \times 10^{-2}\ \text{m})^2 = \boxed{2.0 \times 10^{-4}\ \text{Wb}}$$

15. ***REASONING AND SOLUTION***

a. According to Equation 22.2, we have Φ = BA cos ϕ. If the wall faces north, then

$$\Phi = \text{B}_\text{H}\text{A}\cos 0.0° + \text{B}_\text{V}\text{A}\cos 90° = \text{B}_\text{H}\text{A} = (2.6 \times 10^{-5}\ \text{T})(28\ \text{m}^2) = \boxed{7.3 \times 10^{-4}\ \text{Wb}}$$

b. If the wall faces east, then

$$\Phi = \text{B}_\text{H}\text{A}\cos 90° + \text{B}_\text{V}\text{A}\cos 90° = \boxed{0\ \text{Wb}}$$

c. The normal to the floor is vertical, so

$$\Phi = \text{B}_\text{H}\text{A}\cos 90° + \text{B}_\text{V}\text{A}\cos 0.0° = \text{B}_\text{V}\text{A} = (4.2 \times 10^{-5}\ \text{T})(112\ \text{m}^2) = \boxed{4.7 \times 10^{-3}\ \text{Wb}}$$

16. ***REASONING AND SOLUTION*** The change in flux ΔΦ is given by ΔΦ = B ΔA cos ϕ, where ΔA is the area of the loop that leaves the region of the magnetic field in a time Δt. This area is the product of the width of the rectangle (0.080 m) and the length v Δt of the side that leaves the magnetic field, ΔA = (0.080 m) v Δt.

$$\Delta\Phi = \text{B}\,\Delta\text{A}\cos\phi = (2.4\ \text{T})\,(0.080\ \text{m})(0.020\ \text{m/s})(2.0\ \text{s})\cos 0.0° = \boxed{7.7 \times 10^{-3}\ \text{Wb}}$$

17. $\boxed{\text{SSM}}$ $\boxed{\text{WWW}}$ ***REASONING*** The general expression for the magnetic flux through an area *A* is given by Equation 22.2: $\Phi = BA\cos\phi$, where *B* is the magnitude of the magnetic field and ϕ is the angle of inclination of the magnetic field B with respect to the normal to the area.

SOLUTION Since the magnetic field B is parallel to the surface for the triangular ends and the bottom surface, the flux through each of these three surfaces is $\boxed{\text{zero}}$.

The flux through the 1.2 m by 0.30 m face is

$$\Phi = (0.25\ \text{T})(1.2\ \text{m})(0.30\ \text{m})\cos 0.0° = \boxed{0.090\ \text{Wb}}$$

For the 1.2 m by 0.50 m side, the area makes an angle ϕ with the magnetic field B, where

$$\phi = 90° - \tan^{-1}\left(\frac{0.30\ \text{m}}{0.40\ \text{m}}\right) = 53°$$

Therefore,

$$\Phi = (0.25\ \text{T})(1.2\ \text{m})(0.50\ \text{m})\cos 53° = \boxed{0.090\ \text{Wb}}$$

18. ***REASONING AND SOLUTION*** Faraday's law gives for the magnitude of the change in the magnetic field

$$\Delta B=\frac{(\text{emf})\Delta t}{NA}=\frac{(1.5\text{ V})(0.050\text{ s})}{(100)(0.040\text{ m})(0.060\text{ m})}=\boxed{0.31\text{ T}}$$

19. ***REASONING AND SOLUTION*** The average emf induced in the circular wire is given by

$$\text{emf}=-B\left(\frac{A-A_0}{t-t_0}\right)\cos\phi$$

The change in the area is equal to the final area of the circle ($A = 0$) minus the initial area ($A_0 = \pi r^2$).

$$\text{emf}=-B\left(\frac{0-\pi r^2}{t-t_0}\right)\cos\phi$$

$$\text{emf}=-(0.55\text{ T})\left[\frac{0-\pi\left(2.0\times10^{-2}\text{ m}\right)^2}{0.25\text{ s}-0}\right]\cos 0.0°=\boxed{2.8\times10^{-3}\text{ V}}$$

20. ***REASONING*** According to Faraday's law as given in Equation 22.3 (without the minus sign), the magnitude of the emf is $\text{emf} = \Delta\Phi/\Delta t$ for a single turn ($N = 1$). Since the normal is parallel to the magnetic field, the angle ϕ between the normal and the field is $\phi = 0°$ when calculating the flux Φ from Equation 22.2: $\Phi = BA\cos 0° = BA$. We will use this expression for the flux in Faraday's law.

SOLUTION Representing the flux as $\Phi = BA$, we find that Faraday's law (without the minus sign) becomes

$$\text{emf}=\frac{\Delta\Phi}{\Delta t}=\frac{\Delta(BA)}{\Delta t}=\frac{B\Delta A}{\Delta t}\qquad(1)$$

In this result we have used the fact that the field magnitude B is constant. Rearranging Equation (1) gives

$$\frac{\Delta A}{\Delta t}=\frac{\text{emf}}{B}=\frac{2.6\text{ V}}{1.7\text{ T}}=\boxed{1.5\text{ m}^2/\text{s}}$$

21. $\boxed{\text{SSM}}$ ***REASONING*** According to Equation 22.3, the average emf induced in a coil of N loops is $\text{emf} = -N\Delta\Phi/\Delta t$.

SOLUTION For the circular coil in question, the flux through a single turn changes by

$$\Delta\Phi = BA\cos 45° - BA\cos 90° = BA\cos 45°$$

during the interval of $\Delta t = 0.010$ s. Therefore, for N turns, Faraday's law gives the magnitude of the emf (without the minus sign) as

$$\text{emf}=\frac{NBA\cos 45°}{\Delta t}$$

Since the loops are circular, the area A of each loop is equal to πr^2. Solving for B, we have

$$B=\frac{(\text{emf})\Delta t}{N\pi r^2\cos 45°}=\frac{(0.065\text{ V})(0.010\text{ s})}{(950)\pi(0.060\text{ m})^2\cos 45°}=\boxed{8.6\times10^{-5}\text{ T}}$$

22. ***REASONING AND SOLUTION*** The magnitude of the emf is given by Faraday's law to be

$$\text{emf} = N(\Delta B/\Delta t)A\cos 0.0°$$

so

$$\Delta B/\Delta t = \text{emf}/(NA)$$

Ohm's law gives emf = IR, so

$$\frac{\Delta B}{\Delta t}=\frac{IR}{NA}=\frac{\left(7.0\times10^{-3}\text{ A}\right)(14\,\Omega)}{(75)\left(8.5\times10^{-3}\text{ m}^2\right)}=\boxed{0.15\text{ T/s}}$$

23. ***REASONING AND SOLUTION*** Faraday's law gives (using only the magnitude of the induced emf)

$$\Delta t = BA\cos 0.0°/\text{emf} = (1.5\text{ T})(0.032\text{ m}^2)/(0.010\text{ V}) = \boxed{4.8\text{ s}}$$

24. ***REASONING AND SOLUTION*** The rod may be viewed as sweeping out an area whose initial value is 0.0 m^2 and final value is $\pi r^2/4$. The flux change due to this sweep is

$$\Delta\Phi = B\pi r^2/4$$

so Faraday's law gives the magnitude of the emf to be

$$\text{emf} = \Delta\Phi/\Delta t = (1/4)(0.16\text{ T})(\pi)(1.5\text{ m})^2/(0.66\text{ s}) = \boxed{0.43\text{ V}}$$

25. $\boxed{\text{SSM}}$ $\boxed{\text{WWW}}$ ***REASONING AND SOLUTION*** According to Ohm's law, the emf developed by the coil is $\text{emf} = IR$, which, when combined with the definition of electric current becomes $\text{emf} = (\Delta q)R/(\Delta t)$. The magnitude of the emf is also given by Equation 22.3 (Faraday's law) without the minus sign:

$$\text{emf}=N\frac{\Delta\Phi}{\Delta t}=N\left(\frac{BA\cos 0°-0}{\Delta t}\right)=\frac{NBA}{\Delta t}$$

Combining the two expressions for the emf, we have

$$\frac{(\Delta q)R}{\Delta t}=\frac{NBA}{\Delta t}\qquad\text{or}\qquad B=\frac{(\Delta q)R}{NA}=\frac{(8.87\times10^{-3}\text{ C})(45.0\,\Omega)}{(1850)(4.70\times10^{-4}\text{ m}^2)}=\boxed{0.459\text{ T}}$$

26. ***REASONING*** According to Faraday's law as given in Equation 22.3 (without the minus sign), the magnitude of the emf is $\text{emf} = \Delta\Phi/\Delta t$ for a single turn ($N = 1$). Since the magnetic field is perpendicular to the plane of the loop, it is parallel to the normal. Therefore, the angle ϕ between the normal and the field is $\phi = 0°$ when calculating the flux Φ from Equation 22.2: $\Phi = BA\cos 0° = BA$. We will use this expression for the flux in Faraday's law.

SOLUTION Representing the flux as $\Phi = BA$, we find that Faraday's law (without the minus sign) becomes

$$\text{emf}=\frac{\Delta\Phi}{\Delta t}=\frac{\Delta(BA)}{\Delta t}=\frac{BA_{\text{circle}}-BA_{\text{square}}}{\Delta t}\qquad(1)$$

In this expression $A_{\text{circle}} = \pi r^2$. The circumference of the circle is $2\pi r$ and each side of the square has a length L of one fourth of this value or $L = \pi r/2$. The area of the square is, then $A_{\text{square}} = L^2 = \pi^2 r^2/4$. Using these expressions for A_{circle} and A_{square} in Equation (1), we find that the magnitude of the emf is

$$\text{emf}=\frac{BA_{\text{circle}}-BA_{\text{square}}}{\Delta t}=\frac{B\left(\pi r^2-\pi^2 r^2/4\right)}{\Delta t}=\frac{B\pi r^2(1-\pi/4)}{\Delta t}$$

$$=\frac{(0.15\text{ T})\pi(0.30\text{ m})^2(1-\pi/4)}{0.22\text{ s}}=\boxed{0.041\text{ V}}$$

27. ***REASONING AND SOLUTION*** Faraday's law can be used if we can find the flux change through the triangle as the bar slides.

$$\Delta\Phi = B\Delta A = B(bh/2 - b_0h_0/2)$$

where the b's and h's represent the bases and heights of the triangle. At time zero, The height and base of the triangle are both zero. At time, $\Delta t = t = 5.0$ s,

$$h = b\tan 15°$$

and

$$b = vt$$

Now

$$\Delta\Phi = (1/2)\,B(vt)^2\tan 15°$$

Faraday's law gives the magnitude of the emf to be

$$\text{emf} = \Delta\Phi/\Delta t = (1/2)\,Bv^2t\tan 15°$$

$$\text{emf} = (1/2)\,(0.42\text{ T})(0.40\text{ m/s})^2(5.0\text{ s})\tan 15° = \boxed{0.045\text{ V}}$$

28. ***REASONING AND SOLUTION*** Consider one revolution of either rod. The magnitude of the emf induced across the rod is

$$\text{emf} = B\Delta A/\Delta t = B(\pi L^2)/\Delta t$$

The angular speed of the rods is

$$\omega = 2\pi/\Delta t$$

so

$$\text{emf} = BL^2\omega/2$$

The rod tips have opposite polarity since they are rotating in opposite directions. Hence, the difference in potentials of the tips is

$$\Delta V = BL^2\omega$$

so

$$\omega=\frac{\Delta V}{BL^2}=\frac{4.5\times10^3\text{ V}}{(4.7\text{ T})(0.68\text{ m})^2}=\boxed{2100\text{ rad/s}}$$

29. $\boxed{\text{SSM}}$ ***REASONING AND SOLUTION*** If the north and south poles of the magnet are interchanged, the currents in the ammeter would simply be reversed in direction.

Therefore, in Figure 22.1*b*, the current will flow $\boxed{\text{right to left}}$ through the ammeter.

Similarly, in Figure 22.1*c*, the current will flow $\boxed{\text{left to right}}$ through the ammeter.

30. ***REASONING AND SOLUTION*** The current, *I*, produces a field, B, perpendicular to the plane of the circuit containing the resistance *R* and into the paper. As *I* increases, B increases, and the induced field must be directed out of the paper to counteract the increase in B. The current in the circuit necessary to produce this induced field must be counterclockwise. Therefore, this current flows through the resistor from $\boxed{\text{right to left}}$.

31. ***REASONING AND SOLUTION***

a. When the triangle is crossing the + y axis, the magnetic flux through it begins to increase. The induced field must be into the paper by Lenz's law. The induced current must, therefore, be $\boxed{\text{CW}}$.

b. When the triangle crosses the –x axis, the flux through it is not changing at all. No induced field will be produced and there will be $\boxed{\text{NO induced current}}$.

c. Upon crossing the –y axis the coil will experience a decrease in flux so the induced field will be out of the paper. The induced current must then be $\boxed{\text{CCW}}$.

d. As the triangle crosses the +x axis, the flux through it is not changing at all. No induced field will be produced and there will be $\boxed{\text{NO induced current}}$.

32. ***REASONING AND SOLUTION***

a. When the switch is opened, the flux through coils *A* and *B* will decrease. The induced fields produced by each coil must, according to Lenz's law, oppose the change in flux due to the applied field. The induced field produced by *A* will be down, and the induced field produced by *B* will be up. The induced current directions necessary to produce the induced fields are then

$$\boxed{\text{CW for A and CCW for B}}$$

b. When the switch is closed, the fluxes through the coils will increase. The induced fields will then reverse directions as will the currents. The currents are then

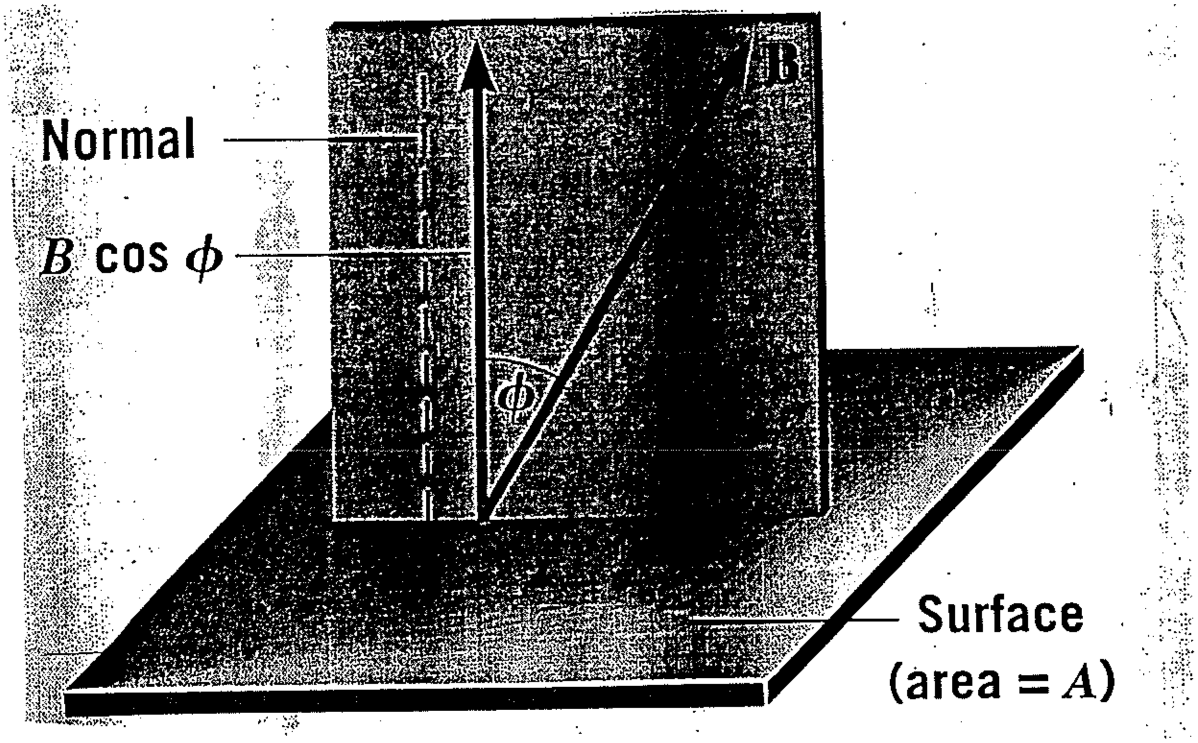
$$\boxed{\text{CCW for A and CW for B}}$$

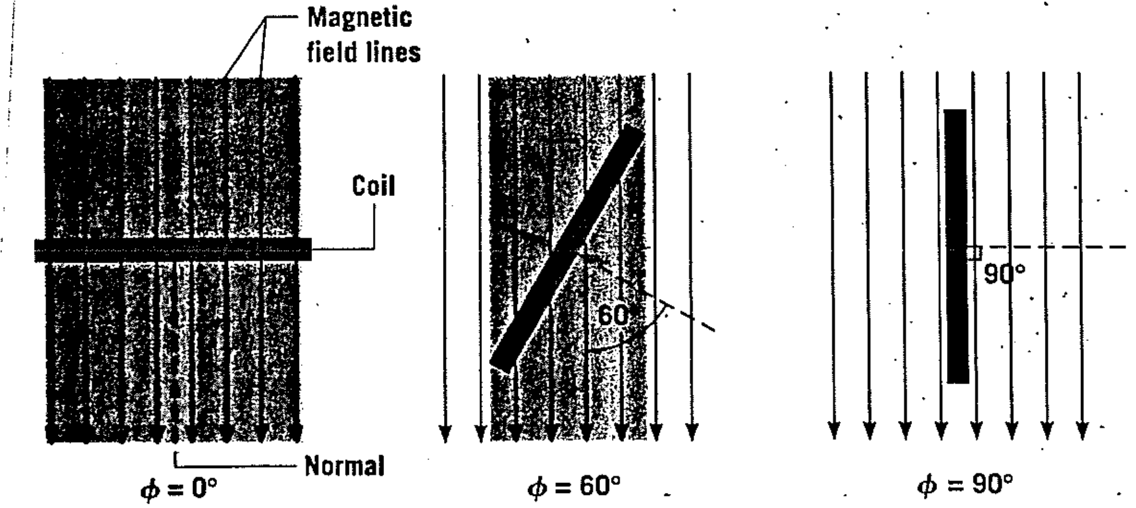
33. $\boxed{\text{SSM}}$ ***REASONING*** In solving this problem, we apply Lenz's law, which essentially says that the change in magnetic flux must be opposed by the induced magnetic field.

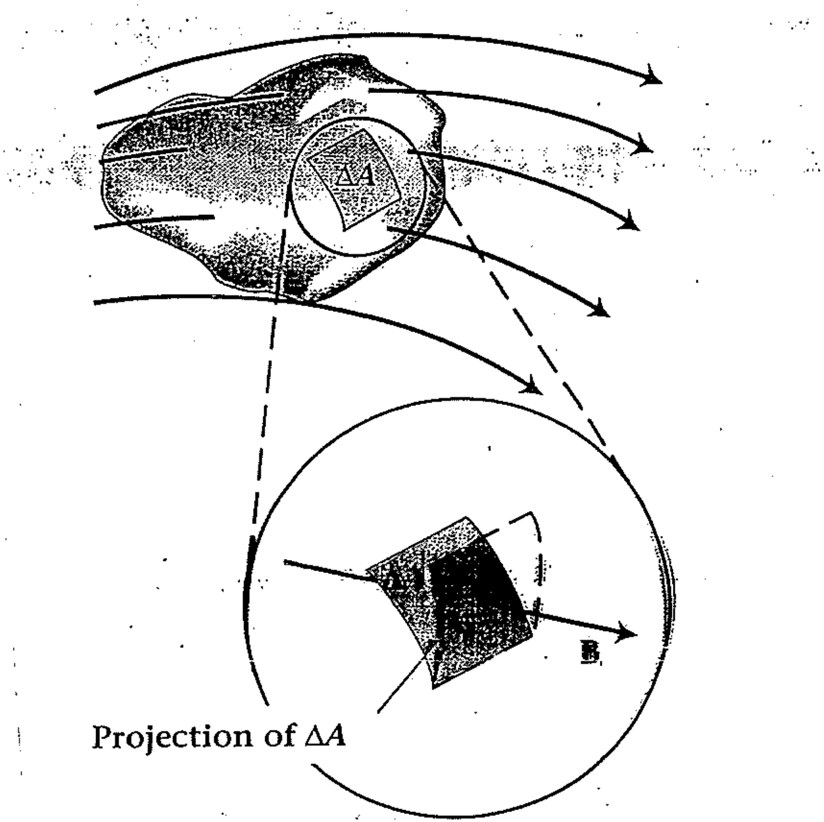
SOLUTION

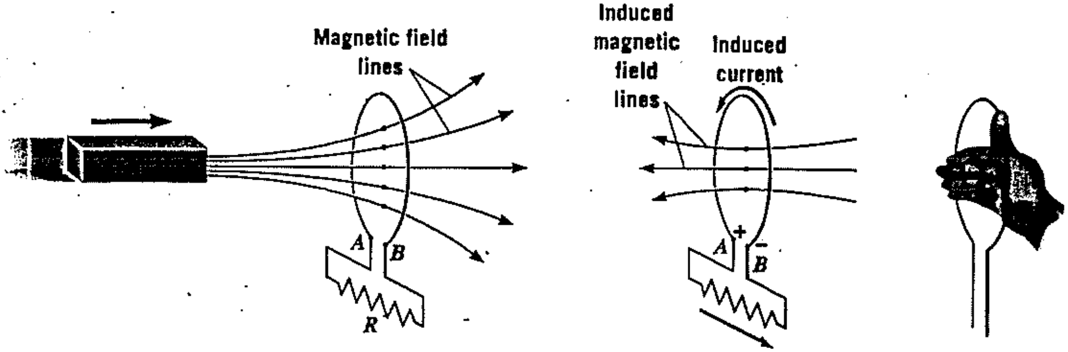
a. The magnetic field due to the wire in the vicinity of position 1 is directed out of the paper. The coil is moving closer to the wire into a region of higher magnetic field, so the flux through the coil is increasing. Lenz's law demands that the induced field counteract this increase. The direction of the induced field, therefore, must be into the paper. The current in the coil must be $\boxed{\text{clockwise}}$.

b. In region 2, the magnetic field is directed into the paper and is decreasing as the coil moves away from the wire. The induced magnetic field, therefore, must be directed into the paper, so the current in the coil must be $\boxed{\text{clockwise}}$.


Normal
$B \cos \phi$
ϕ
$\mathbf{B}$
Surface
(area = A)


Magnetic field lines
Coil
Normal
$\phi = 0°$
60°
$\phi = 60°$
90°
$\phi = 90°$


ΔA
ΔA
B
Projection of ΔA


Magnetic field lines
A
B
R
Induced magnetic field lines
Induced current
+
−
A
B

(a)

(b)

Magnetism
Practice Test

MULTIPLE CHOICE

1. The earth's magnetic north pole is magnetically

a) north.
b) south.
c) neutral.

2. The SI unit of magnetic field is the

a) weber.
b) gauss.
c) tesla.
d) lorentz.

3. A vertical wire carries a current straight up in a region where the magnetic field vector points due north. What is the direction of the resulting force on this current?

a) Down
b) North
c) East
d) West

4. A wire carries a current of 10 A in a direction of 30ø with respect to the direction of a 0.30-T magnetic field. Find the magnitude of the magnetic force on a 0.50 m length of the wire.

a) 0.75 N
b) 1.5 N
c) 3.0 N
d) 6.0 N

5. A 2.0-m wire carrying a current of 0.60 A is oriented parallel to a uniform magnetic field of 0.50 T. What is the magnitude of the force it experiences?

a) zero
b) 0.60 N
c) 0.15 N
d) 0.30 N

6. What is the force per meter on a straight wire carrying 5.0 A when it is placed in a magnetic field of 0.020 T? The wire makes an angle of 27ø with respect to the magnetic field lines.

a) 0.022 N
b) 0.045 N
c) 0.17 N
d) 0.26 N

7. The direction of the force on a current-carrying wire in a magnetic field is described by which of the following?

a) perpendicular to the current

b) perpendicular to the magnetic field
c) both a) and b) are valid
d) neither a) nor b) is valid

8. A stationary proton is in a uniform magnetic field of 0.20 T. What is the magnitude of the magnetic force on the proton?

a) zero
b) 1.6X10-20 N
c) 3.2X10-20 N
d) 1.6X10-21 N

9. A proton moving at 5.0X104 m/s horizontally enters a region where a magnetic field of 0.12 T is present, directed vertically downward. What force acts on the proton?

a) zero
b) 3.2X10-16 N
c) 6.4X10-16 N
d) 9.6X10-16 N

10. At a particular instant, an electron moves eastward at speed V in a uniform magnetic field that is directed straight downward. The magnetic force that acts on it is

a) zero.
b) directed upward.
c) directed to the south.
d) none of the above.

11. A charged particle is injected into a uniform magnetic field such that its velocity vector is perpendicular to the magnetic field vector. Ignoring the particle's weight, the particle will

a) move in a straight line.
b) follow a spiral path.
c) move along a parabolic path.
d) follow a circular path.

12. An electron moving along the +x axis enters a region where there is a uniform magnetic field in the +y direction. What is the direction of the magnetic force on the electron? (+x to right, +y up, and +z out of the page.)

a) +z direction
b) -z direction
c) -y direction
d) -x direction

13. Which of the following is correct?

a) When a current carrying wire is in your right hand, thumb in the direction of the magnetic field lines, your fingers point in the direction of the current.
b) When a current carrying wire is in your left hand, thumb in the direction of the magnetic field lines, your fingers point in the direction of the current.
c) When a current carrying wire is in your right hand, thumb in direction of the current, your fingers point in the direction of the magnetic field lines.
d) When a current carrying wire is in your left hand, thumb pointing in the

direction of the current, your fingers point in the direction of the magnetic field lines.

14. How much current must flow for 1.0X10-3 T of magnetic field to be present 1.0 cm from a wire?

a) 0.050 A
b) 9.2 A
c) 16 A
d) 50 A

15. A high power line carrying 1000 A generates what magnetic field at the ground, 10 m away?

a) 4.7X10-6 T
b) 6.4X10-6 T
c) 2.0X10-5 T
d) 5.6X10-5 T

16. At what distance from a long straight wire carrying a current of 5.0 A is the magnitude of the magnetic field due to the wire equal to the strength of the earth's magnetic field of about 5.0X10-5 T?

a) 1.0 cm
b) 2.0 cm
c) 3.0 cm
d) 4.0 cm

17. Two long parallel wires placed side-by-side on a horizontal table carry identical size currents in opposite directions. The wire on your right carries current toward you, and the wire on your left carries current away from you. From your point of view, the magnetic field at the point exactly midway between the two wires

a) points up.
b) points down.
c) points toward you.
d) is zero.

18. At double the distance from a long current-carrying wire, the strength of the magnetic field produced by that wire decreases to

a) 1/8 of its original value.
b) 1/4 of its original value.
c) 1/2 of its original value.
d) none of the above.

19. A horizontal wire carries a current straight toward you. From your point of view, the magnetic field caused by this current

a) points directly away from you.
b) points to the left.
c) circles the wire in a clockwise direction.
d) circles the wire in a counter-clockwise direction.

20. A vertical wire carries a current straight down. To the east of this wire, the magnetic field points

a) north.
b) east.
c) south.
d) down.

21. Two long parallel wires carry currents of 20 A and 5.0 A in opposite directions. The wires are separated by 0.20 m. What is the magnetic field midway between the two wires?

a) 1.0X10-5 T
b) 3.0X10-5 T
c) 4.0X10-5 T
d) 5.0X10-5 T

22. Two long parallel wires carry currents of 5.0 A and 8.0 A in the same direction. The wires are separated by 0.30 m. Find the magnetic force per unit length between the two wires.

a) 2.7X10-5 N attractive
b) 7.2X10-5 N attractive
c) 2.7X10-5 N repulsive
d) 7.2X10-5 N repulsive

23. What is the magnetic field at the center of a circular loop of wire of radius 4.0 cm when a current of 2.0 A flows in the wire?

a) 1.3X10-6 T
b) 3.1X10-6 T
c) 1.3X10-5 T
d) 3.1X10-5 T

24. A current carrying circular loop of wire lies flat on a table top. When viewed from above, the current moves around the loop in a counterclockwise sense. What is the direction of the magnetic field caused by this current, inside the loop? The magnetic field

a) circles the loop in a clockwise direction.
b) circles the loop in a counterclockwise direction.
c) points straight up.
d) points straight down.

25. A solenoid 20 cm long is wound with 5000 turns of wire. What magnetic field is produced at the center of the solenoid when a current of 10 A flows?

a) 1.6 T
b) 0.84 T
c) 0.67 T
d) 0.31 T

26. Calculate the magnitude of the magnetic field at the center of a solenoid which has 100 turns, is 0.10 m long and carries a current of 1.0 A.

a) 1.1 mT
b) 1.3 mT
c) 1.5 mT
d) 1.7 mT

27. What is the magnetic moment of a rectangular loop of 120 turns that carries 6.0 A if its dimensions are 4.0 cm X 8.0 cm?

a) 0.23 Aúm2
b) 2.3 Aúm2
c) 23 Aúm2
d) 230 Aúm2

28. A circular loop of wire of cross-sectional area 0.12 m2 consists of 200 turns, each carrying 0.50 A. It is placed in a magnetic field of 0.050 T oriented at 30ø to the plane of the loop. What torque acts on the loop?

a) 0.25 múN
b) 0.52 múN
c) 2.5 múN
d) 5.2 múN

29. Consider two current-carrying circular loops. Both are made from one strand of wire and both carry the same current, but one has twice the radius of the other. Compared to the magnetic moment of the smaller loop, the magnetic moment of the larger loop is

a) 16 times stronger.
b) 8 times stronger.
c) 4 times stronger.
d) 2 times stronger.

30. The maximum torque on a current carrying loop occurs when the angle between the loop's magnetic moment and the magnetic field vector is

a) 0ø
b) 90ø
c) 180ø
d) None of the above.

31. When placed askew in a magnetic field, a current carrying loop that is free to rotate in any direction will experience a torque until its magnetic moment vector

a) is at right angles to the magnetic field vector.
b) makes a 45ø angle with the magnetic field vector.
c) makes an angle of 270ø with the magnetic field vector.
d) is aligned with the magnetic field vector.

32. A circular loop of radius 0.10 m is rotating in a uniform magnetic field of 0.20 T. Find the magnetic flux through the loop when the plane of the loop and the magnetic field vector are parallel.

a) zero
b) 3.1X10-3 Túm2
c) 5.5X10-3 Túm2
d) 6.3X10-3 Túm2

33. A circular loop of radius 0.10 m is rotating in a uniform magnetic field of 0.20 T. Find the magnetic flux through the loop when the plane of the loop and the magnetic field vector are perpendicular.

a) zero
b) 3.1X10-3 Túm2
c) 5.5X10-3 Túm2
d) 6.3X10-3 Túm2

34. A coil is wrapped with 200 turns of wire on a square frame with sides 18 cm. A uniform magnetic field is applied perpendicular to the plane of the coil. If the field changes uniformly from 0.50 T to 0 in 8.0 s, find the average value of the induced emf.

a) 2.1 mV
b) 4.1 mV
c) 0.21 V
d) 0.41 V

35. A coil of 160 turns and area 0.20 m2 is placed with its axis parallel to a magnetic field of 0.40 T. The magnetic field changes from 0.40 T in the x-direction to 0.40 T in the negative x-direction in 2.0 s. If the resistance of the coil is 16 ê, at what rate is power generated in the coil?

a) 5.0 W
b) 10 W
c) 15 W
d) 20 W

36. A wire moves across a magnetic field. The emf produced in the wire depends on

a) the field's magnetic flux.
b) the length of the wire.
c) the orientation of the wire with respect to the magnetic field vector.
d) all of the above.

37. The cross-sectional area of an adjustable single loop is reduced from 1.0 m2 to 0.25 m2 in 0.10 s. What is the average emf that is induced in this coil if it is in a region where B = 2.0 T upward, and the coil's plane is perpendicular to B?

a) 12 V
b) 15 V
c) 18 V
d) 21 V

38. Faraday's law of induction states that the emf induced in a loop of wire is proportional to

a) the magnetic flux.
b) the magnetic flux density times the loop's area.
c) the time variation of the magnetic flux.
d) current divided by time.

39. The flux through a coil changes from 4.0X10-5 Wb to 5.0X10-5 Wb in 0.10 s. What emf is induced in this coil?

a) 5.0X10-4 V
b) 4.0X10-4 V

c) 1.0X10-4 V
d) None of the above

40. A coil lies flat on a table top in a region where the magnetic field vector points straight up. The magnetic field vanishes suddenly. When viewed from above, what is the sense of the induced current in this coil as the field fades?

a) The induced current flows counterclockwise.
b) The induced current flows clockwise.
c) There is no induced current in this coil.
d) The current flows clockwise initially, and then it flows counterclockwise before stopping.

41. A circular loop of wire is rotated at constant angular speed about an axis whose direction can be varied. In a region where a uniform magnetic field points straight down, what must be the orientation of the loop's axis of rotation if the induced emf is to be zero?

a) Any horizontal orientation will do.
b) It must make an angle of 450 to the vertical.
c) It must be vertical.
d) None of the above.

42. A horizontal rod (oriented in the east-west direction) is moved northward at constant velocity through a magnetic field that points straight down. Which statement is true?

a) The west end of the rod is at higher potential than the east end.
b) The east end of the rod is at higher potential than the west end.
c) The top surface of the rod is at higher potential than the bottom surface.
d) The bottom surface of the rod is at higher potential than the top surface.

43. A circular coil lies flat on a horizontal table. A bar magnet is held above its center with its north pole pointing down. The stationary magnet induces (when viewed from above)

a) no current in the coil.
b) a clockwise current in the coil.
c) a counterclockwise current in the coil.
d) a current whose direction cannot be determined from the information given.

44. A circular coil lies flat on a horizontal table. A bar magnet is held above its center with its north pole pointing down, and released. As it approaches the coil, the falling magnet induces (when viewed from above)

a) no current in the coil.
b) a clockwise current in the coil.
c) a counterclockwise current in the coil.
d) a current whose direction cannot be determined from the information provided.

45. A long straight wire lies on a horizontal table and carries an ever-increasing current northward. Two coils of wire lie flat on the table, one on either side of the wire. When viewed from above, the induced current circles

a) clockwise in both coils.
b) counterclockwise in both coils.

c) clockwise in the east coil and counterclockwise in the west coil.
d) counterclockwise in the east coil and clockwise in the west coil.

46. A coil lies flat on a level table top in a region where the magnetic field vector points straight up. The magnetic field suddenly grows stronger. When viewed from above, what is the direction of the induced current in this coil as the field increases?

a) counterclockwise
b) clockwise
c) Clockwise initially, then counterclockwise before stopping.
d) There is no induced current in this coil.

47. A coil lies flat on a horizontal table top in a region where the magnetic field points straight down. The magnetic field disappears suddenly. When viewed from above, what is the direction of the induced current in this coil as the field disappears?

a) counterclockwise
b) clockwise
c) Clockwise initially, then counterclockwise before stopping.
d) There is no induced current.

48. According to Lenz's law, the direction of an induced current in a conductor will be that which tends to prduce which of the following effects?

a) enhance the effect which produces it.
b) produce a greater heating effect.
c) produce the greatest voltage.
d) oppose the effect which produces it.

49. A bar magnet falls through a loop of wire with the north pole entering first. As the north pole enters the wire, the induced current will be (as viewed from above)

a) zero
b) clockwise
c) counterclockwise
d) to top of loop