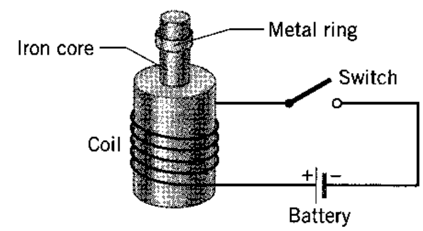
magnetic flux through the coil does not change. But when the robot deviates from the parallel path, an induced emf appears in the coil. The emf is sent to electronic circuits that bring the robot back to the path. Explain why an emf would be induced in the sensor coil.

10. In a car, the generator-like action of the alternator occurs while the engine is running and keeps the battery fully charged. The headlights would discharge an old and failing battery quickly if it were not for the alternator. Explain why the engine of a parked car runs more "quietly" with the headlights off than with them on when the battery is in bad shape.

11. In Figure 22.3 a coil of wire is being stretched. (a) Using Lenz's law, verify that the induced current in the coil has the direction shown in the drawing. (b) Deduce the direction of the induced current if the direction of the external magnetic field in the figure were reversed. Explain.

12. (a) When the switch in the circuit in the drawing is closed, a current is established in the coil and the metal ring "jumps" upward. Explain this behavior. (b) Describe what would happen to the ring if the battery polarity were reversed.



13. The string of an electric guitar vibrates in a standing wave pattern that consists of nodes and antinodes. (Section 17.5 discusses standing waves.) Where should an electromagnetic pickup be located in the standing wave pattern to produce a maximum emf, at a node or an antinode? Why?

14. An electric motor in a hair drier is running at normal speed and, thus, is drawing a relatively small current, as in part (b) of Example 12. What happens to the current drawn by the motor if the shaft is prevented from turning, so the back emf is suddenly reduced to zero? Remembering that the wire in the coil of the motor has some resistance, what happens to the temperature of the coil? Justify your answers.

15. One transformer is a step-up device, while another is step-down. These two units have the same voltage across and the same current in their primary coils. Does either one deliver more power to the circuit attached to the secondary coil? If so, which one? Ignore any heat loss within the transformers and account for your answer.

PROBLEMS

ssm Solution is in the Student Solutions Manual. www Solution is available on the World Wide Web at http://www.wiley.com/college/cutnell
This icon represents a biomedical application.

Section 22.2 Motional Emf

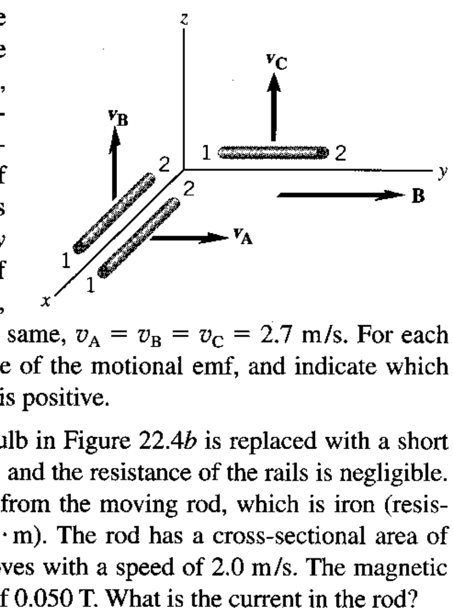
1. ssm A spark can jump between two nontouching conductors if the potential difference between them is sufficiently large. A potential difference of approximately 940 V is required to produce a spark in an air gap of 1.0×10^{-4} m. Suppose the light bulb in Figure 22.4*b* is replaced by such a gap. How fast would a 1.3-m rod have to be moving in a magnetic field of 4.8 T to cause a spark to jump across the gap?

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

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

4. In 1996 NASA performed an experiment, called the Tethered Satellite experiment. In this experiment a 2.0×10^4-m length of wire was let out by the space shuttle Atlantis to generate a motional emf. The shuttle had an orbital speed of 7.6×10^3 m/s, and the magnitude of the earth's magnetic field at the location of the wire was 5.1×10^{-5} T. If the wire had moved perpendicular to the earth's magnetic field, what would have been the motional emf generated between the ends of the wire?

5. 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.** 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 = $9.7 \times 10^{-8}\ \Omega \cdot$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?

***7. 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)?

***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.** Review Conceptual Example 3 and Figure 22.7*b* 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. 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.

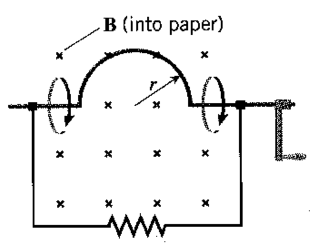
Section 22.3 Magnetic Flux

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

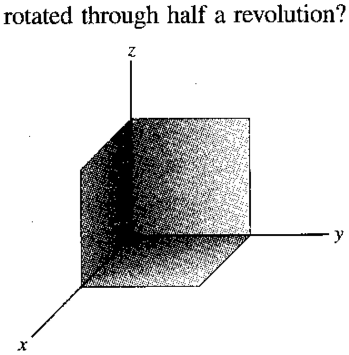
10. A hand is held flat and placed in a uniform magnetic field of magnitude 0.35 T. The hand has an area of 0.0160 m^2 and negligible thickness. Determine the magnetic flux that passes through the hand when the normal to the hand is (a) parallel and (b) perpendicular to the magnetic field.

11. 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?

12. A loop of wire has the shape shown in the drawing. The top part of the wire is bent into a semicircle of radius $r = 0.20$ m. The normal to the plane of the loop is parallel to a constant magnetic field of magnitude 0.75 T. What is the change $\Delta\Phi$ in the magnetic flux that passes through the loop when, starting with the position shown in the drawing, the semicircle is rotated through half a revolution?

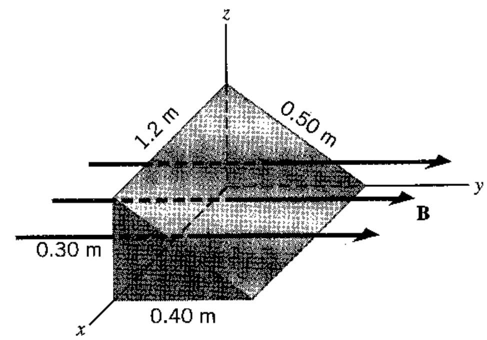


13. The drawing shows three square surfaces, one lying in the *xy* plane, one in the *xz* plane, and one in the *yz* plane. The sides of each square have lengths of 2.0×10^{-2} m. A uniform magnetic field exists in this region, and its components are: $B_x = 0.50$ T, $B_y = 0.80$ T, and $B_z = 0.30$ 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.

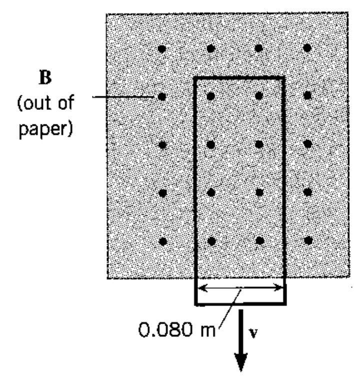


14. A house has a floor area of 112 m^2 and an outside wall that has an area of 28 m^2. The earth's magnetic field here has a horizontal component of 2.6×10^{-5} T that points due north and a vertical component of 4.2×10^{-5} T that points straight down, toward the earth. Determine the magnetic flux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

***15. 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.



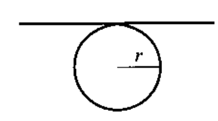
***16.** A rectangular loop of wire is moving toward the bottom of the page with a speed of 0.020 m/s (see the drawing). The loop is leaving a region in which a 2.4-T magnetic field exists; the magnetic field outside this region is zero. During a time of 2.0 s, what is the magnitude of the *change* in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



Section 22.4 Faraday's Law of Electromagnetic Induction

17. A 300-turn rectangular loop of wire has an area per turn of 5.0×10^{-3} m^2. At $t_0 = 0$ s a magnetic field is turned on, and its magnitude increases to 0.40 T when $t = 0.80$ s. The field is directed at an angle of $\phi = 30.0°$ with respect to the normal of the loop. (a) Find the magnitude of the average emf induced in the loop. (b) If the loop is a closed circuit whose resistance is 6.0 Ω, determine the average induced current.

18. The drawing shows a straight wire, a part of which is bent into the shape of a circle. The radius of the circle is 2.0 cm. A constant magnetic field of magnitude 0.55 T is directed perpendicular 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.



19. ssm A circular coil (950 turns, radius = 0.060 m) is rotating in a uniform magnetic field. At $t = 0$ s, 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.

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. 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.

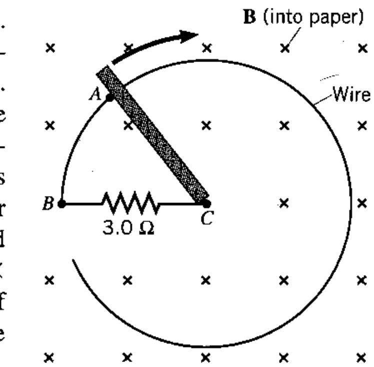
22. A constant magnetic field passes through a single rectangular loop whose dimensions are 0.35 m × 0.55 m. The magnetic field has a magnitude of 2.1 T and is inclined at an angle of 65° with respect to the normal to the plane of the loop. (a) If the magnetic field decreases to zero in a time of 0.45 s, what is the magnitude of the average emf induced in the loop? (b) If the magnetic field remains constant at its initial value of 2.1 T, what is the magnitude of the rate $\Delta A/\Delta t$ at which the area should change so that the average emf has the same magnitude?

23. 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?

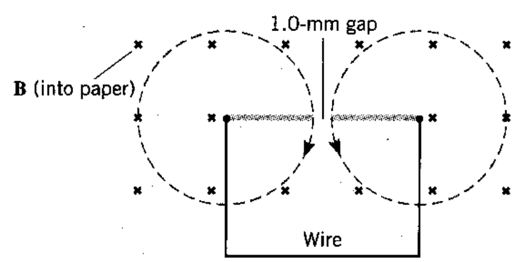
***24.** A piece of copper wire is formed into a single circular loop of radius 12 cm. A magnetic field is oriented parallel to the normal to the loop, and it increases from 0 to 0.60 T in a time of 0.45 s. The wire has a resistance per unit length of $3.3 \times 10^{-2}\ \Omega/m$. What is the average electrical energy dissipated in the resistance of the wire?

***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 $4.70 \times 10^{-4}\ m^2$. 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.** The drawing shows a copper wire (negligible resistance) bent into a circular shape with a radius of 0.50 m. The radial section BC is fixed in place, while the copper bar AC sweeps around at an angular speed of 15 rad/s. The bar makes electrical contact with the wire at all times. The wire and the bar have negligible resistance. A uniform magnetic field exists everywhere, is perpendicular to the plane of the circle, and has a magnitude of 3.8×10^{-3} T. Find the magnitude of the current induced in the loop ABC.

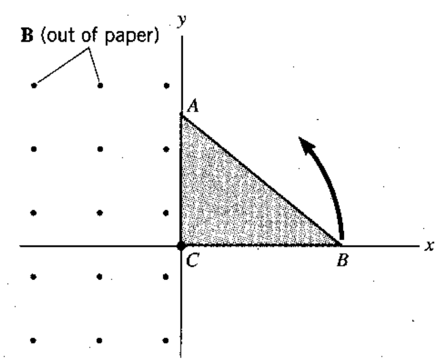


****27.** Two 0.68-m-long conducting rods are rotating at the same speed in opposite directions, and both are perpendicular to a 4.7-T magnetic field. As the drawing shows, the ends of these rods come to within 1.0 mm of each other as they rotate. Moreover, the fixed ends about which the rods are rotating 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

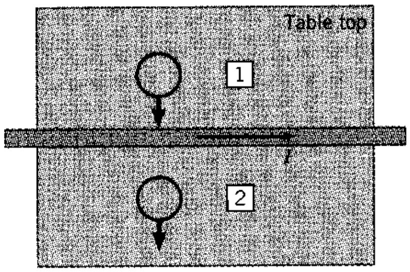
28. The drawing shows that a uniform magnetic field is directed perpendicularly out of the plane of the paper and fills the entire region to the left of the y axis. There is no magnetic field to the right of the y axis. A rigid right triangle ABC is made of copper wire. The triangle rotates counterclockwise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



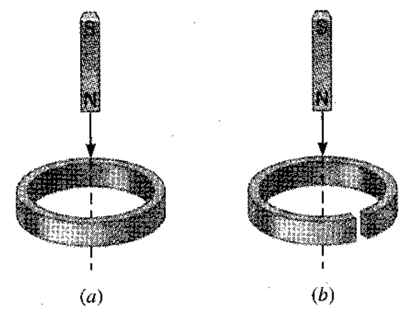
29. ssm In Figure 22.1, suppose the north and south poles of the magnet were interchanged. Determine the direction of the current through the ammeter in parts b and c of the picture (left-to-right or right-to-left). Give your rationale.

30. Review the drawing that accompanies Problem 12. The semicircular piece of wire rotates through half a revolution in the direction shown, starting from the position indicated in the drawing. Which end of the resistor, the left or the right end, is positive? Explain your reasoning.

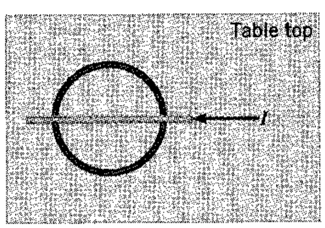
31. ssm Review Conceptual Example 9 as an aid in understanding this problem. A long, straight wire lies on a table and carries a current I. As the drawing shows, a small circular loop of wire is pushed across the top of the table from position 1 to position 2. Determine the direction of the induced current,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



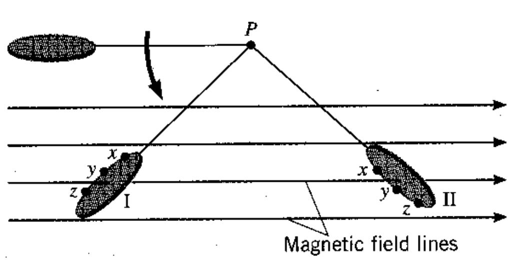
***32.** The drawing shows a bar magnet falling through a metal ring. In part a the ring is solid all the way around, but in part b it has been cut through. (a) Explain why the motion of the magnet in part a is retarded when the magnet is above the ring and below the ring as well. Draw any induced currents that appear in the ring. (b) Explain why the motion of the magnet is unaffected by the ring in part b.



***33.** 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.

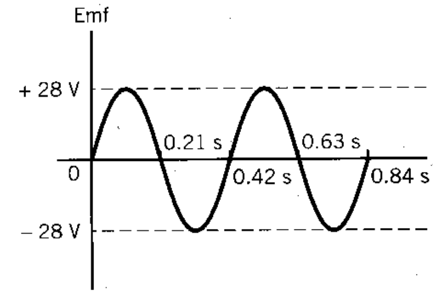


****34.** A wire loop is suspended from a string that is attached to point P in the drawing. When released, the loop swings downward, from left to right, through a uniform magnetic field, with the plane of the loop remaining perpendicular to the plane of the paper at all times. (a) Determine the direction of the current induced in the loop as it swings past the locations labeled I and II. Specify the direction 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.



Section 22.7 The Electric Generator

35. ssm www The drawing shows a plot of the output emf of a generator as a function of time t. The coil of this device has a cross-sectional area per turn of 0.020 m^2 and contains 150 turns. Find (a) the frequency f of the generator in hertz, (b) the angular speed ω in rad/s, and (c) the magnitude of the magnetic field.



36. One generator uses a magnetic field of 0.10 T and has a coil area per turn of 0.045 m^2. A second generator has a coil area per turn of 0.015 m^2. The generator coils have the same number of turns and rotate at the same angular speed. What magnetic field should be used in the second generator, so that its peak emf is the same as that of the first generator?

37. You are requested to design a 60.0-Hz ac generator whose maximum emf is to be 5500 V. The generator is to contain a 150-turn coil whose area per turn is 0.85 m^2. What should be the magnitude of the magnetic field in which the coil rotates?

38. A vacuum cleaner is plugged into a 120.0-V socket and uses 3.0 A of current in normal operation when the back emf generated by the electric motor is 72.0 V. Find the coil resistance of the motor.

39. ssm A generator has a square coil consisting of 248 turns. The coil rotates at 79.1 rad/s in a 0.170-T magnetic field. The peak output of the generator is 75.0 V. What is the length of one side of the coil?

40. A 120.0-volt motor draws a current of 7.00 A when running at normal speed. The resistance of the armature wire is 0.720 Ω. (a) Determine the back emf generated by the motor. (b) What is the current at the instant when the motor is just turned on and has not begun to rotate? (c) What series resistance must be added to limit the starting current to 15.0 A?

***41. ssm** At its normal operating speed, an electric fan motor draws only 15.0% of the current it draws when it just begins to turn the fan blade. The fan is plugged into a 120.0-V socket. What back emf does the motor generate at its normal operating speed?

***42.** The coil of a generator has a radius of 0.14 m. When this coil is unwound, the wire from which it is made has a length of 5.7 m. The magnetic field of the generator is 0.20 T, and the coil rotates at an angular speed of 25 rad/s. What is the peak emf of this generator?

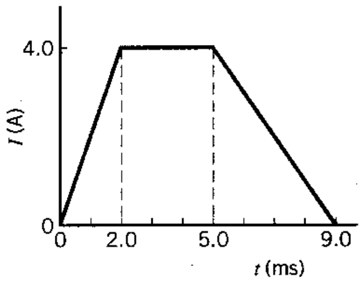
****43.** A motor is designed to operate on 117 V and draws a current of 12.2 A when it first starts up. At its normal operating speed, the motor draws a current of 2.30 A. Obtain (a) the resistance of the armature coil, (b) the back emf developed at normal speed, and (c) the current drawn by the motor at one-third normal speed.

Section 22.8 Mutual Inductance and Self-Inductance

44. The average emf induced in the secondary coil is 0.12 V when the current in the primary coil changes from 3.4 to 1.6 A in 0.14 s. What is the mutual inductance of the coils?

45. **ssm** Suppose you wish to make a solenoid whose self-inductance is 1.4 mH. The inductor is to have a cross-sectional area of 1.2×10^{-3} m^2 and a length of 0.052 m. How many turns of wire are needed?

46. The current through a 3.2-mH inductor varies with time according to the graph shown in the drawing. What is the average induced emf during the time intervals (a) 0–2.0 ms, (b) 2.0–5.0 ms, and (c) 5.0–9.0 ms?



47. Mutual induction can be used as the basis for a metal detector. A typical setup uses two large coils that are parallel to each other and have a common axis. Because of mutual induction, the ac generator connected to the primary coil causes an emf of 0.46 V to be induced in the secondary coil. When someone without metal objects walks through the coils, the mutual inductance and, thus, the induced emf do not change much. But when a person carrying a handgun walks through, the mutual inductance increases. If the mutual inductance increases by a factor of three, find the new value of the induced emf. The change in emf can be used to trigger an alarm.

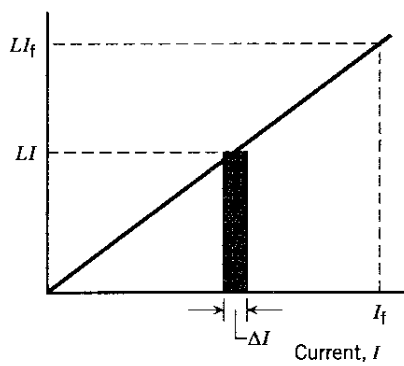
48. Two coils have a mutual inductance of 2.5 mH. In the primary coil the current changes by 3.0 A in 0.040 s. The circuit of the secondary coil has a resistance of 2.0 Ω. Find the magnitude of the average current induced in the secondary coil.

49. **ssm** The earth's magnetic field, like any magnetic field, stores energy. The maximum strength of the earth's field is about 7.0×10^{-5} T. Find the maximum magnetic energy stored in the space above a city if the space occupies an area of 5.0×10^{8} m^2 and has a height of 1500 m.

***50.** A magnetic field has a magnitude of 12 T. What is the magnitude of an electric field that stores the same energy per unit volume as this magnetic field?

***51.** A long, current-carrying solenoid with an air core has 1750 turns per meter of length and a radius of 0.0180 m. A coil of 125 turns is wrapped tightly around the outside of the solenoid. What is the mutual inductance of this system?

***52.** The purpose of this problem is to show that the work W needed to establish a final current I_f in an inductor is $W = \frac{1}{2}LI_f^2$ (Equation 22.10). In Section 22.8 we saw that the amount of work ΔW needed to change the current through an inductor by an amount ΔI is $\Delta W = LI(\Delta I)$, where L is the inductance. The drawing shows a graph of LI versus I. Notice that $LI(\Delta I)$ is the area of the shaded vertical rectangle whose height is LI and whose width is ΔI. Use this fact to show that the total work W needed to establish a current I_f is $W = \frac{1}{2}LI_f^2$.



****53.** **ssm** A solenoid has a cross-sectional area of 6.0×10^{-4} m^2, consists of 400 turns per meter, and carries a current of 0.40 A. A 10-turn coil is wrapped tightly around the circumference of the solenoid. The ends of the coil are connected to a 1.5-Ω resistor. Suddenly, a switch is opened, and the current in the solenoid dies to zero in a time of 0.050 s. Find the average current induced in the coil.

Section 22.9 Transformers

54. A neon sign requires 12 000 V for its operation. It operates from a 220-V receptacle. (a) What type of transformer, step-up or step-down, is needed? (b) What must be the turns ratio N_s/N_p of the transformer?

55. **ssm** Electric doorbells found in many homes require 10.0 V to operate. To obtain this voltage from the standard 120-V supply, a transformer is used. Is a step-up or a step-down transformer needed, and what is its turns ratio N_s/N_p?

56. The batteries in a portable CD player are recharged by a unit that plugs into a wall socket. Inside the unit is a step-down transformer with a turns ratio of 1 : 13. The wall socket provides 120 V. What voltage does the secondary coil of the transformer provide?

57. The secondary coil of a step-up transformer provides the voltage that operates an electrostatic air filter. The turns ratio of the transformer is 43 : 1. The primary coil is plugged into a standard 120-V outlet. The current in the secondary coil is 1.5×10^{-3} A. Find the power consumed by the air filter.

58. In some places, insect "zappers," with their blue lights, are a familiar sight on a summer's night. These devices use a high voltage to electrocute insects. One such device uses an ac voltage of 4320 V, which is obtained from a standard 120.0-V outlet by means of a transformer. If the primary coil has 21 turns, how many turns are in the secondary coil?

***59.** **ssm** A generating station is producing 1.2×10^{6} W of power that is to be sent to a small town located 7.0 km away. Each of the two wires that comprise the transmission line has a resistance per kilometer of length of 5.0×10^{-2} Ω/km. (a) Find the power lost in heating the wires if the power is transmitted at 1200 V. (b) A 100 : 1 step-up transformer is used to raise the voltage before the power is transmitted. How much power is now lost in heating the wires?

***60.** In a television set the power needed to operate the picture tube is 95 W and is derived from the secondary coil of a transformer. There is a current of 5.3 mA in the secondary coil. The primary coil is connected to a 120-V receptacle. Find the turns ratio N_s/N_p of the transformer.

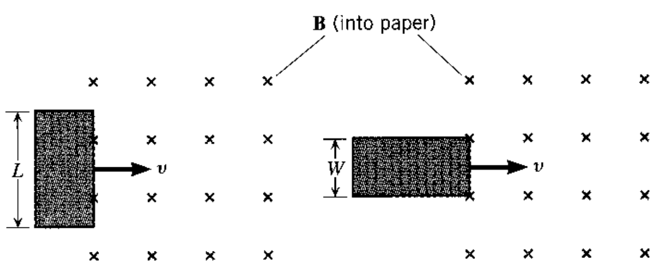
****61.** A generator is connected across the primary coil (N_p turns) of a transformer, while a resistance R_2 is connected across the secondary coil (N_s turns). This circuit is equivalent to a circuit in which a single resistance R_1 is connected directly across the generator, without the transformer. Show that $R_1 = (N_p/N_s)^2 R_2$, by starting with Ohm's law as applied to the secondary coil.

ADDITIONAL PROBLEMS

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

63. The maximum strength of the earth's magnetic field is about 7.0×10^{-5} T near the south magnetic pole. In principle, this field could be used with a rotating coil to generate 60.0-Hz ac electricity. What is the minimum number of turns (area per turn = 0.016 m^2) that the coil must have to produce an rms voltage of 120 V?

64. Parts *a* and *b* of the drawing show the same uniform and constant (in time) magnetic field **B** directed perpendicularly into the paper over a rectangular region. Outside this region, there is no field. Also shown is a rectangular coil (one turn), which lies in the plane of the paper. In part *a* the long side of the coil (length = L) is just at the edge of the field region, while in part *b* the short side (width = W) is just at the edge. It is known that $L/W = 3.0$. In both parts of the drawing the coil is pushed into the field with the same velocity **v** until it is completely within the field region. The magnitude of the average emf induced in the coil in part *a* is 0.15 V. What is its magnitude in part *b*?



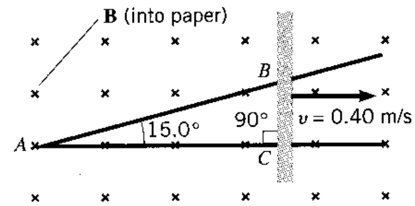
65. ssm Suppose in Figure 22.1 that the bar magnet is held stationary, but the coil of wire is free to move. Which way will current be directed through the ammeter, left-to-right or right-to-left, when the coil is moved (a) to the left and (b) to the right? Explain.

66. The resistances of the primary and secondary coils of a transformer are 56 and 14 Ω, respectively. Both coils are made from lengths of the same copper wire. The circular turns of each coil have the same diameter. Find the turns ratio N_s/N_p.

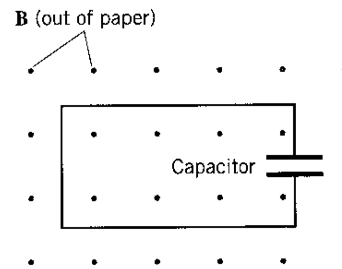
67. ssm The coil of an ac generator has an area per turn of 1.2×10^{-2} m^2 and consists of 500 turns. The coil is situated in a 0.13-T magnetic field and is rotating at an angular speed of 34 rad/s. What is the emf induced in the coil at the instant when the normal to the loop makes an angle of 27° with respect to the direction of the magnetic field?

***68.** A 3.0-μF capacitor has a voltage of 35 V between its plates. What must be the current in a 5.0-mH inductor, such that the energy stored in the inductor equals the energy stored in the capacitor?

***69.** 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.



***70.** 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.



Problem 70

***71. ssm** A magnetic field is passing through a loop of wire whose area is 0.018 m^2. The direction of the magnetic field is parallel to the normal to the loop, and the magnitude of the field is increasing at the rate of 0.20 T/s. (a) Determine the magnitude of the emf induced in the loop. (b) Suppose the area of the loop can be enlarged or shrunk. If the magnetic field is increasing as in part (a), at what rate (in m^2/s) should the area be changed at the instant when $B = 1.8$ T if the induced emf is to be zero? Explain whether the area is to be enlarged or shrunk.

***72.** A long solenoid (cross-sectional area = 1.0×10^{-6} m^2, number of turns per unit length = 2400 turns/m) is bent into a circular shape so it looks like a doughnut. This wire-wound doughnut is called a toroid. Assume that the diameter of the solenoid is small compared to the radius of the toroid, which is 0.050 m. With this assumption, use the results of Example 13 to determine the self-inductance of the toroid.

****73.** The armature of an electric drill motor has a resistance of 15.0 Ω. When connected to a 120.0-V outlet, the motor rotates at its normal speed and develops a back emf of 108 V. (a) What is the current through the motor? (b) If the armature "freezes up" due to a lack of lubrication in the bearings and can no longer rotate, what is the current in the stationary armature? (c) What is the current when the motor runs at only half speed?

****74.** Coil 1 is a flat circular coil that has N_1 turns and a radius R_1. At its center is a much smaller flat, circular coil that has N_2 turns and radius R_2. The planes of the coils are parallel. Assume that coil 2 is so small that the magnetic field due to coil 1 has nearly the same value at all points covered by the area of coil 2. Determine an expression for the mutual inductance between these two coils in terms of μ_0, N_1, R_1, N_2, and R_2.

CONCEPTS & CALCULATIONS
GROUP LEARNING PROBLEMS

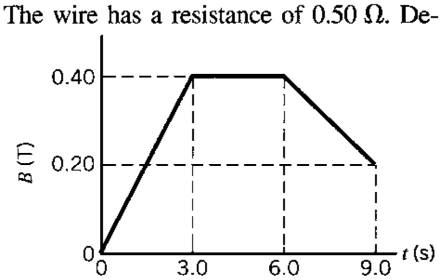
Note: Each of these problems consists of Concept Questions followed by a related quantitative Problem. They are designed for use by students working alone or in small learning groups. The Concept Questions involve little or no mathematics and are intended to stimulate group discussions. They focus on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

75. Concept Questions Two circuits contain an emf produced by a moving metal rod, like that in Figure 22.4*b*. The speed of the rod is the same in each circuit, but the bulb in circuit 1 has one-half the resistance of the bulb in circuit 2. The circuits are otherwise identical. Is (a) the motional emf and (b) the current in circuit 1 greater than, the same as, or less than, that in circuit 2? (c) If the speed of the rod in circuit 1 were doubled, how would the power delivered to the light bulb compare to that in circuit 2? Provide a reason for each of your answers.

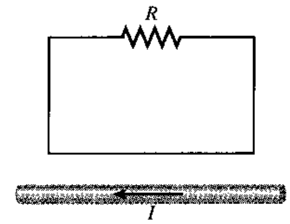
Problem The resistance of the light bulb in circuit 1 is 55 Ω, while that in circuit 2 is 110 Ω. Determine (a) the ratio $\mathcal{E}_1/\mathcal{E}_2$ of the emfs and (b) the ratio I_1/I_2 of the currents. (c) If the speed of the rod in circuit 1 is twice that in circuit 2, what is the ratio P_1/P_2 of the powers? Check to see that your answers are consistent with your answers to the Concept Questions.

76. Concept Questions A magnetic field passes through a stationary wire loop, and its magnitude changes in time according to the graph in the drawing. The direction of the field remains constant, however. There are three equal time intervals indicated in the graph: 0–3.0 s, 3.0–6.0 s, and 6.0–9.0 s. (a) Is the induced emf equal to zero during any of the intervals? (b) During which interval is the magnitude of the induced emf the largest? (c) If the direction of the current induced during the first interval is clockwise, what is the direction during the third interval? In all cases, provide a reason for your answer.

Problem The loop consists of 50 turns of wire and has an area of 0.15 m². The magnetic field is oriented parallel to the normal to the loop. (a) For each interval, determine the magnitude of the induced emf. (b) The wire has a resistance of 0.50 Ω. Determine the induced current for the first and third intervals. Make sure your answers are consistent with your answers to the Concept Questions.



77. Concept Questions The drawing shows a straight wire carrying a current *I*. Above the wire is a rectangular loop that contains a resistor *R*. (a) Does the magnetic field produced by the current *I* penetrate the loop and generate a magnetic flux? (b) When is there an induced current in the loop, if the current *I* is constant or if it is decreasing in time? (c) When there is an induced magnetic field produced by the loop, does it always have a direction that is opposite to the direction of the magnetic field produced by the current *I*? Provide a reason for each answer.



Problem If the current *I* is decreasing in time, what is the direction of the induced current through the resistor *R*—left-to-right or right-to-left? Give your reasoning.

78. Concept Questions A flat coil of wire has an area *A*, *N* turns, and a resistance *R*. It is situated in a magnetic field, such that the normal to the coil is parallel to the magnetic field. The coil is then rotated through an angle of 90°, so that the normal becomes perpendicular to the magnetic field. (a) Why is an emf induced in the coil? (b) What determines the amount of induced current in the coil? (c) How is the amount of charge that flows related to the induced current?

Problem The coil has an area of 1.5×10^{-3} m², 50 turns, and a resistance of 140 Ω. During the time it is rotating, a charge of 8.5×10^{-5} C flows in the coil. What is the magnitude of the magnetic field?

79. Concept Questions A constant current *I* exists in a solenoid whose inductance is *L*. The current is then reduced to zero in a certain amount of time. (a) If the wire from which the solenoid is made has no resistance, is there a voltage across the solenoid during the time when the current is constant? (b) If the wire from which the solenoid is made has no resistance, is there an emf across the solenoid during the time that the current is being reduced to zero? (c) Does the solenoid store electrical energy when the current is constant? If so, express this energy in terms of the current and the inductance. (d) When the current is reduced from its constant value to zero, what is the rate at which energy is removed from the solenoid? Express your answer in terms of the initial current, the inductance, and the time during which the current goes to zero.

Problem A solenoid has an inductance of $L = 3.1$ H and carries a current of $I = 15$ A. (a) If the current goes from 15 to 0 A in a time of 75 ms, what is the emf induced in the solenoid? (b) How much electrical energy is stored in the solenoid? (c) At what rate must the electrical energy be removed from the solenoid when the current is reduced to zero in 75 ms?

80. Concept Questions The rechargeable batteries for a laptop computer need a much smaller voltage than what a wall socket provides. Therefore, a transformer is plugged into the wall socket and produces the necessary voltage for charging the batteries. (a) Is the transformer a step-up or a step-down transformer? (b) Is the current that goes through the batteries greater than, equal to, or smaller than the current coming from the wall socket? (c) If the transformer has a negligible resistance, is the electrical power delivered to the batteries greater than, equal to, or less than the power coming from the wall socket? In all cases, provide a reason for your answer.

Problem The batteries of a laptop computer are rated at 9.0 V, and a current of 225 mA is used to charge them. The wall socket provides a voltage of 120 V. (a) Determine the turns ratio of the transformer. (b) What is the current coming from the wall socket? (c) Find the power delivered by the wall socket and the power sent to the batteries. Be sure your answers are consistent with your answers to the Concept Questions.