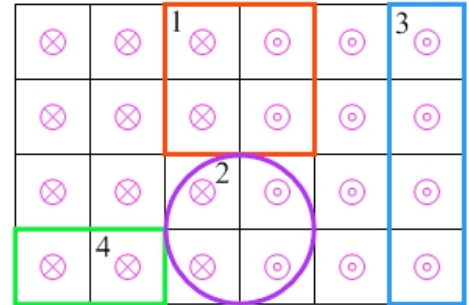


## End-of-Chapter Exercises

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

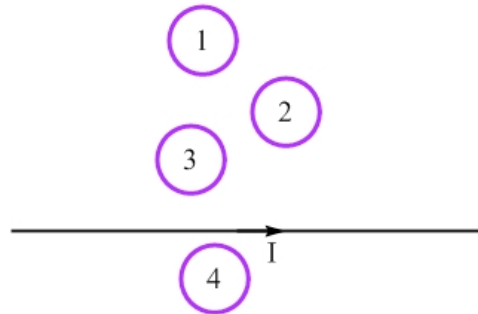
- The four areas in Figure 20.34 are in a magnetic field. The field has a constant magnitude, but it is directed into the page on the left half of the figure and out of the page in the right half. (a) Rank the areas based on the magnitude of the net flux passing through them, from largest to smallest. (b) Defining out of the page to be the positive direction for magnetic flux, rank the areas based on the net flux, from most positive to most negative.



**Figure 20.34:** Four different regions in a magnetic field. The field is directed into the page in the left half of the figure and out of the page in the right half. For Exercises 1 and 2.

- Repeat Exercise 1, but now the magnitude of the magnetic field in the left half of the figure is triple the magnitude of the field in the right half.
- At a particular instant in time, there is no magnetic field passing through a conducting loop. (a) Could the emf induced in the loop be zero at that instant? Explain. (b) Could the emf induced in the loop be non-zero at that instant? Explain.

- As shown in Figure 20.35, four identical loops are placed near a long straight wire that carries a current to the right. The wire is in the same plane as the loops. (a) Rank the loops based on the magnitude of the net flux passing through them, from largest to smallest. (b) Defining out of the page to be the positive direction for magnetic flux, rank the loops based on the net flux, from most positive to most negative.



**Figure 20.35:** Four identical loops near a long straight wire carrying current to the right, for Exercise 4.

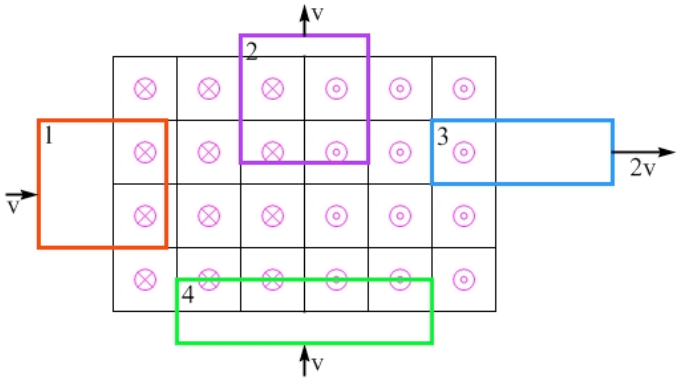
- A long straight wire carrying current out of the page passes through the middle of a circular conducting loop that is in the plane of the page, as shown in Figure 20.36. In what direction is the induced current in the loop when the current in the long straight wire is increasing in magnitude?



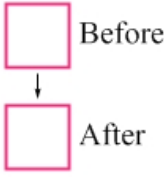
- Rank the four loops in Figure 20.37 based on (a) the magnitude of the induced current, from largest to smallest, and (b) the induced current, from largest clockwise to largest counterclockwise. The loops, which all have the same resistance, are moving with the velocities indicated either into (loops 1 and 4) or out of (loops 2 and 3) a region of magnetic field. The field has the same magnitude within the rectangular region, but is directed into the page in the left half of the region and out of the page in the right half.

**Figure 20.36:** A long straight wire passes through the center of a conducting loop. The current in the long straight wire is directed out of the page, and is increasing in magnitude. For Exercise 5.

**Figure 20.37:** Four conducting loops, all of the same resistance, are moving with the velocities indicated either into (loops 1 and 4) or out of (loops 2 and 3) a region of magnetic field, for Exercise 6.

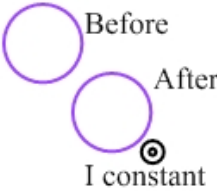


7. A square conducting loop located below a long straight current-carrying wire is moved away from the wire, as shown in Figure 20.38. While the loop is moving, the induced current in the loop is observed to be directed clockwise around the loop. In which direction is the current in the long straight wire?



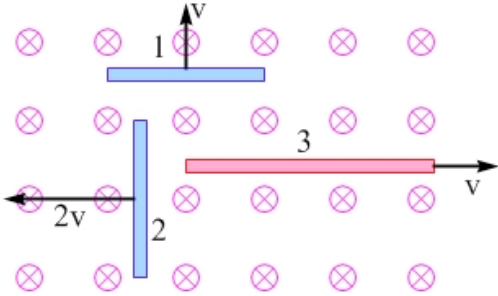
**Figure 20.38:** A square conducting loop is moved away from a long straight current-carrying wire, for Exercise 7.

8. A conducting loop is moved closer to a long straight wire, as shown in Figure 20.39. The current in the wire is constant, and directed out of the page, while the loop is in the plane of the page. While the loop is moving toward the wire, in what direction is the induced current in the loop? Explain.



**Figure 20.39:** A conducting loop is moved closer to a long straight wire that carries a constant current directed out of the page, for Exercise 8.

9. Three conducting rods are moving with the velocities shown in Figure 20.40 through a region of uniform magnetic field that is directed into the page. You measure the motional emf of each bar with a voltmeter connected across the long dimension of each rod. For instance, for rods 1 and 3 you measure the potential difference between the right end and the left end of the rod. Rank the rods based on the magnitude of the potential difference you measure.

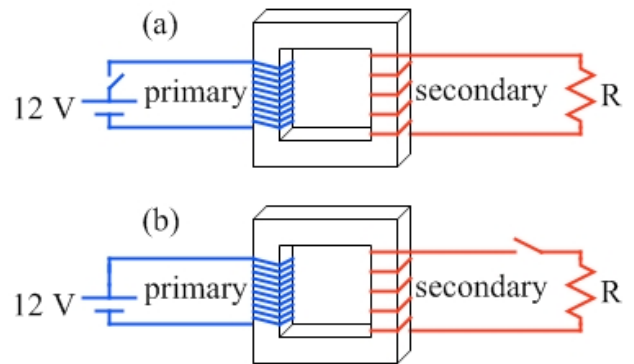


**Figure 20.40:** Three conducting rods are moving through a region of uniform magnetic field. The velocity and orientation of each rod is shown on the diagram. For Exercises 9 and 10.

10. Return to the situation shown in Figure 20.40 and described in Exercise 9. Which of the following is at a higher potential, considering the motional emf? (a) The left end of rod 1 or the right end of rod 1? (b) The upper end of rod 2 or the lower end of rod 2? (c) The left end of rod 3 or the right end of rod 3?

11. As shown in part (a) of Figure 20.41, a 12-volt battery is connected through a switch to the primary coil of a transformer. The secondary coil, which has fewer turns than the primary, is connected to a resistor. The switch is initially open. When the switch is closed, which of the following statements correctly describes the potential difference across the resistor? Explain your choice.

- A constant potential difference of 12 V.
- A non-zero constant potential difference that is smaller than 12 V.
- A constant potential difference that is larger than 12 V.
- A non-zero potential difference when the switch closes that quickly drops to zero.
- The potential difference is zero the whole time.



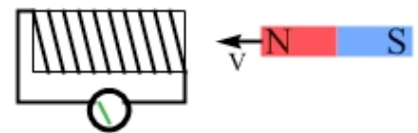
**Figure 20.41:** In (a), a 12-volt battery is connected to the primary coil of a transformer through a switch that is initially open. The secondary coil is connected to a resistor. In (b), the switch has been moved to the secondary side of the transformer.

12. Repeat Exercise 11, but use part (b) of Figure 20.41, in which the switch is moved to the secondary side of the transformer.

**Exercises 13 – 17 deal with Faraday’s Law.**

13. A circular wire loop, with a single turn, has a radius of 12 cm. The loop is in a magnetic field that is decreasing at the rate of 0.20 T/s. At a particular instant in time, the field has a magnitude of 1.7 T. At that instant, determine the emf induced in the loop if (a) the field is directed perpendicular to the plane of the loop, (b) the field is directed parallel to the plane of the loop, (c) the angle between the field and the loop’s area vector is  $30^\circ$ .

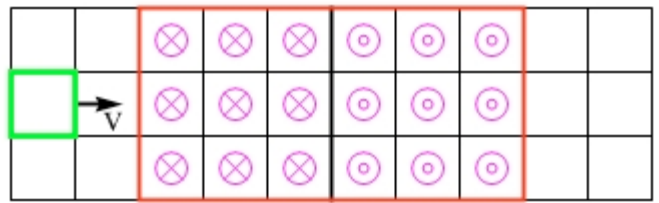
14. A coil of wire is connected to a galvanometer, as shown in Figure 20.42. The galvanometer needle deflects left when current is directed to the left through the coil; is vertical when there is no current, and deflects right when current is directed to the right. When a magnet, with its north pole closer to the magnet, is moved toward the right end of the coil, the galvanometer needle deflects to the left. In which direction will the needle deflect in the following cases? In all cases, the axis of the magnet coincides with the axis of the coil. (a) The magnet remains at rest inside the coil, with the south pole sticking out of the right end of the magnet. (b) The magnet, with its south pole closer to the magnet, is moved to the right away from the coil. (c) The magnet, with its south pole closer to the coil, remains at rest, while the coil is moved toward the magnet. The magnet is to the right of the coil at all times.



**Figure 20.42:** A coil, galvanometer, and magnet, for Exercise 14.

15. Figure 20.43 shows a square loop traveling at a constant velocity of 10 cm/s to the right through a region of magnetic field. The field is confined to the outlined rectangular region. The field is directed into the page in the left half of this region, and out of the page in the right half of this region. The field has the same magnitude at all points within the region. The small squares on the diagram measure  $10\text{ cm} \times 10\text{ cm}$ , and the loop is shown at  $t = 0$ . Rank the following times based on the magnitude of the emf induced in the loop as it moves through the field:  $t_A = 0.5\text{ s}$ ;  $t_B = 1.5\text{ s}$ ;  $t_C = 4.5\text{ s}$ ; and  $t_D = 6.0\text{ s}$ .

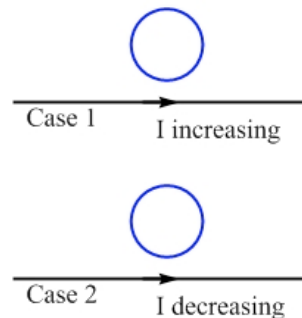
**Figure 20.43:** A square loop moves through a magnetic field that is confined to the outlined rectangular region outlined. The magnetic field is directed into the page in the left half of this region, and out of the page in the right half. For Exercises 15 – 17.



16. Return to the situation described in Exercise 15, and shown in Figure 20.43. The loop is made from a single turn, and has a resistance of  $6.0 \Omega$ . The magnitude of the magnetic field at all locations in the region outlined in red is  $3.0 \text{ T}$ . (a) Sketch a motion diagram for the loop, showing its location at regular intervals. (b) Defining out of the page to be the positive direction for flux, draw a graph of the magnetic flux through the loop as a function of time. (c) Draw a graph of the emf induced in the loop as a function of time. (d) Find the maximum magnitude of the current induced in the loop as the loop moves through the magnetic field.
17. Return to the situation described in Exercises 15 and 16, and shown in Figure 20.43. If the loop's speed is increased by a factor of 3, do any of the following change as the loop moves through the field? Explain. (a) The maximum magnitude of the loop's magnetic flux. (b) The maximum magnitude of the induced emf. (c) The peak current in the loop.

**Exercises 18 – 22 are designed to give you practice applying the pictorial method of solving problems involving Faraday's law.**

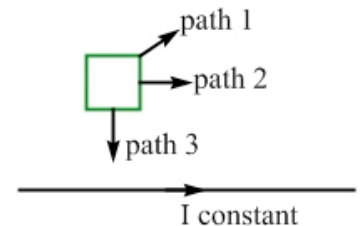
18. As shown in Figure 20.44, a conducting loop is near a long straight wire that carries current to the right. In case 1, the current is increasing in magnitude. In case 2, the current is decreasing in magnitude. (a) If the magnitude of the induced current in the loop is the same in both cases, what does this tell us about the current in the two cases? (b) What is the direction of the induced current in the two cases? Justify your current directions by drawing the sets of three pictures associated with the pictorial method.



**Figure 20.44:** Two cases involving a conducting loop near a long straight wire, for Exercise 18.

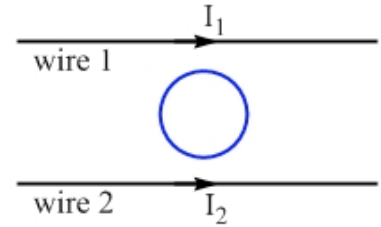
19. Much like the situation shown in Figure 20.44, a conducting loop is placed above a long straight wire. The loop does not move with respect to the wire, while the current in the wire can be directed either left or right and may be increasing, decreasing, or constant. At a particular instant in time, the induced current in the loop is directed clockwise. (a) Could the current in the wire be directed to the right at this instant? Explain using the pictorial method. (b) Could the current in the wire be directed to the left at this instant? Explain using the pictorial method.

20. A square conducting loop is placed above a long straight wire that carries a constant current to the right. The loop can be moved along one of the three paths shown in Figure 20.45. (a) Rank the paths based on the magnitude of the current induced in the loop, assuming the speed of the loop is the same for each path. (b) Draw the set of three pictures associated with the pictorial method, and use the pictures to determine the direction of the current induced in the loop when it follows path 1. Repeat the process for (c) path 2, and (d) path 3.



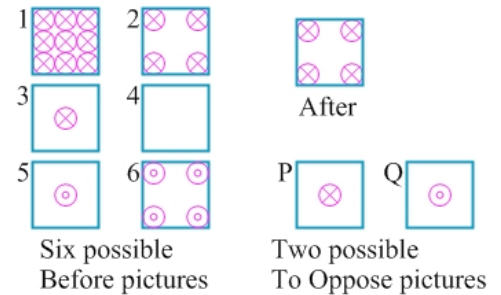
**Figure 20.45:** A square conducting loop is placed above a long straight wire that carries a constant current to the right. The loop can be moved along one of the three paths shown. For Exercise 20.

21. A conducting loop is placed exactly halfway between two parallel wires, each carrying a current to the right, as shown in Figure 20.46. At a particular instant in time, the currents in the wires have the same magnitude, but these currents may be increasing or decreasing. At this instant, we observe that there is a clockwise induced current in the loop. (a) Could one of the two currents be neither increasing or decreasing at this instant? Explain. (b) Could both currents be increasing in magnitude (possibly at different rates) at this instant? Explain. (c) Could one current be increasing while the other is decreasing at this instant? Explain.



**Figure 20.46:** A conducting loop is located halfway between two wires that carry current to the right. At a particular instant, the currents in the two wires have the same magnitude. For Exercise 21.

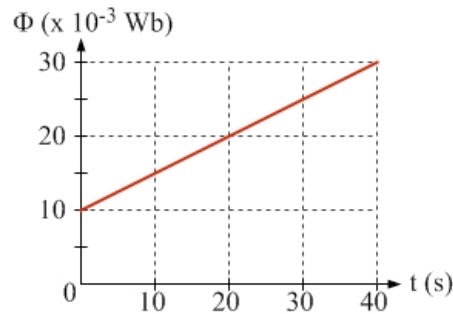
22. Figure 20.47 shows a particular After picture, showing the field lines passing through a conducting loop After some change is made in the external field, along with six possible Before pictures and two possible To Oppose pictures. (a) For the To Oppose picture P, in which direction is the induced current in the loop? (b) For the To Oppose picture Q, in which direction is the induced current in the loop? (c) Which of the Before pictures could go with the After picture and the To Oppose picture P? Select all that apply. (d) Which of the Before pictures could go with the After picture and the To Oppose picture Q? Select all that apply.



**Figure 20.47:** Six possible Before pictures, a particular After picture, and two possible To Oppose pictures, for the situation of a square conducting loop in a magnetic field. For Exercise 22.

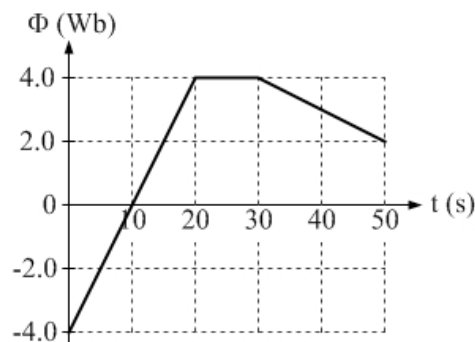
**Exercises 23 – 27 are designed to give you practice working with graphs of magnetic flux versus time in induced emf situations.**

23. Consider the graph of magnetic flux through a conducting loop, as a function of time, shown in Figure 20.48. (a) At which time,  $t = 10$  s,  $t = 20$  s, or  $t = 30$  s, does the induced emf have the largest magnitude? Explain. (b) Assuming the loop has a single turn, what is the magnitude of the induced emf at  $t = 20$  s?



**Figure 20.48:** A graph of the magnetic flux passing through a particular conducting loop as a function of time, for Exercise 23.

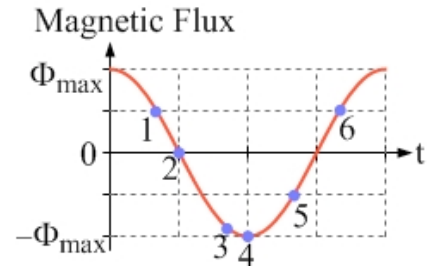
24. The graph in Figure 20.49 shows the magnetic flux through a conducting loop as a function of time. The units of flux are webers, which are equivalent to tesla meters<sup>2</sup>. The flux in the loop changes because the magnetic field passing through the loop changes. The loop itself is stationary. Compare the magnitude of the current induced in the loop at the following times. For each pair of times, state at which times the induced current has a larger magnitude, and explain your answer. (a) 5 s and 10 s. (b) 5 s and 18 s. (c) 5 s and 25 s. (d) 5 s and 40 s. (e) 25 s and 40 s.



**Figure 20.49:** A graph showing the magnetic flux passing through a conducting loop as a function of time, for Exercises 24 – 26.



25. Return to the situation described in Exercise 24, and the graph in Figure 20.49. (a) If the conducting loop has a single turn, plot a graph of the emf induced in the loop as a function of time. Use the graph to answer the following questions. If the induced current at  $t = 5$  s is directed clockwise, in what direction is the induced current in the loop at (b)  $t = 10$  s? (c)  $t = 15$  s? (d)  $t = 40$  s?
26. Return to the situation described in Exercise 24, and the graph in Figure 20.49. The loop has a resistance of  $0.10 \Omega$ , an area of  $20 \text{ m}^2$ , and consists of a single turn. (a) What is the magnitude of the magnetic field passing through the loop at  $t = 15$  s? Assume that the field is uniform and the direction of the field is perpendicular to the plane of the loop. (b) What is the magnitude of the current in the loop at  $t = 15$  s?

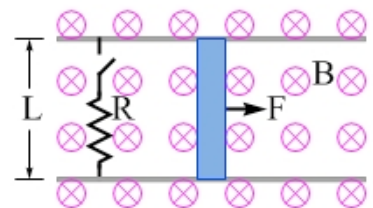


**Figure 20.50:** The graph shows the magnetic flux through a particular loop, which is at rest, as a function of time. Six points are labeled on the graph. For Exercise 27.

27. Figure 20.50 shows a graph of the magnetic flux, as a function of time, through a loop that is at rest. (a) If the induced current in the loop is directed clockwise at the instant corresponding to point 1, at which of the other five points is the induced current directed clockwise? (b) Compare the magnitude of the emf induced in the loop at point 3 and at point 4. (c) At which of the six points does the induced emf have its largest magnitude? Explain. (d) At which of the six points does the induced emf have its smallest magnitude? Explain.

**Exercises 28 – 30 are designed to give you practice with motional emf situations.**

28. A Boeing 747 has a wingspan of 64 m. (a) If the jet is flying north at a speed of 800 km/h in a region where the vertical component of the Earth's magnetic field is  $4.0 \times 10^{-5} \text{ T}$ , directed down, what is the motional emf measured from wingtip to wingtip? (b) Which wingtip is at a higher potential?
29. As shown in Figure 20.51, you exert a constant force  $F$  to the right on a conducting rod that can move without friction along a pair of conducting rails. The rails are connected at the left end by a resistor and a switch that is initially open. There is a uniform magnetic field directed into the page. You do two experiments, starting with the rod at rest both times. For the first experiment the switch is open, and for the second experiment the switch is closed. If you apply the same force for the same amount of time in each experiment, in which experiment will the rod be moving faster? Explain your answer.



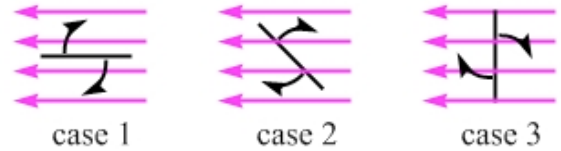
**Figure 20.51:** The conducting bar can move without friction on the conducting rails. The rails are connected at the left end by a resistor and a switch, which is initially open. For Exercises 29 and 30.

30. As shown in Figure 20.51, you exert a constant force  $F$  to the right on a conducting rod of length  $L$  that can move without friction along a pair of conducting rails. The rails are connected at the left end by a resistor of resistance  $R$ , and we can assume that the resistance of each rail and the rod is negligible in comparison to  $R$ . The switch, which is shown open in the diagram, is closed. There is a uniform magnetic field of magnitude  $B$  directed into the page, and the rod begins from rest. Both the rails and the magnetic field extend a long way to the right. (a) In terms of the variables specified here, determine the speed of the rod a long time after the rod begins to move. (b) What is the magnitude of the constant force required for the rod to reach a maximum speed of  $2.0 \text{ m/s}$ , if  $L = 20 \text{ cm}$ ,  $B = 0.20 \text{ T}$ , and  $R = 10 \Omega$ ?

**Exercises 31 – 35 deal with electric generators.**

31. You have a hand-crank generator with a 100-turn coil, of area  $0.020 \text{ m}^2$ , which can spin through a uniform magnetic field that has a magnitude of  $0.30 \text{ T}$ . You can turn the crank at a maximum rate of 3 turns per second, but the hand crank is connected to the coil through a set of gears that makes the coil spin at a rate 8 times larger than the rate at which you turn the crank. What is the maximum emf you can expect to get out of this generator?

32. A particular electric generator consists of a single loop of wire rotating at constant angular velocity in a uniform magnetic field. Figure 20.52 shows three side views of the loop as the loop rotates clockwise, with the loop at various positions. Rank the three positions based on (a) the magnitude of the magnetic flux passing through the loop, and (b) the magnitude of the induced emf in the loop.



**Figure 20.52:** Three side views of a loop rotating in a uniform magnetic field. The plane of the loop is parallel to the magnetic field in case 1, at a  $45^\circ$  angle to the field in case 2, and perpendicular to the field in case 3. For Exercise 32.

33. At a particular location, the Earth's magnetic field has a magnitude of  $5.0 \times 10^{-5} \text{ T}$ . At what angular frequency would you have to spin a 200-turn coil in this field to generate alternating current with a peak emf of  $12 \text{ V}$ , if each turn of the coil measures  $5.0 \text{ cm} \times 5.0 \text{ cm}$ ?
34. You are designing an electric generator to mimic the alternating current put out by a wall socket in North America, which has a peak voltage of  $170 \text{ V}$  and a frequency of  $60 \text{ Hz}$ . The magnets you are using create a uniform magnetic field of  $0.10 \text{ T}$ . How many turns will you use in your coil, and what area will each of your turns have?
35. **Back emf.** In an electric motor, current flowing through a coil in a magnetic field gives rise to a torque that makes the coil spin. However, a coil spinning in a magnetic field acts as an electric generator, so the coil has an induced emf (known as back emf) that gives rise to an induced current. (a) Based on the principles of physics that we addressed in this chapter, would you expect the induced current to add to the original current in the coil, or subtract from it? Explain. (b) When a motor is first turned on, it takes a few seconds for the coil to reach its operating angular velocity. What happens to the net current in the motor during this start-up period? Is this consistent with a phenomenon you have probably observed, that when a device with a motor, such as an air conditioner, first starts up, the lights in your house dim for a couple of seconds? Note that the compressor in the air conditioner acts as a motor.

**Exercises 36 – 40 involve transformers and the distribution of electricity.**

36. The power transformer in a typical microwave provides  $1000 \text{ W}$  at an rms voltage of  $2400 \text{ V}$  on the secondary side. The primary is connected to a wall socket, which has an rms voltage of  $120 \text{ V}$ . The primary coil has 100 turns. Assuming the transformer is ideal, determine: (a) the number of turns in the secondary coil, (b) the rms current in the secondary, and (c) the rms current in the primary.
37. The AC adapter for a particular computer is plugged into the wall, so the primary side of the transformer in the adapter is connected to a  $60 \text{ Hz}$  signal with an rms voltage of  $120 \text{ V}$  and an rms current of  $2.0 \text{ A}$ . (a) The secondary of the transformer puts out

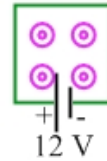
- alternating current with an rms voltage of 20 V. Assuming the transformer is ideal, what is the rms current in the secondary? (b) After transforming the signal to 20 V AC, the adapter uses capacitors and diodes to turn the signal into direct current electricity at a voltage of 16 V and a current of 5 A. How much power, in this DC electricity, is provided to the computer by the adapter? (c) Use your answers to parts (a) and (b) to explain why, when you hold the adapter in your hand, the adapter feels rather warm.
38. A particular step-down transformer has its primary coil connected to the alternating current from a wall socket. Assuming the transformer is ideal, compare the following: (a) the power in the primary and the power in the secondary, (b) the rms voltage in the primary and the rms voltage in the secondary, (c) the rms current in the primary and the rms current in the secondary, (d) the frequency of the alternating current in the primary and secondary.
39. If you travel from one country to another, such as from the United States to England, you will find that an electronic device designed to plug into a North American wall socket will not plug into a wall socket in England. (a) There is a good reason for this. Explain why it is a good idea that European wall sockets do not directly accept North American plugs, and vice versa. (b) Travelers can purchase a travel adapter, which allows a North American device to be plugged into a European wall socket. In addition to matching the different plugs and sockets, a travel adapter is a transformer. What is the ratio of the number of turns in the two coils in such a travel adapter?
40. A typical pole-mounted transformer, the last step in the power distribution process before electricity is delivered to residential customers, has an rms voltage of 7200 volts on the primary coil. The secondary coil has an rms output voltage of 240 volts, which is delivered to one or more houses. (a) What is the ratio of the number in turns in the primary to the number in the secondary? (b) If the current on the primary side is 6.0 A, and each house requires an rms current of 50 A, how many houses can the transformer supply electricity to?

### General problems and conceptual questions

41. A large glass window has an area of  $6.0 \text{ m}^2$ . The Earth's magnetic field in the region of the window has a magnitude of  $5.0 \times 10^{-5} \text{ T}$ . (a) What is the maximum possible magnitude of the magnetic flux through the window from the Earth's field? (b) If the flux has a magnitude of  $1.0 \times 10^{-4} \text{ T m}^2$ , what is the angle between the window's area vector and the Earth's magnetic field?
42. A particular flat conducting loop has an area of  $5.0 \times 10^{-3} \text{ m}^2$ . The loop is at rest in a uniform magnetic field, directed perpendicular to the plane of the loop, which has a magnitude of 2.0 T. The field has a constant magnitude and direction. (a) Determine the magnitude of the magnetic flux passing through the loop. (b) Determine the magnitude of the emf induced in the loop in a 5.0-second interval.
43. Return to the situation shown in Figure 20.17, which we analyzed qualitatively in Essential Question 20.3. The magnetic field has a magnitude of 2.0 T, the value of  $v$  is 6.0 m/s, and the resistance of each single-turn loop is  $3.0 \Omega$ . If each small square in the picture measures  $10 \text{ cm} \times 10 \text{ cm}$ , determine the magnitude and direction of the induced current in (a) loop 1, (b) loop 2, (c) loop 3, and (d) loop 4.

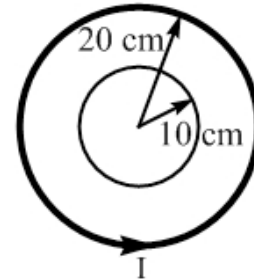


44. A square loop consists of a single turn with a resistance of  $4.0\ \Omega$ . The loop measures  $10\ \text{cm} \times 10\ \text{cm}$ , and has a uniform magnetic field passing through it that is directed out of the page. The loop contains a 12-volt battery, connected as shown in Figure 20.53. At the instant shown in the figure, there is no net current in the loop. At what rate is the magnetic field changing, and is the field increasing or decreasing in magnitude?



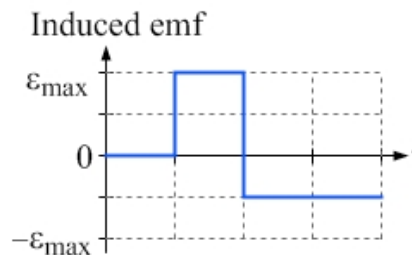
**Figure 20.53:** A square loop containing a 12-volt battery has no net current. For Exercise 44.

45. Figure 20.54 shows a cross-sectional view of a single-turn conducting loop, with a radius of  $10\ \text{cm}$ , inside a long current-carrying solenoid. The solenoid has a radius of  $20\ \text{cm}$ , and has  $1000$  turns per meter. The current in the solenoid is directed counterclockwise, and is increasing in magnitude. Draw a set of three pictures (Before, After, and To Oppose) to determine the direction of the induced current in the conducting loop.
46. Return to the situation described in Exercise 45, and shown in Figure 20.54. If the current in the solenoid is increasing at the rate of  $0.20\ \text{A/s}$ , and the loop has a resistance of  $4.0\ \Omega$ , determine the magnitude of the induced current in the conducting loop.



**Figure 20.54:** A conducting loop, with a radius of  $10\ \text{cm}$ , is placed at the center of a long current-carrying solenoid, which has a radius of  $20\ \text{cm}$ . For Exercises 45 and 46.

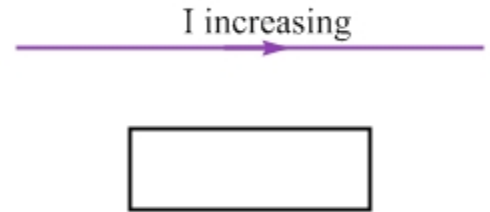
47. Figure 20.55 shows a graph of the emf induced in a loop as a function of time. (a) Plot a graph of the corresponding magnetic flux through the loop as a function of time. Your graph should be consistent with Figure 20.54 as well as Faraday's Law. (b) Is there only one possible flux graph for part (a), or are there multiple solutions possible? Explain.



**Figure 20.55:** A graph of the emf induced in a loop as a function of time. For Exercise 47.

48. You probably have a credit or debit card with a magnetic stripe on the back. The magnetic stripe contains information that is stored in the pattern of magnetic fields on the stripe. When you put your card in a card reader, such as at a checkout counter, you need to slide the card through quickly. Using the principles of physics we have addressed in this chapter, explain how the card reader works, and why sliding the card through the reader slowly does not work.
49. There are many applications of electromagnetic induction, in addition to those we have examined in this chapter. Choose **one** of the following three subjects, and write a couple of paragraphs about how it works, highlighting in particular the role of electromagnetic induction. 1. An electric guitar. 2. A tape recorder. 3. A hard disk in a computer.
50. A biomedical application of electromagnetic induction is magnetoencephalography (MEG), which uses the tiny magnetic fields generated by currents in the brain to create an image of neural activity in the brain. Do some research about MEG, and write a couple of paragraphs describing it.

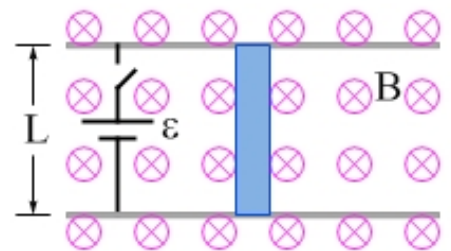
51. As shown in Figure 20.56, a conducting wire loop is placed below a long straight wire that is carrying a current to the right. The current in the wire is increasing in magnitude. (a) In which direction is the induced current in the loop? (b) The loop experiences a net force because of the interaction between the current in the long straight wire and the induced current. In what direction is this force? (c) If the loop moves in response to this net force, explain how this motion is consistent with Lenz's Law.



**Figure 20.56:** A conducting loop near a current-carrying long straight wire, for Exercise 51. The current in the wire is increasing.

52. There are some flashlights that do not require batteries. Instead, the flashlight has a magnet that moves back and forth through a coil when you shake it. The coil is connected to a capacitor which is in turn connected to a light-emitting diode (LED), which can glow brightly without requiring much current. Explain how such a flashlight works.

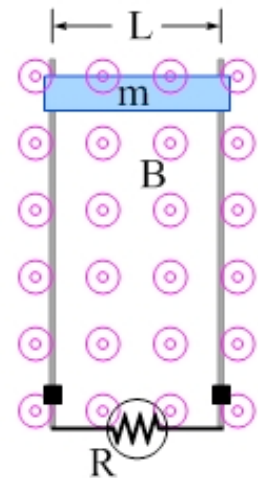
53. Figure 20.57 shows a conducting bar of length  $L$  that can move without friction on a pair of conducting rails. The rails are joined at the left by a battery of emf  $\epsilon$  and a switch that is initially open. The bar, which is initially at rest, has a resistance  $R$ , and we will assume the resistance of all other parts of the circuit is negligible. The whole apparatus is in a uniform magnetic field, directed into the page, of magnitude  $B$ . Both the rails and the magnetic field extend far to the left and right. In terms of the variables specified above, determine the magnitude and direction of: (a) the current in the circuit immediately after the switch is closed, (b) the net force on the bar immediately after the switch is closed, (c) the current in the circuit a long time after the switch is closed, (d) the net force on the bar a long time after the switch is closed, and (e) the magnitude and direction of the velocity of the bar a long time after the switch is closed.



**Figure 20.57:** The bar, which is initially at rest, can slide without friction on the conducting rails. The rails are connected together on the left by a battery and a switch. For Exercises 53 and 54.

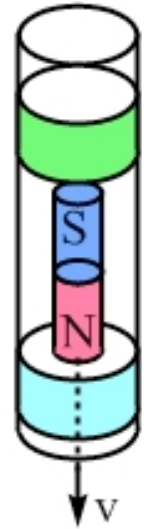
54. Repeat Exercise 53 (illustrated in Figure 20.57), but now use the values  $L = 20$  cm,  $\epsilon = 12$  V,  $R = 6.0 \Omega$ , and  $B = 5.0 \times 10^{-2}$  T.

55. A conducting rod of mass  $m$  and length  $L$  can slide with no friction down a pair of vertical conducting rails, as shown in Figure 20.58. The rails are joined at the bottom by a light bulb of resistance  $R$ . The rails have stops near the bottom to prevent the rod from smashing the bulb. There is a uniform magnetic field of magnitude  $B$  directed out of the page. When the rod is released from rest, the force of gravity causes the rod to accelerate down the rails, but the rod soon reaches a terminal velocity (that is, it falls at constant speed). (a) In what direction is the induced current through the light bulb? (b) Sketch two free-body diagrams, one just after the bar is released and one when it has reached terminal velocity. (c) In terms of the variables specified here and  $g$ , the magnitude of the acceleration due to gravity, find an expression for the constant speed of the rod. (d) Describe what happens to the brightness of the light bulb as the rod accelerates from rest, and once the rod reaches terminal speed.



**Figure 20.58:** When a conducting rod of mass  $m$  is released from rest, it slides down the two vertical rails, for Exercise 55.

56. You can demonstrate the effect of eddy currents by dropping a magnet down a pipe made from copper or aluminum, as shown in Figure 20.59. In this case, the magnet is a bar magnet with its north pole at the lower end. Two sections of the tube are outlined, one near the top and one near the bottom. (a) Analyze the lower section of the tube to determine in which direction the eddy currents circulate in that section as the magnet approaches from above. What effect do these eddy currents have on the magnet? (b) Repeat for the upper section of the tube, to determine in which direction the eddy currents circulate in that section as the magnet moves farther away, and the effect of those currents on the magnet.

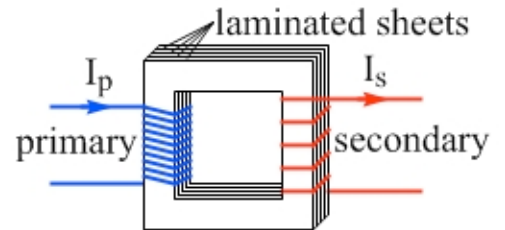


**Figure 20.59:** A pipe made of conducting, but non-ferromagnetic, material, through which a magnet has been dropped. For Exercise 56.

57. In Exploration 20.5, we explored how eddy currents can be used to bring a train to a stop. In that exploration, the magnetic field from the electromagnets was directed into the page. If the field was reversed, coming out of the page instead, would the train speed up or slow down? Explain.

58. The secondary of the transformer in a cathode ray tube television provides an rms voltage of 24 kV. The primary is connected to a wall socket, which has an rms voltage of 120 V. The primary coil has 100 turns, and the transformer is ideal. The television has a power rating of 75 W. (a) Find the number of turns in the secondary coil. (b) Find the rms current in the secondary, and (c) the rms current in the primary.

59. As shown in Figure 20.60, the ferromagnetic core of a transformer is generally made from several laminated sheets, which are electrically insulated from one another, rather than being made from a single piece of metal. This method of construction reduces the losses associated with eddy currents in the core itself. Explain how this works.



**Figure 20.60:** The core of a transformer is generally made from several laminated sheets, which are electrically insulated from one another, rather than being made from a single piece of metal. For Exercise 59.

60. A power company experiences losses of 20 kW when it transmits electricity along a particular transmission line at an rms voltage of 250 kV. What would the transmission losses be if the rms voltage was transformed to 500 kV instead?
61. Do some research about the War of Currents, the battle between the advocates of DC and the advocates of AC, which occurred during the late 1800's in the United States, and write a few paragraphs about it.