CHAPTER

20 Static Electricity

Section Review

20.1 Electric Charge pages 541–545

page 545

1. **Charged Objects** After a comb is rubbed on a wool sweater, it is able to pick up small pieces of paper. Why does the comb lose that ability after a few minutes?

   The comb loses its charge to its surroundings and becomes neutral once again.

2. **Types of Charge** In the experiments described earlier in this section, how could you find out which strip of tape, B or T, is positively charged?

   Bring a positively charged glass rod near the two strips of tape. The one that is repelled by the rod is positive.

3. **Types of Charge** A pith ball is a small sphere made of a light material, such as plastic foam, often coated with a layer of graphite or aluminum paint. How could you determine whether a pith ball that is suspended from an insulating thread is neutral, is charged positively, or is charged negatively?

   Bring an object of known charge, such as a negatively charged hard rubber rod, near the pith ball. If the pith ball is repelled, it has the same charge as the rod. If it is attracted, it may have the opposite charge or be neutral. To find out which, bring a positively charged glass rod near the pith ball. If they repel, the pith ball is positive; if they attract, the pith ball must be neutral.

4. **Charge Separation** A rubber rod can be charged negatively when it is rubbed with wool. What happens to the charge of the wool? Why?

   The wool becomes positively charged because it gives up electrons to the rubber rod.

5. **Conservation of Charge** An apple contains trillions of charged particles. Why don't two apples repel each other when they are brought together?

   Each apple contains equal numbers of positive and negative charges, so they appear neutral to each other.

6. **Charging a Conductor** Suppose you hang a long metal rod from silk threads so that the rod is isolated. You then touch a charged glass rod to one end of the metal rod. Describe the charges on the metal rod.

   The glass rod attracts electrons off the metal rod, so the metal becomes positively charged. The charge is distributed uniformly along the rod.

7. **Charging by Friction** You can charge a rubber rod negatively by rubbing it with wool. What happens when you rub a copper rod with wool?

   Because the copper is a conductor, it remains neutral as long as it is in contact with your hand.

8. **Critical Thinking** It once was proposed that electric charge is a type of fluid that flows from objects with an excess of the fluid to objects with a deficit. Why is the current two-charge model better than the single-fluid model?

   The two-charge model can better explain the phenomena of attraction and repulsion. It also explains how objects can become charged when they are rubbed together. The single-fluid model indicated that the charge should be equalized on objects that are in contact with each other.

Practice Problems

20.2 Electric Force pages 546–553

page 552

9. A negative charge of -2.0×10^{-4} C and a positive charge of 8.0×10^{-4} C are separated by 0.30 m. What is the force between the two charges?

$$F = \frac{Kq_Aq_B}{{d_{AB}}^2} = \frac{(9.0\times10^{9}\ \mathrm{N{\cdot}m^2/C^2})(2.0\times10^{-4}\ \mathrm{C})(8.0\times10^{-4}\ \mathrm{C})}{(0.30\ \mathrm{m})^2}$$

$$= 1.6\times10^{4}\ \mathrm{N}$$

10. A negative charge of -6.0×10^{-6} C exerts an attractive force of 65 N on a second charge that is 0.050 m away. What is the magnitude of the second charge?

$$F = \frac{Kq_Aq_B}{{d_{AB}}^2}$$

$$q_B = \frac{F{d_{AB}}^2}{Kq_A} = \frac{(65\ \mathrm{N})(0.050\ \mathrm{m})^2}{(9.0\times10^{9}\ \mathrm{N{\cdot}m^2/C^2})(6.0\times10^{-6}\ \mathrm{C})}$$

$$= 3.0\times10^{-6}\ \mathrm{C}$$

11. The charge on B in Example Problem 1 is replaced by a charge of $+3.00\ \mu$C. Diagram the new situation and find the net force on A.

Magnitudes of all forces remain the same. The direction changes to 42° above the $-x$ axis, or 138°.

12. Sphere A is located at the origin and has a charge of $+2.0\times10^{-6}$ C. Sphere B is located at $+0.60$ m on the x-axis and has a charge of -3.6×10^{-6} C. Sphere C is located at $+0.80$ m on the x-axis and has a charge of $+4.0\times10^{-6}$ C. Determine the net force on sphere A.

$$F_{\text{B on A}} = K\frac{q_Aq_B}{{d_{AB}}^2} = (9.0\times10^{9}\ \mathrm{N{\cdot}m^2/C^2})\frac{(2.0\times10^{-6}\ \mathrm{C})(3.6\times10^{-6}\ \mathrm{C})}{(0.60\ \mathrm{m})^2} = 0.18\ \mathrm{N}$$

direction: toward the right

$$F_{\text{C on A}} = K\frac{q_Aq_C}{{d_{AC}}^2} = (9.0\times10^{9}\ \mathrm{N{\cdot}m^2/C^2})\frac{(2.0\times10^{-6}\ \mathrm{C})(4.0\times10^{-6}\ \mathrm{C})}{(0.80\ \mathrm{m})^2} = 0.1125 = \mathrm{N}$$

direction: toward the left

$$F_{\text{net}} = F_{\text{B on A}} - F_{\text{C on A}} = (0.18\ \mathrm{N}) - (0.1125\ \mathrm{N}) = 0.068\ \mathrm{N}\ \text{toward the right}$$

13. Determine the net force on sphere B in the previous problem.

$$F_{\text{A on B}} = K\frac{q_Aq_B}{{d_{AB}}^2}$$

$$F_{\text{C on B}} = K\frac{q_Aq_B}{{d_{AB}}^2}$$

$$F_{\text{net}} = F_{\text{C on B}} - F_{\text{A on B}}$$

$$= K\frac{q_Bq_C}{{d_{BC}}^2} - K\frac{q_Aq_B}{{d_{AB}}^2}$$

$$= (9.0\times10^{9}\ \text{N·m}^2/\text{C}^2)\frac{(3.6\times10^{-6}\ \text{C})(4.0\times10^{-6}\ \text{C})}{(0.20\ \text{m})^2} - (9.0\times10^{9}\ \text{N·m}^2/\text{C}^2)\frac{(2.0\times10^{-6}\ \text{C})(3.6\times10^{-6}\ \text{C})}{(0.60\ \text{m})^2}$$

= 3.1 N toward the right

Section Review

20.2 Electric Force pages 546–553

page 553

14. Force and Charge How are electric force and charge related? Describe the force when the charges are like charges and the force when the charges are opposite charges.

Electric force is directly related to each charge. It is repulsive between like charges and attractive between opposite charges.

15. Force and Distance How are electric force and distance related? How would the force change if the distance between two charges were tripled?

Electric force is inversely related to the square of the distance between charges. If the distance is tripled, the force will be one-ninth as great.

16. Electroscopes When an electroscope is charged, the leaves rise to a certain angle and remain at that angle. Why do they not rise farther?

As the leaves move farther apart, the electric force between them decreases until it is balanced by the gravitational force pulling down on the leaves.

17. Charging an Electroscope Explain how to charge an electroscope positively using

a. a positive rod.

Touch the positive rod to the electroscope. Negative charges will move to the rod, leaving the electroscope positively charged.

b. a negative rod.

Bring the negative rod near, but not touching the electroscope. Touch (ground) the electroscope with your finger, allowing electrons to be repelled off of the electroscope into your finger. Remove your finger and then remove the rod.

18. Attraction of Neutral Objects What two properties explain why a neutral object is attracted to both positively and negatively charged objects?

Charge separation, caused by the attraction of opposite charges and the repulsion of like charges, moves the opposite charges in the neutral body closer to the charged object and the like charges farther away. The inverse relation between force and distance means that the nearer, opposite charges will attract more than the more distant, like charges will repel. The overall effect is attraction.

19. Charging by Induction In an electroscope being charged by induction, what happens when the charging rod is moved away before the ground is removed from the knob?

Charge that had been pushed into the ground by the rod would return to the electroscope from the ground, leaving the electroscope neutral.

20. Electric Forces Two charged spheres are held a distance, r, apart. One sphere has a charge of $+3\mu\text{C}$, and the other sphere has a charge of $+9\mu\text{C}$. Compare the force of the $+3\mu\text{C}$ sphere on the $+9\mu\text{C}$ sphere with the force of the $+9\mu\text{C}$ sphere on the $+3\mu\text{C}$ sphere.

The forces are equal in magnitude and opposite in direction.

21. Critical Thinking Suppose that you are testing Coulomb's law using a small, positively charged plastic sphere and a large, positively charged metal sphere. According to Coulomb's law, the force depends on $1/r^2$, where r is the distance between the centers of the spheres. As the spheres get close together, the force is smaller than expected from Coulomb's law. Explain.

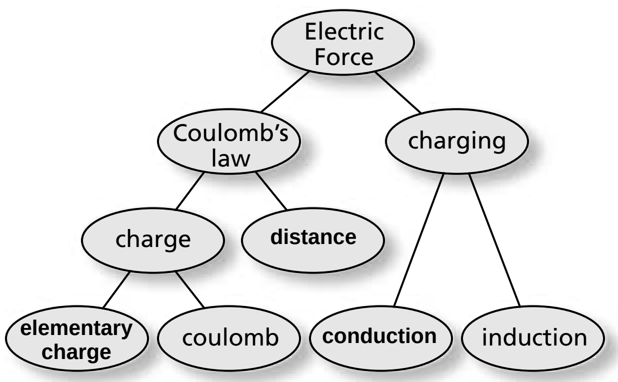
Some charges on the metal sphere will be repelled to the opposite side from the plastic sphere, making the effective distance between the charges greater than the distance between the spheres' centers.

Chapter Assessment

Concept Mapping

page 558

22. Complete the concept map below using the following terms: *conduction, distance, elementary charge.*



Mastering Concepts

page 558

23. If you comb your hair on a dry day, the comb can become positively charged. Can your hair remain neutral? Explain. (20.1)

No. By conservation of charge, your hair must become negatively charged.

24. List some insulators and conductors. (20.1)

Student answers will vary but may include dry air, wood, plastic, glass, cloth, and deionized water as insulators; and metals, tap water, and your body as conductors.

25. What property makes metal a good conductor and rubber a good insulator? (20.1)

Metals contain free electrons; rubber has bound electrons.

26. **Laundry** Why do socks taken from a clothes dryer sometimes cling to other clothes? (20.2)

They have been charged by contact as they rub against other clothes, and thus, are attracted to clothing that is neutral or has an opposite charge.

27. **Compact Discs** If you wipe a compact disc with a clean cloth, why does the CD then attract dust? (20.2)

Rubbing the CD charges it. Neutral particles, such as dust, are attracted to a charged object.

28. **Coins** The combined charge of all electrons in a nickel is hundreds of thousands of coulombs. Does this imply anything about the net charge on the coin? Explain. (20.2)

No. Net charge is the difference between positive and negative charges. The coin still can have a net charge of zero.

29. How does the distance between two charges impact the force between them? If the distance is decreased while the charges remain the same, what happens to the force? (20.2)

Electric force is inversely proportional to the distance squared. As distance decreases and charges remain the same, the force increases as the square of the distance.

30. Explain how to charge a conductor negatively if you have only a positively charged rod. (20.2)

Bring the conductor close to, but not touching, the rod. Ground the conductor in the presence of the charged rod; then, remove the ground before removing the charged rod. The conductor will have a net negative charge.

Applying Concepts

page 558

31. How does the charge of an electron differ from the charge of a proton? How are they similar?

The charge of the proton is exactly the same size as the electron, but has the opposite sign.

32. Using a charged rod and an electroscope, how can you find whether or not an object is a conductor?

Use a known insulator to hold one end of the object against the electroscope. Touch the other end with the charged rod. If the electroscope indicates a charge, the object is a conductor.

33. A charged rod is brought near a pile of tiny plastic spheres. Some of the spheres are attracted to the rod, but as soon as they touch the rod, they are flung off in different directions. Explain.

The natural spheres are initially attracted to the charged rod, but they acquire the same charge as the rod when they touch it. As a result, they are repelled from the rod.

34. **Lightning** Lightning usually occurs when a negative charge in a cloud is transported to Earth. If Earth is neutral, what provides the attractive force that pulls the electrons toward Earth?

The charge in the cloud repels electrons on Earth, causing a charge separation by induction. The side of Earth closest to the cloud is positive, resulting in an attractive force.

35. Explain what happens to the leaves of a positively charged electroscope when rods with the following charges are brought close to, but not touching, the electroscope.

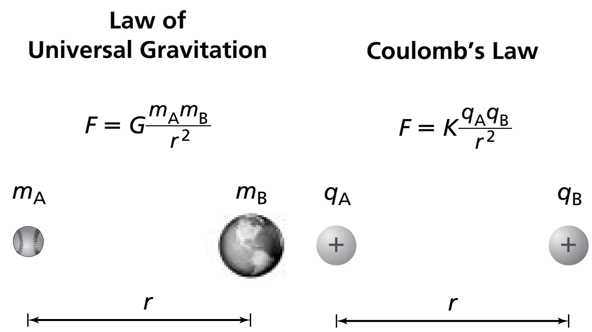
a. positive

The leaves will move farther apart.

b. negative

The leaves will drop slightly.

36. As shown in **Figure 20-13,** Coulomb's law and Newton's law of universal gravitation appear to be similar. In what ways are the electric and gravitational forces similar? How are they different?



■ **Figure 20-13** (Not to scale)

Similar: inverse-square dependence on distance, force proportional to product of two masses or two charges; different: only one sign of mass, so gravitational force is always attractive; two signs of charge, so electric force can be either attractive or repulsive.

37. The constant, *K*, in Coulomb's equation is much larger than the constant, *G*, in the universal gravitation equation. Of what significance is this?

The electric force is much larger than the gravitational force.

38. The text describes Coulomb's method for charging two spheres, A and B, so that the charge on B was exactly half the charge on A. Suggest a way that Coulomb could have placed a charge on sphere B that was exactly one-third the charge on sphere A.

After changing spheres A and B equally, sphere B is touched to two other equally sized balls that are touching each other. The charge on B will be divided equally among all three balls, leaving one-third the total charge on it.

39. Coulomb measured the deflection of sphere A when spheres A and B had equal charges and were a distance, *r*, apart. He then made the charge on B one-third the charge on A. How far apart would the two spheres then have had to be for A to have had the same deflection that it had before?

To have the same force with one-third the charge, the distance would have to be decreased such that $d^2 = 1/3$, or 0.58 times as far apart.

40. Two charged bodies exert a force of 0.145 N on each other. If they are moved so that they are one-fourth as far apart, what force is exerted?

$\boldsymbol{F \propto \frac{1}{d^2}}$ **and** $\boldsymbol{F \propto \frac{1}{\left(\frac{1}{4}\right)^2}}$**, so** $\boldsymbol{F}$ **= 16 times the original force.**

41. Electric forces between charges are enormous in comparison to gravitational forces. Yet, we normally do not sense electric forces between us and our surroundings, while we do sense gravitational interactions with Earth. Explain.

Gravitational forces only can be attractive. Electric forces can be either attractive or repulsive, and we can sense only their vector sums, which are generally small. The gravitational attraction to Earth is larger and more noticeable because of Earth's large mass.

Mastering Problems

20.2 Electric Force

page 559

Level 1

42. Two charges, q_A and q_B, are separated by a distance, r, and exert a force, F, on each other. Analyze Coulomb's law and identify what new force would exist under the following conditions.

a. q_A is doubled

$2q_A$**, then new force =** $2F$

b. q_A and q_B are cut in half

$\frac{1}{2}q_A$ **and** $\frac{1}{2}q_B$**, then new force =** $\left(\frac{1}{2}\right)\left(\frac{1}{2}\right)F = \frac{1}{4}F$

c. r is tripled

$3d$**, then new force =** $\frac{F}{(3)^2} = \frac{1}{9}F$

d. r is cut in half

$\frac{1}{2}d$**, then new force =** $\frac{F}{\left(\frac{1}{2}\right)^2} = \frac{3}{4}F = 4F$

e. q_A is tripled and r is doubled

$3q_A$ **and** $2d$**, then new force =** $\frac{(3)F}{(2)^2} = \frac{3}{4}F$

43. Lightning A strong lightning bolt transfers about 25 C to Earth. How many electrons are transferred?

$$(-25\ \text{C})\left(\frac{1\ \text{electron}}{-1.60\times10^{-19}\ \text{C}}\right) = 1.6\times10^{20}\ \text{electrons}$$

44. Atoms Two electrons in an atom are separated by 1.5×10^{-10} m, the typical size of an atom. What is the electric force between them?

$$F = \frac{Kq_Aq_B}{d^2} = \frac{(9.0\times10^{9}\ \text{N·m}^2/\text{C}^2)(1.60\times10^{-19}\ \text{C})(1.60\times10^{-19}\ \text{C})}{(1.5\times10^{-10}\ \text{m})^2}$$

$$= 1.0\times10^{-8}\ \text{N, away from each other}$$

45. A positive and a negative charge, each of magnitude 2.5×10^{-5} C, are separated by a distance of 15 cm. Find the force on each of the particles.

$$F = \frac{Kq_Aq_B}{d^2} = \frac{(9.0\times10^9\ \text{N·m}^2/\text{C}^2)(2.5\times10^{-5}\ \text{C})(2.5\times10^{-5}\ \text{C})}{(1.5\times10^{-1}\ \text{m})^2}$$

$= 2.5\times10^2$ **N, toward the other charge**

46. A force of 2.4×10^2 N exists between a positive charge of 8.0×10^{-5} C and a positive charge of 3.0×10^{-5} C. What distance separates the charges?

$$F = \frac{Kq_Aq_B}{d^2}$$

$$d = \sqrt{\frac{Kq_Aq_B}{F}} = \sqrt{\frac{(9.0\times10^9\ \text{N·m}^2/\text{C}^2)(8.0\times10^{-5}\ \text{C})(3.0\times10^{-5}\ \text{C})}{2.4\times10^2\ \text{N}}}$$

$= 0.30$ **m**

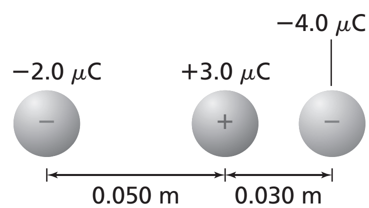
47. Two identical positive charges exert a repulsive force of 6.4×10^{-9} N when separated by a distance of 3.8×10^{-10} m. Calculate the charge of each.

$$F = \frac{Kq_Aq_B}{d^2} = \frac{Kq^2}{d^2}$$

$$q = \sqrt{\frac{Fd^2}{K}} = \sqrt{\frac{(6.4\times10^{-9}\ \text{N})(3.8\times10^{-10}\ \text{m})^2}{9.0\times10^9\ \text{N·m}^2/\text{C}^2}} = 3.2\times10^{-19}\ \text{C}$$

Level 2

48. A positive charge of 3.0 μC is pulled on by two negative charges. As shown in **Figure 20-14,** one negative charge, −2.0 μC, is 0.050 m to the west, and the other, −4.0 μC, is 0.030 m to the east. What total force is exerted on the positive charge?



■ **Figure 20-14**

$$F_1 = \frac{(9.0\times10^9\ \text{N·m}^2/\text{C}^2)(3.0\times10^{-6}\ \text{C})(2.0\times10^{-6}\ \text{C})}{(0.050\ \text{m})^2}$$

$= 22$ **N west**

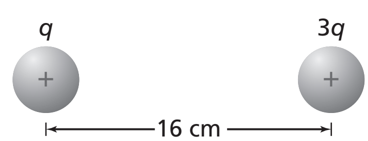
$$F_2 = \frac{(9.0\times10^9\ \text{N·m}^2/\text{C}^2)(3.0\times10^{-6}\ \text{C})(4.0\times10^{-6}\ \text{C})}{(0.030\ \text{m})^2}$$

$= 120$ **N east**

$$F_{net} = F_2 + F_1 = (1.2\times10^2\ \text{N}) - (2.2\times10^1\ \text{N})$$

$= 98$ **N, east**

49. **Figure 20-15** shows two positively charged spheres, one with three times the charge of the other. The spheres are 16 cm apart, and the force between them is 0.28 N. What are the charges on the two spheres?



■ **Figure 20-15**

$$F = K\frac{q_Aq_B}{d^2} = K\frac{q_A3q_A}{d^2}$$

$$q_A = \sqrt{\frac{Fd^2}{3K}} = \sqrt{\frac{(0.28\ \text{N})(0.16\ \text{m})^2}{3(9.0\times10^9\ \text{N·m}^2/\text{C}^2)}} = 5.2\times10^{-7}\ \text{C}$$

$$q_B = 3q_A = 1.5\times10^{-6}\ \text{C}$$

50. **Charge in a Coin** How many coulombs of charge are on the electrons in a nickel? Use the following method to find the answer.

a. Find the number of atoms in a nickel. A nickel has a mass of about 5 g. A nickel is 75 percent Cu and 25 percent Ni, so each mole of the coin's atoms will have a mass of about 62 g.

A coin is $\frac{5\ \text{g}}{62\ \text{g}} = 0.08$ mole.

Thus, it has $(0.08)(6.02\times10^{23}) = 5\times10^{22}$ atoms

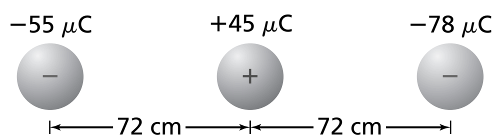
b. Find the number of electrons in the coin. On average, each atom has 28.75 electrons.

$(5\times10^{22}$ atoms$)(28.75$ electrons/atom$) = 1\times10^{24}$ electrons

c. Find the coulombs on the electrons.

$(1.6\times10^{-19}$ coulombs/electron$)(1\times10^{24}$ electrons$) = 2\times10^5$ coulombs

51. Three particles are placed in a line. The left particle has a charge of $-55\ \mu$C, the middle one has a charge of $+45\ \mu$C, and the right one has a charge of $-78\ \mu$C. The middle particle is 72 cm from each of the others, as shown in **Figure 20-16.**



■ **Figure 20-16**

a. Find the net force on the middle particle.

Let left be the negative direction

$$F_{net} = -F_l + (F_r) = -\frac{Kq_mq_l}{d^2} + \frac{Kq_mq_r}{d^2}$$

$$= \frac{-(9.0\times10^9\ \text{N·m}^2/\text{C}^2)(45\times10^{-6}\ \text{C})(55\times10^{-6}\ \text{C})}{(0.72\ \text{m})^2} + \frac{(9.0\times10^9\ \text{N·m}^2/\text{C}^2)(45\times10^{-6}\ \text{C})(78\times10^{-6}\ \text{C})}{(0.72\ \text{m})^2}$$

= 18 N, right

b. Find the net force on the right particle.

$$F_{net} = F_l + (-F_m) = +\frac{Kq_lq_r}{(2d)^2} - \frac{Kq_mq_r}{d^2}$$

$$= \frac{(9.0\times10^9\ \text{N·m}^2/\text{C}^2)(55\times10^{-6}\ \text{C})(78\times10^{-6}\ \text{C})}{(2(0.72\ \text{m}))^2} + \frac{(9.0\times10^9\ \text{N·m}^2/\text{C}^2)(45\times10^{-6}\ \text{C})(78\times10^{-6}\ \text{C})}{(0.72\ \text{m})^2}$$

= −42 N, left

Mixed Review

page 559

Level 1

52. A small metal sphere with charge 1.2×10^{-5} C is touched to an identical neutral sphere and then placed 0.15 m from the second sphere. What is the electric force between the two spheres?

The two spheres share the charge equally, so

$$F = K\frac{q_A q_B}{d^2} = (9.0\times10^9\ \mathrm{N\cdot m^2/C^2})\frac{(6.0\times10^{-6}\ \mathrm{C})(6.0\times10^{-6}\ \mathrm{C})}{(0.15\ \mathrm{m})^2} = 14\ \mathrm{N}$$

53. Atoms What is the electric force between an electron and a proton placed 5.3×10^{-11} m apart, the approximate radius of a hydrogen atom?

$$F = K\frac{q_A q_B}{d^2} = (9.0\times10^9\ \mathrm{N\cdot m^2/C^2})\frac{(1.60\times10^{-19}\ \mathrm{C})(1.60\times10^{-19}\ \mathrm{C})}{(5.3\times10^{-11}\ \mathrm{m})^2} = 8.2\times10^{-8}\ \mathrm{N}$$

54. A small sphere of charge 2.4 μC experiences a force of 0.36 N when a second sphere of unknown charge is placed 5.5 cm from it. What is the charge of the second sphere?

$$F = K\frac{q_A q_B}{d^2}$$

$$q_B = \frac{Fd^2}{Kq_A} = \frac{(0.36\ \mathrm{N})(5.5\times10^{-2}\ \mathrm{m})^2}{(9.0\times10^9\ \mathrm{N\cdot m^2/C^2})(2.4\times10^{-6}\ \mathrm{C})} = 5.0\times10^{-8}\ \mathrm{C}$$

55. Two identically charged spheres placed 12 cm apart have an electric force of 0.28 N between them. What is the charge of each sphere?

$$F = K\frac{q_A q_B}{d^2}, \text{ where } q_A = q_B$$

$$q = \sqrt{\frac{Fd^2}{K}} = \sqrt{\frac{(0.28\ \mathrm{N})(1.2\times10^{-1}\ \mathrm{m})^2}{(9.0\times10^9\ \mathrm{N\cdot m^2/C^2})}}$$

$$= 6.7\times10^{-7}\ \mathrm{C}$$

56. In an experiment using Coulomb's apparatus, a sphere with a charge of 3.6×10^{-8} C is 1.4 cm from a second sphere of unknown charge. The force between the spheres is 2.7×10^{-2} N. What is the charge of the second sphere?

$$F = K\frac{q_A q_B}{d^2}$$

$$q_B = \frac{Fd^2}{Kq_A} = \sqrt{\frac{(2.7\times10^{-2}\ \mathrm{N})(1.4\times10^{-2}\ \mathrm{m})^2}{(9.0\times10^9\ \mathrm{N\cdot m^2/C^2})(3.6\times10^{-8}\ \mathrm{C})}}$$

$$= 1.6\times10^{-8}\ \mathrm{C}$$

57. The force between a proton and an electron is 3.5×10^{-10} N. What is the distance between these two particles?

$$F = K\frac{q_A q_B}{d^2}$$

$$d = \sqrt{K\frac{q_A q_B}{F^2}}$$

$$= \sqrt{(9.0\times10^9\ \mathrm{N\cdot m^2/C^2})\frac{(1.60\times10^{-19}\ \mathrm{C})(1.6\times10^{-19}\ \mathrm{C})}{3.5\times10^{-10}\ \mathrm{N}}} = 8.1\times10^{-10}\ \mathrm{m}$$

Thinking Critically

page 560

58. Apply Concepts Calculate the ratio of the electric force to the gravitational force between the electron and the proton in a hydrogen atom.

$$\frac{F_e}{F_g} = \frac{K\frac{q_e q_p}{d^2}}{G\frac{m_e m_p}{d^2}} = \frac{Kq_e q_p}{Gm_e m_p}$$

$$= \frac{(9.0\times10^9\ \text{N·m}^2/\text{C}^2)(1.60\times10^{-19}\ \text{C})^2}{(6.67\times10^{-11}\ \text{N·m}^2/\text{kg}^2)(9.11\times10^{-31}\ \text{kg})(1.67\times10^{-27}\ \text{kg})} = 2.3\times10^{39}$$

59. Analyze and Conclude Sphere A, with a charge of +64 μC, is positioned at the origin. A second sphere, B, with a charge of −16 μC, is placed at 11.00 m on the *x*-axis.

a. Where must a third sphere, C, of charge +12 μC be placed so there is no net force on it?

The attractive and repulsive forces must cancel, so

$$F_{AC} = K\frac{q_A q_C}{d_{AC}{}^2} = K\frac{q_B q_C}{d_{BC}{}^2} = F_{BC}, \text{ so}$$

$$\frac{q_A}{d_{AC}{}^2} = \frac{q_B}{d_{BC}{}^2}, \text{ and } 16d_{AC}{}^2 = 64d_{BC}{}^2, \text{ or}$$

$$d_{AC}{}^2 = 4d_{BC}{}^2, \text{ so } d_{AC} = 2d_{BC}$$

The third sphere must be placed at +2.00 m on the *x*-axis so it is twice as far from the first sphere as from the second sphere.

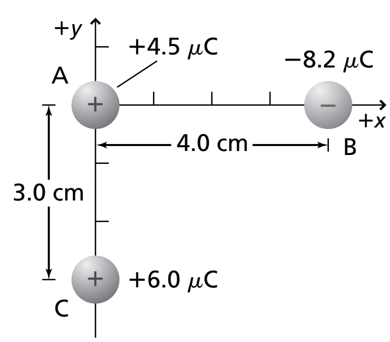
b. If the third sphere had a charge of +6 μC, where should it be placed?

The third charge, q_C, cancels from the equation, so it doesn't matter what its magnitude or sign is.

c. If the third sphere had a charge of −12 μC, where should it be placed?

As in part b, the magnitude and sign of the third charge, q_C, do not matter.

60. Three charged spheres are located at the positions shown in **Figure 20-17.** Find the total force on sphere B.



■ **Figure 20-17**

$$F_1 = F_{\text{A on B}}$$

$$= \frac{Kq_A q_B}{d^2} = \frac{(9.0\times10^9\ \text{N·m}^2/\text{C}^2)(4.5\times10^{-6}\ \text{C})(-8.2\times10^{-6}\ \text{C})}{(0.040\ \text{m})^2}$$

$= -208 \text{ N} = 208 \text{ N, to left}$

The distance between the other two charges is

$\sqrt{(0.040 \text{ m})^2 + (0.030 \text{ m})^2} = 0.050 \text{ m}$

$\theta_1 = \tan^{-1}\left(\frac{0.030 \text{ m}}{0.040 \text{ m}}\right)$

$= 37°$ **below the negative *x*-axis, or 217° from the positive *x*-axis.**

$F_2 = F_{\text{C on B}}$

$= \frac{Kq_Cq_B}{d^2} = \frac{(9.0\times10^9 \text{ N·m}^2/\text{C})(8.2\times10^{-6} \text{ C})(6.0\times10^{-6} \text{ C})}{(0.050 \text{ m})^2}$

$= -177 \text{ N} = 177 \text{ N}$ **at 217° from the positive *x*-axis** $(37° + 180°)$

The components of F_2 are:

$F_{2x} = F_2 \cos\theta = (177 \text{ N})(\cos 217°) = -142 \text{ N} = 142 \text{ N}$ **to the left**

$F_{2y} = F_2 \sin\theta = (177 \text{ N})(\sin 217°) = -106 \text{ N} = 106 \text{ N}$ **down**

The components of the net (resultant) force are:

$F_{\text{net}, x} = -208 \text{ N} - 142 \text{ N} = -350 \text{ N} = 350 \text{ N}$**, to left**

$F_{\text{net}, y} = 106 \text{ N}$**, down**

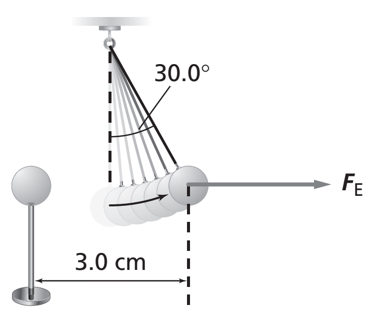
$F_{\text{net}} = \sqrt{(350 \text{ N})^2 + (106 \text{ N})^2} = 366 \text{ N} = 3.7\times10^2 \text{ N}$

$\theta_2 = \tan^{-1}\left(\frac{106 \text{ N}}{350 \text{ N}}\right)$

$= 17°$ **below the negative *x*-axis**

$F_{\text{net}} = 3.7\times10^2 \text{ N}$ **at 197° from the positive *x*-axis**

61. The two pith balls in **Figure 20-18** each have a mass of 1.0 g and an equal charge. One pith ball is suspended by an insulating thread. The other is brought to 3.0 cm from the suspended ball. The suspended ball is now hanging with the thread forming an angle of 30.0° with the vertical. The ball is in equilibrium with F_E, F_g, and F_T. Calculate each of the following.



■ **Figure 20-18**

a. F_g on the suspended ball

$F_g = mg = (1.0\times10^{-3} \text{ kg})(9.80 \text{ m/s}^2) = 9.8\times10^{-3} \text{ N}$

b. F_E

$\tan 30.0° = \frac{F_E}{F_g}$

$$F_E = mg \tan 30.0°$$
$$= (1.0\times10^{-3}\ \text{kg})(9.80\ \text{m/s}^2)(\tan 30.0°)$$
$$= 5.7\times10^{-3}\ \text{N}$$

c. the charge on the balls

$$F = \frac{Kq_Aq_B}{d^2}$$

$$F = \frac{Kq^2}{d^2}$$

$$q = \sqrt{\frac{Fd^2}{K}} = \sqrt{\frac{(5.7\times10^{-3}\ \text{N})(3.0\times10^{-2}\ \text{m}^2)}{(9.0\times10^{9}\ \text{N·m}^2/\text{C}^2)}} = 2.4\times10^{-8}\ \text{C}$$

62. Two charges, q_A and q_B, are at rest near a positive test charge, q_T, of 7.2 μC. The first charge, q_A, is a positive charge of 3.6 μC located 2.5 cm away from q_T at 35°; q_B is a negative charge of -6.6 μC located 6.8 cm away at 125°.

a. Determine the magnitude of each of the forces acting on q_T.

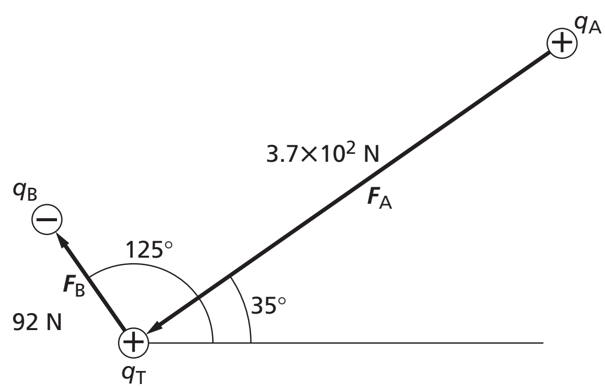
$$F_A = \frac{Kq_Tq_A}{d^2} = \frac{(9.0\times10^{9}\ \text{N·m}^2/\text{C}^2)(7.2\times10^{-6}\ \text{C})(3.6\times10^{-6}\ \text{C})}{(0.025\ \text{m})^2}$$

$$= 3.7\times10^{2}\ \text{N, away (toward } q_T)$$

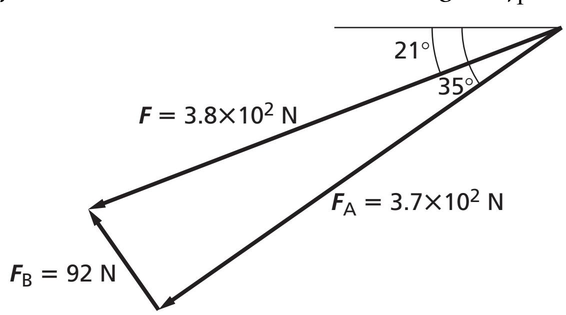
$$F_B = \frac{Kq_Tq_A}{d^2} = \frac{(9.0\times10^{9}\ \text{N·m}^2/\text{C}^2)(7.2\times10^{-6}\ \text{C})(6.6\times10^{-6}\ \text{C})}{(0.068\ \text{m})^2}$$

$$= 92\ \text{N, toward (away from } q_T)$$

b. Sketch a force diagram.



c. Graphically determine the resultant force acting on q_T.



Writing in Physics

page 560

63. **History of Science** Research several devices that were used in the seventeenth and eighteenth centuries to study static electricity. Examples that you might consider include the Leyden jar and the Wimshurst machine. Discuss how they were constructed and how they worked.

Student answers will vary, but should include information such as the following. The Leyden jar, invented in the mid-1740s, was the earliest capacitor. It was used throughout the eighteenth and nineteenth centuries to store charges for electricity-related experiments and demonstrations. The Wimshurst machine was a device used in the nineteenth and early twentieth centuries to produce and discharge static charges. Wimshurst machines, which were replaced by the Van de Graaff generator in the twentieth century, used Leyden jars to store the charges prior to discharge.

64. In Chapter 13, you learned that forces exist between water molecules that cause water to be denser as a liquid between 0°C and 4°C than as a solid at 0°C. These forces are electrostatic in nature. Research electrostatic intermolecular forces, such as van der Waals forces and dipole-dipole forces, and describe their effects on matter.

Answers will vary, but students should describe the interactions between positive and negative charges at the molecular level. Students should note that the strength of these forces accounts for differences in melting and boiling points and for the unusual behavior of water between 0°C and 4°C.

Cumulative Review

page 560

65. Explain how a pendulum can be used to determine the acceleration of gravity. (Chapter 14)

Measure the length and period of the pendulum, and use the equation for the period of a pendulum to solve for *g*.

66. A submarine that is moving 12.0 m/s sends a sonar ping of frequency 1.50×10^3 Hz toward a seamount that is directly in front of the submarine. It receives the echo 1.800 s later. (Chapter 15)

a. How far is the submarine from the seamount?

$$d = vt = (1533\ \text{m/s})(0.900\ \text{s}) = 1380\ \text{m}$$

b. What is the frequency of the sonar wave that strikes the seamount?

$$f_d = f_s\left(\frac{v - v_d}{v - v_s}\right) = (1.50\times10^3\ \text{Hz})\left(\frac{1533\ \text{m/s} - 0.0\ \text{m/s}}{1533\ \text{m/s} - 12.0\ \text{m/s}}\right)$$

$$= 1510\ \text{Hz}$$

c. What is the frequency of the echo received by the submarine?

$$f_d = f_s\left(\frac{v - v_d}{v - v_s}\right) = (1510\ \text{Hz})\left(\frac{1533\ \text{m/s} - (-12.0\ \text{m/s})}{1533\ \text{m/s} - 0.0\ \text{m/s}}\right)$$

$$= 1520\ \text{Hz}$$

67. **Security Mirror** A security mirror is used to produce an image that is three-fourths the size of an object and is located 12.0 cm behind the mirror. What is the focal length of the mirror? (Chapter 17)

$$m = \frac{-d_i}{d_o}$$

$$d_o = \frac{-d_i}{m}$$

$$= \frac{-(-12.0\ \text{cm})}{\frac{3}{4}}$$

$$= 16.0\ \text{cm}$$

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$f = \frac{d_o d_i}{d_o + d_i}$$

$$= \frac{(16.0\text{ cm})(-12.0\text{ cm})}{16.0\text{ cm} + (-12.0\text{ cm})}$$

$$= -48.0\text{ cm}$$

68. A 2.00-cm-tall object is located 20.0 cm away from a diverging lens with a focal length of 24.0 cm. What are the image position, height, and orientation? Is this a real or a virtual image? (Chapter 18)

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$d_i = \frac{d_o f}{d_o - f}$$

$$= \frac{(20.0\text{ cm})(-24.0\text{ cm})}{20.0\text{ cm} - (-24.0\text{ cm})}$$

$$= -10.9\text{ cm}$$

$$m = \frac{h_i}{h_o} = \frac{-d_i}{d_o}$$

$$h_i = \frac{-d_i h_o}{d_o}$$

$$= \frac{-(-10.9\text{ cm})(2.00\text{ cm})}{20.0\text{ cm}}$$

$$= 1.09\text{ cm}$$

This is a virtual image that is upright in orientation, relative to the object.

69. **Spectrometer** A spectrometer contains a grating of 11,500 slits/cm. Find the angle at which light of wavelength 527 nm has a first-order bright band. (Chapter 19)

The number of centimeters per slit is the slit separation distance, *d*.

$$\frac{1\text{ slit}}{d} = 11{,}500\text{ slits/cm}$$

$$d = 8.70\times10^{-5}\text{ cm}$$

$$\lambda = d \sin\theta$$

$$\theta = \sin^{-1}\left(\frac{\lambda}{d}\right)$$

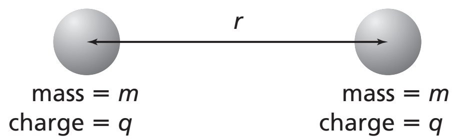
$$= \sin^{-1}\left(\frac{527\times10^{-9}\text{ m}}{8.70\times10^{-3}\text{ m}}\right)$$

$$= 0.00347°$$

Challenge Problem

page 552

As shown in the figure below, two spheres of equal mass, *m*, and equal positive charge, *q*, are a distance, *r*, apart.



■ **Figure 20-11**

1. Derive an expression for the charge, *q*, that must be on each sphere so that the spheres are in equilibrium; that is, so that the attractive and repulsive forces between them are balanced.

The attractive force is gravitation, and the repulsive force is electrostatic, so their expressions may be set equal.

$$F_g = G\frac{m_A m_B}{d^2} = K\frac{q_A q_B}{d^2} = F_e$$

The masses and charges are equal, and the distance cancels, so

$Gm^2 = Kq^2$, and

$$q = m\sqrt{\frac{G}{K}}$$

$$= m\sqrt{\frac{(6.67\times10^{-11}\text{ N·m}^2/\text{kg}^2)}{(9.0\times10^{9}\text{ N·m}^2/\text{C}^2)}}$$

$$= (8.61\times10^{-11}\text{ C/kg})m$$

2. If the distance between the spheres is doubled, how will that affect the expression for the value of *q* that you determined in the previous problem? Explain.

The distance does not affect the value of *q* because both forces are inversely related to the square of the distance, and the distance cancels out of the expression.

3. If the mass of each sphere is 1.50 kg, determine the charge on each sphere needed to maintain the equilibrium.

$$q = (8.61\times10^{-11}\text{ C/kg})(1.50\text{ kg})$$

$$= 1.29\times10^{-10}\text{ C}$$

CHAPTER

21 Electric Fields

Practice Problems

21.1 Creating and Measuring Electric Fields pages 563–568

page 565

1. A positive test charge of 5.0×10^{-6} C is in an electric field that exerts a force of 2.0×10^{-4} N on it. What is the magnitude of the electric field at the location of the test charge?

$$E = \frac{F}{q} = \frac{2.0\times10^{-4}\ \text{N}}{5.0\times10^{-6}\ \text{C}} = 4.0\times10^{1}\ \text{N/C}$$

2. A negative charge of 2.0×10^{-8} C experiences a force of 0.060 N to the right in an electric field. What are the field's magnitude and direction at that location?

$$E = \frac{F}{q} = \frac{0.060\ \text{N}}{2.0\times10^{-8}\ \text{C}} = 3.0\times10^{6}\ \text{N/C}$$

directed to the left

3. A positive charge of 3.0×10^{-7} C is located in a field of 27 N/C directed toward the south. What is the force acting on the charge?

$$E = \frac{F}{q}$$

$$F = Eq = (27\ \text{N/C})(3.0\times10^{-7}\ \text{C})$$

$$= 8.1\times10^{-6}\ \text{N}$$

4. A pith ball weighing 2.1×10^{-3} N is placed in a downward electric field of 6.5×10^{4} N/C. What charge (magnitude and sign) must be placed on the pith ball so that the electric force acting on it will suspend it against the force of gravity?

The electric force and the gravitational force algebraically sum to zero because the ball is suspended, i.e. not in motion:

$$F_g + F_e = 0\text{, so } F_e = -F_g$$

$$E = \frac{F_e}{q}$$

$$q = \frac{F_e}{E} = -\frac{F_g}{E} = -\frac{2.1\times10^{-3}\ \text{N}}{6.5\times10^{4}\ \text{N/C}}$$

$$= -3.2\times10^{-8}\ \text{C}$$

The electric force is upward (opposite the field), so the charge is negative.

5. You are probing the electric field of a charge of unknown magnitude and sign. You first map the field with a 1.0×10^{-6}-C test charge, then repeat your work with a 2.0×10^{-6}-C test charge.

a. Would you measure the same forces at the same place with the two test charges? Explain.

No. The force on the 2.0-μC charge would be twice that on the 1.0-μC charge.

b. Would you find the same field strengths? Explain.

Yes. You would divide the force by the strength of the test charge, so the results would be the same.

page 566

6. What is the magnitude of the electric field strength at a position that is 1.2 m from a point charge of 4.2×10^{-6} C?

$$E = \frac{F}{q'} = K\frac{q}{d^2}$$

$$= (9\times10^{9}\ \text{N·m}^2/\text{C}^2)\frac{(4.2\times10^{-6}\ \text{C})}{(1.2\ \text{m})^2}$$

$$= 2.6\times10^{4}\ \text{N/C}$$

7. What is the magnitude of the electric field strength at a distance twice as far from the point charge in problem 6?

Because the field strength varies as the square of the distance from the point charge, the new field strength will be one-fourth of the old field strength, or 6.5×10^{3} N/C.

8. What is the electric field at a position that is 1.6 m east of a point charge of $+7.2\times10^{-6}$ C?

$$E = \frac{F}{q'} = K\frac{q}{d^2}$$

$$= (9.0\times10^{9}\ \text{N·m}^2/\text{C}^2)\frac{(7.2\times10^{-6}\ \text{C})}{(1.6\ \text{m})^2}$$

$$= 2.5\times10^{4}\ \text{N/C}$$

The direction of the field is east (away from the positive point charge).

9. The electric field that is 0.25 m from a small sphere is 450 N/C toward the sphere. What is the charge on the sphere?

$$E = \frac{F}{q'} = K\frac{q}{d^2}$$

$$q = \frac{Ed^2}{K}$$

$$= \frac{(450\ \text{N/C})(0.25\ \text{m})^2}{(9.0\times10^{9}\ \text{N·m}^2/\text{C}^2)} = -3.1\times10^{-9}\ \text{C}$$

The charge is negative, because the field is directed toward it.

10. How far from a point charge of $+2.4\times10^{-6}$ C must a test charge be placed to measure a field of 360 N/C?

$$E = \frac{F}{q'} = K\frac{q}{d^2}$$

$$d = \sqrt{\frac{Kq}{E}}$$

$$= \sqrt{\frac{(9.0\times10^{9}\ \text{N·m}^2/\text{C}^2)(2.4\times10^{-6}\ \text{C})}{360\ \text{N/C}}}$$

$$= 7.7\ \text{m}$$

Section Review

21.1 Creating and Measuring Electric Fields pages 563–568

page 568

11. Measuring Electric Fields Suppose you are asked to measure the electric field in space. How do you detect the field at a point? How do you determine the magnitude of the field? How do you choose the magnitude of the test charge? What do you do next?

To detect a field at a point, place a test charge at that point and determine if there is a force on it.

To determine the magnitude of the field, divide the magnitude of the force on the test charge by the magnitude of the test charge.

The magnitude of the test charge must be chosen so that it is very small compared to the magnitudes of the charges producing the field.

The next thing you should do is measure the direction of the force on the test charge. The direction of the field is the same as the direction of the force if the test charge is positive; otherwise, it is in the opposite direction.

12. Field Strength and Direction A positive test charge of magnitude 2.40×10^{-8} C experiences a force of 1.50×10^{-3} N toward the east. What is the electric field at the position of the test charge?

$$E = \frac{F}{q} = \frac{1.50\times10^{-3}\ \text{N east}}{2.40\times10^{-8}\ \text{C}}$$

$$= 6.25\times10^{4}\ \text{N/C east}$$

13. Field Lines In Figure 21-4, can you tell which charges are positive and which are negative? What would you add to complete the field lines?

No. The field lines must have arrowheads indicating their directions, from positive to negative charges.

14. Field Versus Force How does the electric field, *E*, at the test charge differ from the force, *F*, on it?

The field is a property of that region of space, and does not depend on the test charge used to measure it. The force depends on the magnitude and sign of the test charge.

15. Critical Thinking Suppose the top charge in Figure 21-2c is a test charge measuring the field resulting from the two negative charges. Is it small enough to produce an accurate measure? Explain.

No. This charge is large enough to distort the field produced by the other charges with its own field. Compare with Figure 21-4b.

Practice Problems

21.2 Applications of Electric Fields pages 569–579

page 571

16. The electric field intensity between two large, charged, parallel metal plates is 6000 N/C. The plates are 0.05 m apart. What is the electric potential difference between them?

$$\Delta V = Ed = (6000\ \text{N/C})(0.05\ \text{m})$$
$$= 300\ \text{J/C} = 3\times10^{2}\ \text{V}$$

17. A voltmeter reads 400 V across two charged, parallel plates that are 0.020 m apart. What is the electric field between them?

$$\Delta V = Ed$$
$$E = \frac{\Delta V}{d} = \frac{400\ \text{V}}{0.020\ \text{m}} = 2\times10^{4}\ \text{N/C}$$

18. What electric potential difference is applied to two metal plates that are 0.200 m apart if the electric field between them is 2.50×10^{3} N/C?

$$\Delta V = Ed = (2.50\times10^{3}\ \text{N/C})(0.200\ \text{m})$$
$$= 5.00\times10^{2}\ \text{V}$$

19. When a potential difference of 125 V is applied to two parallel plates, the field between them is 4.25×10^{3} N/C. How far apart are the plates?

$$\Delta V = Ed$$
$$d = \frac{\Delta V}{E} = \frac{125\ \text{V}}{4.25\times10^{3}\ \text{N/C}} = 2.94\times10^{-2}\ \text{m}$$

20. A potential difference of 275 V is applied to two parallel plates that are 0.35 cm apart. What is the electric field between the plates?

$$E = \frac{\Delta V}{d} = \frac{275\ \text{V}}{3.5\times10^{-3}\ \text{m}} = 7.9\times10^{4}\ \text{N/C}$$

page 572

21. What work is done when 3.0 C is moved through an electric potential difference of 1.5 V?

$$W = q\Delta V = (3.0\ \text{C})(1.5\ \text{V}) = 4.5\ \text{J}$$

22. A 12-V car battery can store 1.44×10^{6} C when it is fully charged. How much work can be done by this battery before it needs recharging?

$$W = q\Delta V = (1.44\times10^{6}\ \text{C})(12\ \text{V})$$
$$= 1.7\times10^{7}\ \text{J}$$

23. An electron in a television picture tube passes through a potential difference of 18,000 V. How much work is done on the electron as it passes through that potential difference?

$$W = q\Delta V = (1.60\times10^{-19}\ \text{C})(1.8\times10^{4}\ \text{V})$$
$$= 2.9\times10^{-15}\ \text{J}$$

24. If the potential difference in problem 18 is between two parallel plates that are 2.4 cm apart, what is the magnitude of the electric field between them?

$$E = \frac{\Delta V}{d} = \frac{5.00\times10^{2}\ \text{V}}{0.024\ \text{m}} = 2.1\times10^{4}\ \text{N/C}$$

25. The electric field in a particle-accelerator machine is 4.5×10^{5} N/C. How much work is done to move a proton 25 cm through that field?

$$W = q\Delta V = qEd$$
$$= (1.60\times10^{-19}\ \text{C})(4.5\times10^{5}\ \text{N/C})(0.25\ \text{m})$$
$$= 1.8\times10^{-14}\ \text{J}$$

page 574

26. A drop is falling in a Millikan oil-drop apparatus with no electric field. What forces are acting on the oil drop, regardless of its acceleration? If the drop is falling at a constant velocity, describe the forces acting on it.

Gravitational force (weight) downward, friction force of air upward. The two forces are equal in magnitude if the drop falls at constant velocity.

27. An oil drop weighs 1.9×10^{-15} N. It is suspended in an electric field of 6.0×10^{3} N/C. What is the charge on the drop? How many excess electrons does it carry?

$F_g = Eq$

$q = \frac{F_g}{E} = \frac{1.9\times10^{-15}\text{ N}}{6.0\times10^{3}\text{ N/C}}$

$= 3.2\times10^{-19}\text{ C}$

$\#\text{ electrons} = \frac{q}{q_e} = \frac{3.2\times10^{-19}\text{ C}}{1.60\times10^{-19}\text{ C}} = 2$

28. An oil drop carries one excess electron and weighs 6.4×10^{-15} N. What electric field strength is required to suspend the drop so it is motionless?

$E = \frac{F}{q} = \frac{6.4\times10^{-15}\text{ N}}{1.60\times10^{-19}\text{ C}} = 4.0\times10^{4}\text{ N/C}$

29. A positively charged oil drop weighing 1.2×10^{-14} N is suspended between parallel plates separated by 0.64 cm. The potential difference between the plates is 240 V. What is the charge on the drop? How many electrons is the drop missing?

$E = \frac{\Delta V}{d} = \frac{240\text{ V}}{6.4\times10^{-3}\text{ m}} = 3.8\times10^{4}\text{ N/C}$

$E = \frac{F}{q}$

$q = \frac{F}{E} = \frac{1.2\times10^{-14}\text{ N}}{3.8\times10^{4}\text{ N/C}} = 3.2\times10^{-19}\text{ C}$

$\#\text{ electrons} = \frac{q}{q_e} = \frac{3.4\times10^{-19}\text{ C}}{1.60\times10^{-19}\text{ C}} = 2$

page 578

30. A 27-μF capacitor has an electric potential difference of 45 V across it. What is the charge on the capacitor?

$q = C\Delta V = (27\times10^{-6}\text{ F})(45\text{ V})$

$= 1.2\times10^{-3}\text{ C}$

31. Both a 3.3-μF and a 6.8-μF capacitor are connected across a 24-V electric potential difference. Which capacitor has a greater charge? What is it?

$q = C\Delta V$, so the larger capacitor has a greater charge.

$q = (6.8\times10^{-6}\text{ F})(24\text{ V}) = 1.6\times10^{-4}\text{ C}$

32. The same two capacitors as in problem 31 are each charged to 3.5×10^{-4} C. Which has the larger electric potential difference across it? What is it?

$\Delta V = \frac{q}{C}$, so the smaller capacitor has the larger potential difference.

$\Delta V = \frac{3.5\times10^{-4}\text{ C}}{3.5\times10^{-6}\text{ F}} = 1.1\times10^{2}\text{ V}$

33. A 2.2-μF capacitor first is charged so that the electric potential difference is 6.0 V. How much additional charge is needed to increase the electric potential difference to 15.0 V?

$q = C\Delta V$

$\Delta q = C(\Delta V_2 - \Delta V_1)$

$= (2.2\times10^{-6}\text{ F})(15.0\text{ V} - 6.0\text{ V})$

$= 2.0\times10^{-5}\text{ C}$

34. When a charge of 2.5×10^{-5} C is added to a capacitor, the potential difference increases from 12.0 V to 14.5 V. What is the capacitance of the capacitor?

$C = \frac{q}{\Delta V_2 - \Delta V_1} = \frac{2.5\times10^{-5}\text{ C}}{14.5\text{ V} - 12.0\text{ V}}$

$= 1.0\times10^{-5}\text{ F}$

Section Review

21.2 Applications of Electric Fields pages 569–579

page 579

35. Potential Difference What is the difference between electric potential energy and electric potential difference?

Electric potential energy changes when work is done to move a charge in an electric field. It depends on the amount of charge involved. Electric potential difference is the work done per unit charge to move a charge in an electric field. It is independent of the amount of charge that is moved.

36. **Electric Field and Potential Difference** Show that a volt per meter is the same as a newton per coulomb.

V/m = J/C·m = N·m/C·m = N/C

37. **Millikan Experiment** When the charge on an oil drop suspended in a Millikan apparatus is changed, the drop begins to fall. How should the potential difference on the plates be changed to bring the drop back into balance?

The potential difference should be increased.

38. **Charge and Potential Difference** In problem 37, if changing the potential difference has no effect on the falling drop, what does this tell you about the new charge on the drop?

The drop is electrically neutral (no electron excess or deficiency).

39. **Capacitance** How much charge is stored on a 0.47-μF capacitor when a potential difference of 12 V is applied to it?

$$q = C\Delta V = (4.7\times10^{-7}\ \text{F})(12\ \text{V})$$
$$= 5.6\times10^{-6}\ \text{C}$$

40. **Charge Sharing** If a large, positively charged, conducting sphere is touched by a small, negatively charged, conducting sphere, what can be said about the following?

a. the potentials of the two spheres

The spheres will have equal potentials.

b. the charges on the two spheres

The large sphere will have more charge than the small sphere, but they will be the same sign. The sign of the charge will depend on which sphere began with more charge.

41. **Critical Thinking** Referring back to Figure 21-3a, explain how charge continues to build up on the metal dome of a Van de Graaff generator. In particular, why isn't charge repelled back onto the belt at point B?

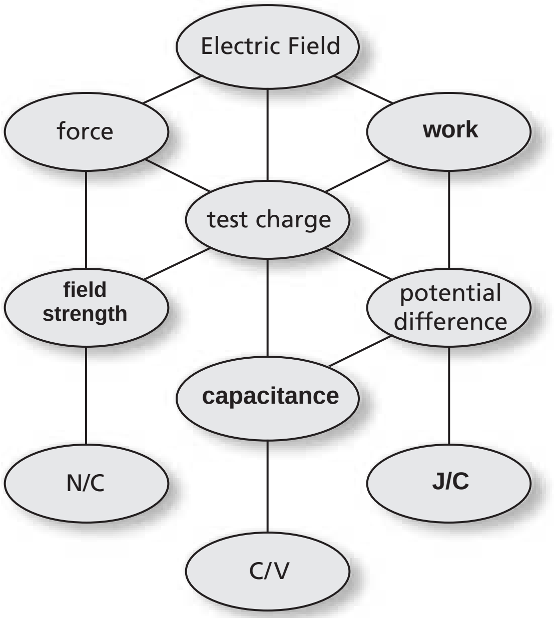
The charges on the metal dome produce no field inside the dome. The charges from the belt are transferred immediately to the outside of the dome, where they have no effect on new charges arriving at point B.

Chapter Assessment

Concept Mapping

page 584

42. Complete the concept map below using the following terms: *capacitance, field strength, J/C, work.*



Mastering Concepts

page 584

43. What are the two properties that a test charge must have? (21.1)

The test charge must be small in magnitude relative to the magnitudes of the charges producing the field and be positive.

44. How is the direction of an electric field defined? (21.1)

The direction of an electric field is the direction of the force on a positive charge placed in the field. This would be away from a positive object and toward a negative object.

45. What are electric field lines? (21.1)

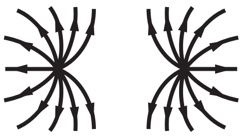
lines of force

46. How is the strength of an electric field indicated with electric field lines? (21.1)

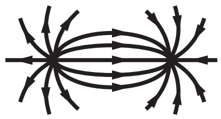
The closer together the electric field lines are, the stronger the electric field.

47. Draw some of the electric field lines between each of the following. (21.1)

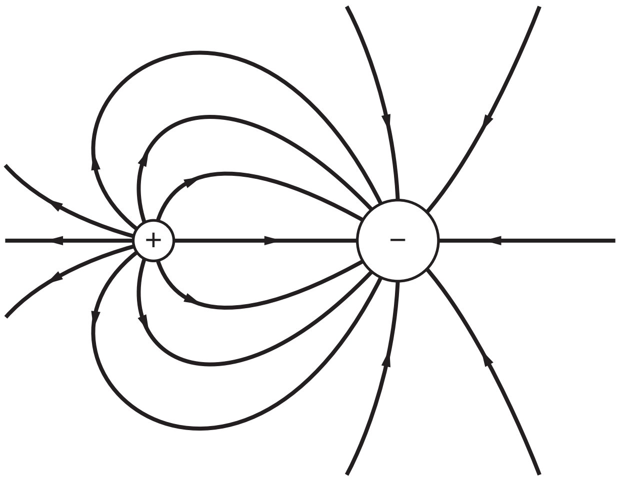
a. two like charges of equal magnitude



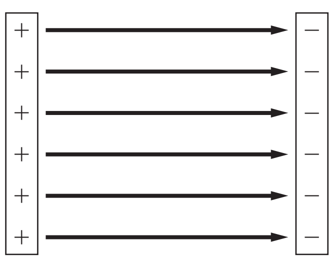
b. two unlike charges of equal magnitude



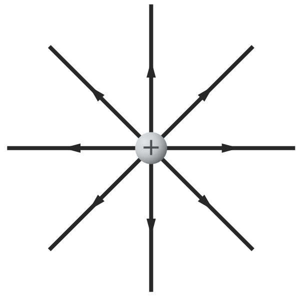
c. a positive charge and a negative charge having twice the magnitude of the positive charge



d. two oppositely charged parallel plates



48. In **Figure 21-15,** where do the electric field lines leave the positive charge end? (21.1)



■ **Figure 21-15**

They end on distant negative charges somewhere beyond the edges of the diagram.

49. What SI unit is used to measure electric potential energy? What SI unit is used to measure electric potential difference? (21.2)

electric potential energy: joule; electric potential: volt

50. Define *volt* in terms of the change in potential energy of a charge moving in an electric field. (21.2)

A *volt* is the change in electric potential energy, ΔPE, resulting from moving a unit test charge, q, a distance, d, of 1 m in an electric field, E, of 1 N/C.

$$\Delta V = \Delta PE/q = Ed$$

51. Why does a charged object lose its charge when it is touched to the ground? (21.2)

The charge is shared with the surface of Earth, which is an extremely large object.

52. A charged rubber rod that is placed on a table maintains its charge for some time. Why is the charged rod not discharged immediately? (21.2)

The table is an insulator, or at least a very poor conductor.

53. A metal box is charged. Compare the concentration of charge at the corners of the box to the charge concentration on the sides of the box. (21.2)

The concentration of charge is greater at the corners.

54. **Computers** Delicate parts in electronic equipment, such as those pictured in **Figure 21-16,** are contained within a metal box inside a plastic case. Why? (21.2)

■ **Figure 21-16**

The metal box shields the parts from external electric fields, which do not exist inside a hollow conductor.

Applying Concepts

pages 584–585

55. What happens to the strength of an electric field when the charge on the test charge is halved?

Nothing. Because the force on the test charge also would be halved, the ratio *F′/q′* and the electric field would remain the same.

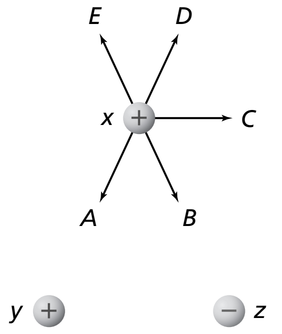
56. Does it require more energy or less energy to move a constant positive charge through an increasing electric field?

Energy is proportional to the force, and the force is proportional to the electric field. Therefore, it requires more energy.

57. What will happen to the electric potential energy of a charged particle in an electric field when the particle is released and free to move?

The electric potential energy of the particle will be converted into kinetic energy of the particle.

58. **Figure 21-17** shows three spheres with charges of equal magnitude, with their signs as shown. Spheres *y* and *z* are held in place, but sphere *x* is free to move. Initially, sphere *x* is equidistant from spheres *y* and *z*. Choose the path that sphere *x* will begin to follow. Assume that no other forces are acting on the spheres.



■ **Figure 21-17**

Sphere *x* will follow path C. It will experience forces shown by D and B. The vector sum is C.

59. What is the unit of electric potential difference in terms of m, kg, s, and C?

$V = \mathrm{J/C} = \mathrm{N{\cdot}m/C} = (\mathrm{kg{\cdot}m/s^2})(\mathrm{m/C})$

$= \mathrm{kg{\cdot}m^2/s^2{\cdot}C}$

60. What do the electric field lines look like when the electric field has the same strength at all points in a region?

They are parallel, equally spaced lines.

61. **Millikan Oil-Drop Experiment** When doing a Millikan oil-drop experiment, it is best to work with drops that have small charges. Therefore, when the electric field is turned on, should you try to find drops that are moving rapidly or slowly? Explain.

Slowly. The larger the charge, the stronger the force, and thus, the larger the (terminal) velocity.

62. Two oil drops are held motionless in a Millikan oil-drop experiment.

a. Can you be sure that the charges are the same?

No. Their masses could be different.

b. The ratios of which two properties of the oil drops have to be equal?

charge to mass ratio, *q/m* (or *m/q*)

63. José and Sue are standing on an insulating platform and holding hands when they are given a charge, as in **Figure 21-18.** José is larger than Sue. Who has the larger amount of charge, or do they both have the same amount?

■ Figure 21-18

José has a larger surface area, so he will have a larger amount of charge.

64. Which has a larger capacitance, an aluminum sphere with a 1-cm diameter or one with a 10-cm diameter?

The 10-cm diameter sphere has a larger capacitance because the charges can be farther apart, reducing potential rise as it is charged.

65. How can you store different amounts of charge in a capacitor?

Change the voltage across the capacitor.

Mastering Problems

21.1 Creating and Measuring Electric Fields pages 585–586

The charge of an electron is -1.60×10^{-19} C.

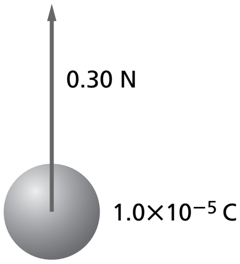
Level 1

66. What charge exists on a test charge that experiences a force of 1.4×10^{-8} N at a point where the electric field intensity is 5.0×10^{-4} N/C?

$$E = \frac{F}{q}$$

$$q = \frac{F}{E} = \frac{1.4\times10^{-8}\text{ N}}{5.0\times10^{-4}\text{ N/C}} = 2.8\times10^{-5}\text{ C}$$

67. A positive charge of 1.0×10^{-5} C, shown in **Figure 21-19,** experiences a force of 0.30 N when it is located at a certain point. What is the electric field intensity at that point?



■ Figure 21-19

$$E = \frac{F}{q} = \frac{0.30\text{ N}}{1.0\times10^{-5}\text{ C}} = 3.0\times10^{4}\text{ N/C}$$

in the same direction as the force

68. A test charge experiences a force of 0.30 N on it when it is placed in an electric field intensity of 4.5×10^{5} N/C. What is the magnitude of the charge?

$$E = \frac{F}{q}$$

$$q = \frac{F}{E} = \frac{0.30\text{ N}}{4.5\times10^{5}\text{ N/C}} = 6.7\times10^{-7}\text{ C}$$

69. The electric field in the atmosphere is about 150 N/C downward.

a. What is the direction of the force on a negatively charged particle?

upward

b. Find the electric force on an electron with charge -1.6×10^{-19} C.

$$E = \frac{F}{q}$$

$$F = qE = (1.6\times10^{-19}\text{ C})(150\text{ N/C})$$

$$= 2.4\times10^{-17}\text{ N}$$

$F = 2.4\times10^{-17}$ **N directed upward**

c. Compare the force in part **b** with the force of gravity on the same electron (mass $= 9.1\times10^{-31}$ kg).

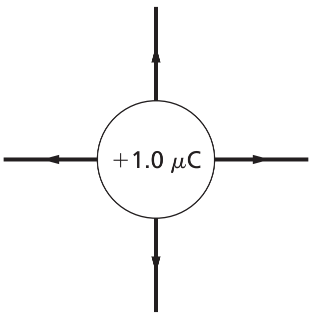
$$F = mg = (9.1\times10^{-31}\text{ kg})(9.80\text{ m/s}^2)$$

$$= 8.9\times10^{-30}\text{ N}$$

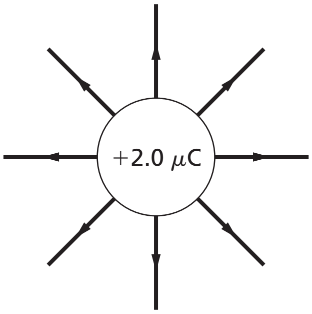
$F = 8.9\times10^{-30}$ **N (downward), more than one trillion times smaller**

70. Carefully sketch each of the following.

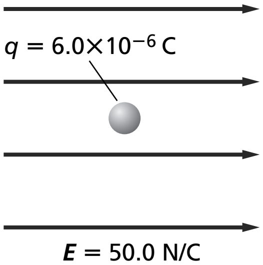
a. the electric field produced by a $+1.0$-μC charge



b. the electric field resulting from a $+2.0$-μC charge (Make the number of field lines proportional to the change in charge.)



71. A positive test charge of 6.0×10^{-6} C is placed in an electric field of 50.0-N/C intensity, as in **Figure 21-20.** What is the strength of the force exerted on the test charge?



■ **Figure 21-20**

$$\boldsymbol{E = \frac{F}{q}}$$

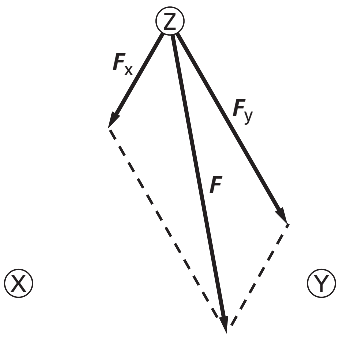
$$\boldsymbol{F = qE = (6.0\times10^{-6}\ \text{C})(50.0\ \text{N/C})}$$

$$\boldsymbol{= 3.0\times10^{-4}\ \text{N}}$$

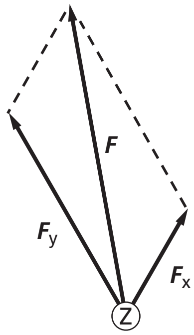
Level 2

72. Charges X, Y, and Z all are equidistant from each other. X has a $+1.0$-μC charge, Y has a $+2.0$-μC charge, and Z has a small negative charge.

a. Draw an arrow representing the force on charge Z.



b. Charge Z now has a small positive charge on it. Draw an arrow representing the force on it.



73. In a television picture tube, electrons are accelerated by an electric field having a value of 1.00×10^{5} N/C.

a. Find the force on an electron.

$$\boldsymbol{E = \frac{F}{q}}$$

$$\boldsymbol{F = Eq}$$

$$\boldsymbol{= (-1.60\times10^{-19}\ \text{C})(1.00\times10^{5}\ \text{N/C})}$$

$$\boldsymbol{= -1.60\times10^{-14}\ \text{N}}$$

b. If the field is constant, find the acceleration of the electron (mass $= 9.11\times10^{-31}$ kg).

$$\boldsymbol{F = ma}$$

$$\boldsymbol{a = \frac{F}{m} = \frac{-1.60\times10^{-14}\ \text{N}}{9.11\times10^{-31}\ \text{kg}}}$$

$$\boldsymbol{= -1.76\times10^{16}\ \text{m/s}^2}$$

74. What is the electric field strength 20.0 cm from a point charge of 8.0×10^{-7} C?

$$\boldsymbol{E = \frac{F}{q'},\ \text{and}\ F = \frac{Kqq'}{d^2}}$$

$$\boldsymbol{\text{so}\ E = \frac{Kq}{d^2}}$$

$$\boldsymbol{= \frac{(9.0\times10^{9}\ \text{N·m}^2/\text{C}^2)(8.0\times10^{-7}\ \text{C})}{(0.200\ \text{m})^2}}$$

$$\boldsymbol{= 1.8\times10^{5}\ \text{N/C}}$$

75. The nucleus of a lead atom has a charge of 82 protons.

a. What are the direction and magnitude of the electric field at 1.0×10^{-10} m from the nucleus?

$$\boldsymbol{Q = (82 \text{ protons})(1.60\times10^{-19} \text{ C/proton})}$$
$$\boldsymbol{= 1.31\times10^{-17} \text{ C}}$$

$$\boldsymbol{E = \frac{F}{q} = \frac{1}{q}\left(\frac{KqQ}{d^2}\right) = \frac{KQ}{d^2}}$$
$$\boldsymbol{= \frac{(9.0\times10^{9} \text{ N·m}^2/\text{C}^2)(1.31\times10^{-17} \text{ C})}{(1.0\times10^{-10} \text{ m})^2}}$$
$$\boldsymbol{= 1.2\times10^{13} \text{ N/C, outward}}$$

b. What are the direction and magnitude of the force exerted on an electron located at this distance?

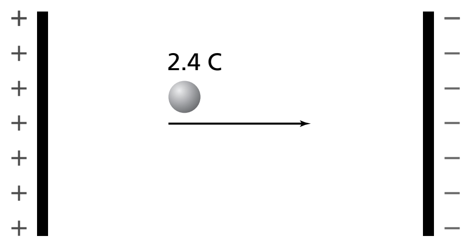
$$\boldsymbol{F = Eq}$$
$$\boldsymbol{= (1.2\times10^{13} \text{ N/C})(-1.60\times10^{-19} \text{ C})}$$
$$\boldsymbol{= -1.9\times10^{-6} \text{ N, toward the nucleus}}$$

21.2 Applications of Electric Fields

pages 586–587

Level 1

76. If 120 J of work is performed to move 2.4 C of charge from the positive plate to the negative plate shown in **Figure 21-21,** what potential difference exists between the plates?



■ **Figure 21-21**

$$\boldsymbol{\Delta V = \frac{W}{q} = \frac{120 \text{ J}}{2.4 \text{ C}} = 5.0\times10^{1} \text{ V}}$$

77. How much work is done to transfer 0.15 C of charge through an electric potential difference of 9.0 V?

$$\boldsymbol{\Delta V = \frac{W}{q}}$$

$$\boldsymbol{W = q\Delta V = (0.15 \text{ C})(9.0 \text{ V}) = 1.4 \text{ J}}$$

78. An electron is moved through an electric potential difference of 450 V. How much work is done on the electron?

$$\boldsymbol{\Delta V = \frac{W}{q}}$$
$$\boldsymbol{W = q\Delta V}$$
$$\boldsymbol{= (-1.60\times10^{-19} \text{ C})(450 \text{ V})}$$
$$\boldsymbol{= -7.2\times10^{-17} \text{ J}}$$

79. A 12-V battery does 1200 J of work transferring charge. How much charge is transferred?

$$\boldsymbol{\Delta V = \frac{W}{q}}$$

$$\boldsymbol{q = \frac{W}{\Delta V} = \frac{1200 \text{ J}}{12 \text{ V}} = 1.0\times10^{2} \text{ C}}$$

80. The electric field intensity between two charged plates is 1.5×10^3 N/C. The plates are 0.060 m apart. What is the electric potential difference, in volts, between the plates?

$$\boldsymbol{\Delta V = Ed}$$
$$\boldsymbol{= (1.5\times10^{3} \text{ N/C})(0.060 \text{ m})}$$
$$\boldsymbol{= 9.0\times10^{1} \text{ V}}$$

81. A voltmeter indicates that the electric potential difference between two plates is 70.0 V. The plates are 0.020 m apart. What electric field intensity exists between them?

$$\boldsymbol{\Delta V = Ed}$$

$$\boldsymbol{E = \frac{\Delta V}{d} = \frac{70.0 \text{ V}}{0.020 \text{ m}} = 3500 \text{ V/m}}$$
$$\boldsymbol{= 3500 \text{ N/C}}$$

82. A capacitor that is connected to a 45.0-V source contains 90.0 μC of charge. What is the capacitor's capacitance?

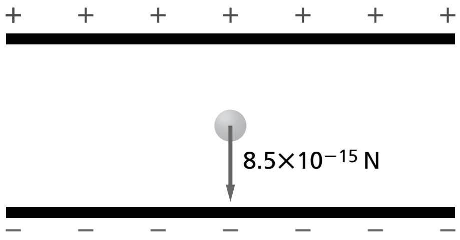
$$\boldsymbol{C = \frac{q}{\Delta V} = \frac{90.0\times10^{-6} \text{ C}}{45.0 \text{ V}} = 2.00 \ \mu\text{F}}$$

83. What electric potential difference exists across a 5.4-μF capacitor that has a charge of 8.1×10^{-4} C?

$$\boldsymbol{C = \frac{q}{\Delta V}}$$

$$\boldsymbol{\Delta V = \frac{q}{C} = \frac{8.1\times10^{-4} \text{ C}}{5.4\times10^{-6} \text{ F}}}$$
$$\boldsymbol{= 1.5\times10^{2} \text{ V}}$$

84. The oil drop shown in **Figure 21-22** is negatively charged and weighs 4.5×10^{-15} N. The drop is suspended in an electric field intensity of 5.6×10^{3} N/C.



■ **Figure 21-22**

a. What is the charge on the drop?

$$E = \frac{F}{q}$$

$$q = \frac{F}{E} = \frac{4.5\times10^{-15}\text{ N}}{5.6\times10^{3}\text{ N/C}}$$

$$= 8.0\times10^{-19}\text{ C}$$

b. How many excess electrons does it carry?

$$(8.0\times10^{-19}\text{ C})\left(\frac{1\text{ electron}}{1.60\times10^{-19}\text{ C}}\right)$$

$$= 5\text{ electrons}$$

85. What is the charge on a 15.0-pF capacitor when it is connected across a 45.0-V source?

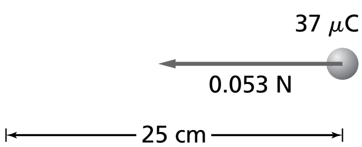
$$C = \frac{q}{\Delta V}$$

$$q = C\Delta V = (15.0\times10^{-12}\text{ F})(45.0\text{ V})$$

$$= 6.75\times10^{-10}\text{ C}$$

Level 2

86. A force of 0.065 N is required to move a charge of 37 μC a distance of 25 cm in a uniform electric field, as in **Figure 21-23.** What is the size of the electric potential difference between the two points?



■ **Figure 21-23**

$$W = Fd$$

$$\text{and } \Delta V = \frac{W}{q} = \frac{Fd}{q}$$

$$= \frac{(0.065\text{ N})(0.25\text{ m})}{37\times10^{-6}\text{ C}}$$

$$= 4.4\times10^{2}\text{ V}$$

87. Photoflash The energy stored in a capacitor with capacitance C, and an electric potential difference, ΔV, is represented by $W = \frac{1}{2}C\Delta V^2$. One application of this is in the electronic photoflash of a strobe light, like the one in **Figure 21-24.** In such a unit, a capacitor of 10.0 μF is charged to 3.0×10^{2} V. Find the energy stored.

■ **Figure 21-24**

$$W = \tfrac{1}{2}C\Delta V^2$$

$$= \left(\tfrac{1}{2}\right)(10.0\times10^{-6}\text{ F})(3.0\times10^{2}\text{ V})^2$$

$$= 0.45\text{ J}$$

88. Suppose it took 25 s to charge the capacitor in problem 87.

a. Find the average power required to charge the capacitor in this time.

$$P = \frac{W}{t} = \frac{0.45\text{ J}}{25\text{ s}} = 1.8\times10^{-2}\text{ W}$$

b. When this capacitor is discharged through the strobe lamp, it transfers all its energy in 1.0×10^{-4} s. Find the power delivered to the lamp.

$$P = \frac{W}{t} = \frac{0.45\text{ J}}{1.0\times10^{-4}\text{ s}} = 4.5\times10^{3}\text{ W}$$

c. How is such a large amount of power possible?

Power is inversely proportional to the time. The shorter the time for a given amount of energy to be expended, the greater the power.

89. **Lasers** Lasers are used to try to produce controlled fusion reactions. These lasers require brief pulses of energy that are stored in large rooms filled with capacitors. One such room has a capacitance of 61×10^{-3} F charged to a potential difference of 10.0 kV.

a. Given that $W = \frac{1}{2}C\Delta V^2$, find the energy stored in the capacitors.

$$W = \frac{1}{2}C\Delta V^2$$
$$= \left(\frac{1}{2}\right)(61\times10^{-3}\ \text{F})(1.00\times10^4\ \text{V})^2$$
$$= 3.1\times10^6\ \text{J}$$

b. The capacitors are discharged in 10 ns (1.0×10^{-8} s). What power is produced?

$$P = \frac{W}{t} = \frac{3.1\times10^6\ \text{J}}{1.0\times10^{-8}\ \text{s}} = 3.1\times10^{14}\ \text{W}$$

c. If the capacitors are charged by a generator with a power capacity of 1.0 kW, how many seconds will be required to charge the capacitors?

$$t = \frac{W}{P} = \frac{3.1\times10^6\ \text{J}}{1.0\times10^3\ \text{W}} = 3.1\times10^3\ \text{s}$$

Mixed Review

page 587

Level 1

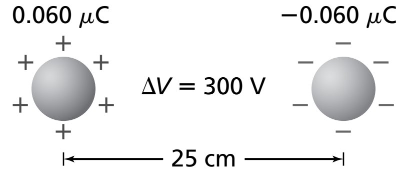
90. How much work does it take to move 0.25 μC between two parallel plates that are 0.40 cm apart if the field between the plates is 6400 N/C?

$$W = q\Delta V = qEd$$
$$= (2.5\times10^{-7}\ \text{C})(6400\ \text{N/C})(4.0\times10^{-3}\ \text{m})$$
$$= 6.4\times10^{-6}\ \text{J}$$

91. How much charge is stored on a 0.22-μF parallel plate capacitor if the plates are 1.2 cm apart and the electric field between them is 2400 N/C?

$$q = C\Delta V = CEd$$
$$= (2.2\times10^{-7}\ \text{F})(2400\ \text{N/C})(1.2\times10^{-2}\ \text{m})$$
$$= 6.3\ \mu\text{C}$$

92. Two identical small spheres, 25 cm apart, carry equal but opposite charges of 0.060 μC, as in **Figure 21-25.** If the potential difference between them is 300 V, what is the capacitance of the system?



■ **Figure 21-25**

$$C = \frac{q}{\Delta V} = \frac{6.0\times10^{-8}\ \text{C}}{300\ \text{V}} = 2\times10^{-10}\ \text{F}$$

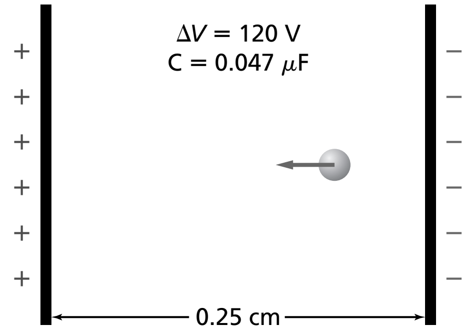
93. The plates of a 0.047 μF capacitor are 0.25 cm apart and are charged to a potential difference of 120 V. How much charge is stored on the capacitor?

$$C = \frac{q}{\Delta V}$$
$$q = C\Delta V$$
$$= (4.7\times10^{-8}\ \text{F})(120\ \text{V})$$
$$= 5.6\times10^{-6}\ \text{C} = 5.6\ \mu\text{C}$$

94. What is the strength of the electric field between the plates of the capacitor in Problem 93 above?

$$\Delta V = Ed$$
$$E = \frac{\Delta V}{d}$$
$$= \frac{120\ \text{V}}{2.5\times10^{-3}\ \text{m}} = 4.8\times10^4\ \text{V/m}$$

95. An electron is placed between the plates of the capacitor in Problem 93 above, as in **Figure 21-26.** What force is exerted on that electron?



■ **Figure 21-26**

$$E = \frac{F}{q}$$

$$F = Eq$$

$$= (4.8\times10^{4}\ \text{V/m})(1.6\times10^{-19}\ \text{C})$$

$$= 7.7\times10^{-15}\ \text{N}$$

96. How much work would it take to move an additional 0.010 μC between the plates at 120 V in Problem 93?

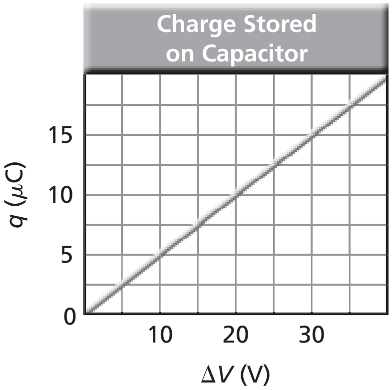
$$\Delta V = \frac{W}{q}$$

$$W = q\Delta V$$

$$= (1.0\times10^{-8}\ \text{C})(120\ \text{V}) = 1.2\times10^{-6}\ \text{J}$$

Level 2

97. The graph in **Figure 21-27** represents the charge stored in a capacitor as the charging potential increases. What does the slope of the line represent?



■ **Figure 21-27**

capacitance of the capacitor

98. What is the capacitance of the capacitor represented by Figure 21-27?

C = slope = 0.50 μF

99. What does the area under the graph line in Figure 21-27 represent?

work done to charge the capacitor

100. How much work is required to charge the capacitor in problem 98 to a potential difference of 25 V?

$$W = \text{area} = \frac{1}{2}bh$$

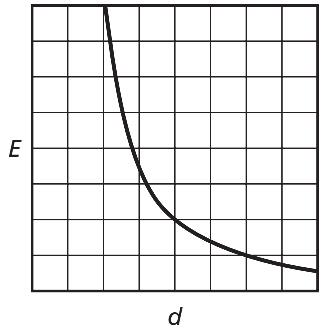
$$= \left(\frac{1}{2}\right)(25\ \text{V})(12.5\ \mu\text{C})$$

$$= 160\ \mu\text{J}$$

101. The work found in Problem 100 above is not equal to $q\Delta V$. Why not?

The potential difference is not constant as the capacitor is charged. Therefore, the area under the graph must be used to find work, not just simple multiplication.

102. Graph the electric field strength near a positive point charge as a function of distance from it.



103. Where is the field of a point charge equal to zero?

Nowhere, or at an infinite distance from the point charge.

104. What is the electric field strength at a distance of zero meters from a point charge? Is there such a thing as a true point charge?

Infinite. No.

Thinking Critically

pages 587–588

105. Apply Concepts Although a lightning rod is designed to carry charge safely to the ground, its primary purpose is to prevent lightning from striking in the first place. How does it do that?

The sharp point on the end of the rod leaks charge into the atmosphere before it has the chance to build up enough potential difference to cause a lightning strike.

106. Analyze and Conclude In an early set of experiments in 1911, Millikan observed that the following measured charges could appear on a single oil drop. What value of elementary charge can be deduced from these data?

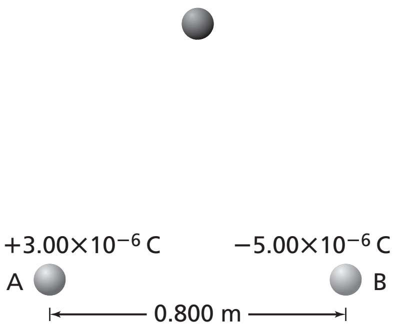
a. 6.563×10^{-19} C
b. 8.204×10^{-19} C
c. 11.50×10^{-19} C
d. 13.13×10^{-19} C
e. 16.48×10^{-19} C
f. 18.08×10^{-19} C
g. 19.71×10^{-19} C
h. 22.89×10^{-19} C
i. 26.13×10^{-19} C

1.63×10^{19} C. Subtracting adjacent values, $b - a$, $c - b$, $d - c$, etc. yields 1.641×10^{-19} C, 3.30×10^{-19} C, 1.63×10^{-19} C, 3.35×10^{-19} C, 1.60×10^{-19} C, 1.63×10^{-19} C, 3.18×10^{-19} C, 3.24×10^{-19} C.

There are two numbers, approximately 1.631×10^{-19} C and 3.2×10^{-19} C, that are common. Averaging each similar group produces one charge of 1.63×10^{-19} C and one charge of 3.27×10^{-19} C (which is two times 1.641×10^{-19} C).

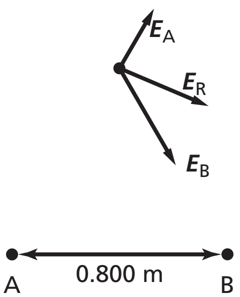
Dividing 1.63×10^{-19} C into each piece of data yields nearly whole-number quotients, indicating it is the value of an elementary charge.

107. Analyze and Conclude Two small spheres, A and B, lie on the x-axis, as in **Figure 21-28.** Sphere A has a charge of $+3.00\times10^{-6}$ C. Sphere B is 0.800 m to the right of sphere A and has a charge of -5.00×10^{-6} C. Find the magnitude and direction of the electric field strength at a point above the x-axis that would form the apex of an equilateral triangle with spheres A and B.



■ **Figure 21-28**

Draw the spheres and vectors representing the fields due to each charge at the given point.



Now do the math:

$$E_A = \frac{F_A}{q'} = \frac{Kq_A}{d^2} = \frac{(9.0\times10^9\ \text{N·m}^2/\text{C}^2)(3.00\times10^{-6}\ \text{C})}{(0.800\ \text{m})^2} = 4.22\times10^4\ \text{N/C}$$

$$E_B = \frac{F_B}{q'} = \frac{Kq_B}{d^2} = \frac{(9.0\times10^9\ \text{N·m}^2/\text{C}^2)(5.00\times10^{-6}\ \text{C})}{(0.800\ \text{m})^2} = 7.03\times10^4\ \text{N/C}$$

$$E_{Ax} = E_A \cos 60.0° = (4.22\times10^4\ \text{N/C})(\cos 60.0°) = 2.11\times10^4\ \text{N/C}$$

$$E_{Ay} = E_A \sin 60.0° = (4.22\times10^4\ \text{N/C})(\sin 60.0°) = 3.65\times10^4\ \text{N/C}$$

$$E_{Bx} = E_B \cos(-60.0°) = (7.03\times10^4\ \text{N/C})(\cos -60.0°) = 3.52\times10^4\ \text{N/C}$$

$$E_{By} = E_B \sin(-60.0°) = (7.03\times10^4\ \text{N/C})(\sin -60.0°) = -6.09\times10^4\ \text{N/C}$$

$$E_x = E_{Ax} + E_{Bx} = (2.11\times10^4\ \text{N/C}) + (3.52\times10^4\ \text{N/C}) = 5.63\times10^4\ \text{N/C}$$

$$E_y = E_{Ay} + E_{By} = (3.65\times10^4\ \text{N/C}) + (-6.09\times10^4\ \text{N/C}) = -2.44\times10^4\ \text{N/C}$$

$$E_R = \sqrt{E_x^2 + E_y^2} = 6.14\times10^4\ \text{N/C}$$

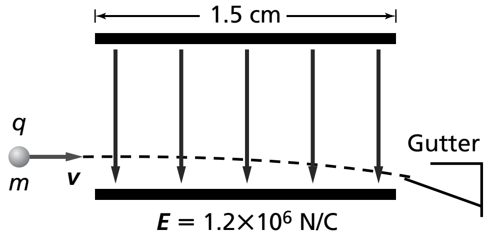
$$\tan\theta = \frac{E_y}{E_x}$$

$$\theta = \tan^{-1}\left(\frac{E_y}{E_x}\right)$$

$$= \tan^{-1}\left(\frac{-2.44\times10^4\ \text{N/C}}{5.63\times10^4\ \text{N/C}}\right)$$

$$= -23.4°$$

108. Analyze and Conclude In an ink-jet printer, drops of ink are given a certain amount of charge before they move between two large, parallel plates. The purpose of the plates is to deflect the charges so that they are stopped by a gutter and do not reach the paper. This is shown in **Figure 21-29.** The plates are 1.5-cm long and have an electric field of $E = 1.2\times10^6$ N/C between them. Drops with a mass $m = 0.10$ ng, and a charge $q = 1.0\times10^{-16}$ C, are moving horizontally at a speed, $v = 15$ m/s, parallel to the plates. What is the vertical displacement of the drops when they leave the plates? To answer this question, complete the following steps.



■ **Figure 21-29**

a. What is the vertical force on the drops?

$$F = Eq$$
$$= (1.0\times10^{-16}\ \text{C})(1.2\times10^6\ \text{N/C})$$
$$= 1.2\times10^{-10}\ \text{N}$$

b. What is their vertical acceleration?

$$a = \frac{F}{m} = \frac{1.2\times10^{-10}\ \text{N}}{1.0\times10^{-13}\ \text{kg}} = 1.2\times10^3\ \text{m/s}^2$$

c. How long are they between the plates?

$$t = \frac{L}{v} = \frac{1.5\times10^{-2}\ \text{m}}{15\ \text{m/s}} = 1.0\times10^{-3}\ \text{s}$$

d. How far are they displaced?

$$y = \frac{1}{2}at^2$$
$$= \left(\frac{1}{2}\right)(1.2\times10^3\ \text{m/s}^2)(1.0\times10^{-3}\ \text{s})^2$$
$$= 6.0\times10^{-4}\ \text{m} = 0.60\ \text{mm}$$

109. Apply Concepts Suppose the Moon had a net negative charge equal to $-q$, and Earth had a net positive charge equal to $+10q$. What value of q would yield the same magnitude of force that you now attribute to gravity?

Equate the expressions for gravitational force and Coulombic force between Earth and the Moon:

$$F = \frac{Gm_E m_M}{d^2} = \frac{Kq_E q_M}{d^2} = \frac{10Kq^2}{d^2}$$

where $-q$ is the net negative charge of the Moon and q_E, the net positive charge of Earth, is $+10q$.
Solve symbolically before substituting numbers.

$$q = \sqrt{\frac{Gm_E m_M}{10K}}$$

$$= \sqrt{\frac{(6.67\times10^{-11}\ \mathrm{N{\cdot}m^2/kg^2})(6.00\times10^{24}\ \mathrm{kg})(7.31\times10^{22}\ \mathrm{kg})}{(10)(9.0\times10^{9}\ \mathrm{N{\cdot}m^2/C^2})}}$$

$$= 1.8\times10^{13}\mathrm{C}$$

Writing in Physics

page 588

110. Choose the name of an electric unit, such as coulomb, volt, or farad, and research the life and work of the scientist for whom it was named. Write a brief essay on this person and include a discussion of the work that justified the honor of having a unit named for him.

Student answers will vary. Some examples of scientists they could choose are Volta, Coulomb, Ohm, and Ampère.

Cumulative Review

page 588

111. Michelson measured the speed of light by sending a beam of light to a mirror on a mountain 35 km away. (Chapter 16)

a. How long does it take light to travel the distance to the mountain and back?

(35 km/trip)(2 trips)(1000 m/1 km)/ 3.00×10^{8} m/s = 2.3×10^{-4} s

b. Assume that Michelson used a rotating octagon with a mirror on each face of the octagon. Also assume that the light reflects from one mirror, travels to the other mountain, reflects off of a fixed mirror on that mountain, and returns to the rotating mirrors. If the rotating mirror has advanced so that when the light returns, it reflects off of the next mirror in the rotation, how fast is the mirror rotating?

$$\left(\frac{2.3\times10^{-4}\ \mathrm{s}}{1\ \mathrm{mirror}}\right)(8\ \mathrm{mirrors/rev}) = 1.8\times10^{-3}\ \mathrm{s/rev} = T$$

$$f = \frac{1}{T} = \frac{1}{1.8\times10^{-3}\ \mathrm{s/rev}} = 5.6\times10^{2}\ \mathrm{rev/s}$$

Note that if students carry extra digits from part a to prevent rounding errors, they will get an answer of 5.4×10^{2} rev/s.

c. If each mirror has a mass of 1.0×10^{1} g and rotates in a circle with an average radius of 1.0×10^{1} cm, what is the approximate centripetal force needed to hold the mirror while is it rotating?

$$F_c = 4\pi^2 mf^2 r$$
$$= 4\pi^2(0.010\ \text{kg})(5.6\times10^2\ \text{rev/s})^2(0.10\ \text{m})$$
$$= 1.2\times10^4\ \text{N}$$

Note that the answer should be 1.2×10^4 N regardless of whether the students use 5.4×10^2 rev/s or 5.6×10^4 rev/s for f.

112. Mountain Scene You can see an image of a distant mountain in a smooth lake just as you can see a mountain biker next to the lake because light from each strikes the surface of the lake at about the same angle of incidence and is reflected to your eyes. If the lake is about 100 m in diameter, the reflection of the top of the mountain is about in the middle of the lake, the mountain is about 50 km away from the lake, and you are about 2 m tall, then approximately how high above the lake does the top of the mountain reach? (Chapter 17)

Since the angle of incidence of the light from the top of the mountain is equal to its angle of reflection from the lake, you and the reflection of the top of the mountain form a triangle that is similar to a triangle formed by the mountain and the top of its reflection in the lake. Your height makes up one side, h_{you} = 2 m and the top of the mountain is halfway across the lake, d_{you} = 50 m. The mountain is a distance d_{mountain} = 50,000 m from its reflection. Find h_{mountain} by equating the ratios of the sides of the two similar triangles.

$$\frac{h_{\text{you}}}{d_{\text{you}}} = \frac{h_{\text{mountain}}}{d_{\text{mountain}}}$$
$$h_{\text{mountain}} = \frac{h_{\text{you}}d_{\text{mountain}}}{d_{\text{you}}}$$
$$= \frac{(2\ \text{m})(50{,}000\ \text{m})}{50\ \text{m}}$$
$$= 2000\ \text{m}$$

113. A converging lens has a focal length of 38.0 cm. If it is placed 60.0 cm from an object, at what distance from the lens will the image be? (Chapter 18)

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$
$$d_i = \frac{d_o f}{d_o - f}$$
$$= \frac{(60.0\ \text{cm})(38.0\ \text{cm})}{60.0\ \text{cm} - 38.0\ \text{cm}}$$
$$= 104\ \text{cm}$$

The image is 104 cm from the lens.

114. A force, F, is measured between two charges, Q and q, separated by a distance, r. What would the new force be for each of the following? (Chapter 20)

a. r is tripled

***F*/9**

b. Q is tripled

3*F*

c. both r and Q are tripled

***F*/3**

d. both r and Q are doubled

***F*/2**

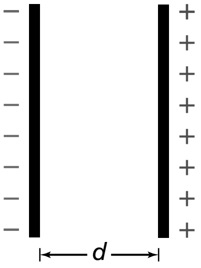
e. all three, r, Q, and q, are tripled

F

Challenge Problem

page 579

The plates of a capacitor attract each other because they carry opposite charges. A capacitor consisting of two parallel plates that are separated by a distance, *d*, has capacitance, *C*.



1. Derive an expression for the force between the two plates when the capacitor has charge, *q*.

   Combine the following equations:

   $$F = Eq,\ E = \frac{\Delta V}{d},\ \text{and}\ \Delta V = \frac{q}{C}$$

   $$F = Eq = \left(\frac{\Delta V}{d}\right)q = \left(\frac{\left(\frac{q}{C}\right)}{d}\right)q = \frac{q^2}{Cd}$$

2. What charge must be stored on a 22-μF capacitor to have a force of 2.0 N between the plates if they are separated by 1.5 mm?

   $$F = \frac{q^2}{Cd}$$

   $$\text{so } q = \sqrt{FCd}$$

   $$= \sqrt{(2.0\ \text{N})(2.2\times10^{-5}\ \text{F})(1.5\times10^{-3}\ \text{m})}$$

   $$= 2.6\times10^{-4}\ \text{C}$$

CHAPTER 22

Current Electricity

Practice Problems

22.1 Current and Circuits pages 591–600

page 594

1. The current through a lightbulb connected across the terminals of a 125-V outlet is 0.50 A. At what rate does the bulb convert electric energy to light? (Assume 100 percent efficiency.)

$P = IV = (0.50\ \text{A})(125\ \text{V}) = 63\ \text{J/s} = 63\ \text{W}$

2. A car battery causes a current of 2.0 A through a lamp and produces 12 V across it. What is the power used by the lamp?

$P = IV = (2.0\ \text{A})(12\ \text{V}) = 24\ \text{W}$

3. What is the current through a 75-W lightbulb that is connected to a 125-V outlet?

$P = IV$

$I = \frac{P}{V} = \frac{75\ \text{W}}{125\ \text{V}} = 0.60\ \text{A}$

4. The current through the starter motor of a car is 210 A. If the battery maintains 12 V across the motor, how much electric energy is delivered to the starter in 10.0 s?

$P = IV$ and $E = Pt$

Thus, $E = IVt = (210\ \text{A})(12\ \text{V})(10.0\ \text{s})$

$= 2.5\times10^{4}\ \text{J}$

5. A flashlight bulb is rated at 0.90 W. If the lightbulb drops 3.0 V, how much current goes through it?

$P = IV$

$I = \frac{P}{V} = \frac{0.90\ \text{W}}{3.0\ \text{V}} = 0.30\ \text{A}$

page 598

For all problems, assume that the battery voltage and lamp resistances are constant, no matter what current is present.

6. An automobile panel lamp with a resistance of 33 Ω is placed across a 12-V battery. What is the current through the circuit?

$I = \frac{V}{R} = \frac{12\ \text{V}}{33\ \Omega} = 0.36\ \text{A}$

7. A motor with an operating resistance of 32 Ω is connected to a voltage source. The current in the circuit is 3.8 A. What is the voltage of the source?

$V = IR = (3.8\ \text{A})(32\ \Omega) = 1.2\times10^{2}\ \text{V}$

8. A sensor uses 2.0×10^{-4} A of current when it is operated by a 3.0-V battery. What is the resistance of the sensor circuit?

$R = \frac{V}{I} = \frac{3.0\ \text{V}}{2.0\times10^{-4}\ \text{A}} = 1.5\times10^{4}\ \Omega$

9. A lamp draws a current of 0.50 A when it is connected to a 120-V source.

a. What is the resistance of the lamp?

$R = \frac{V}{I} = \frac{120\ \text{V}}{0.50\ \text{A}} = 2.4\times10^{2}\ \Omega$

b. What is the power consumption of the lamp?

$P = IV = (0.50\ \text{A})(120\ \text{V}) = 6.0\times10^{1}\ \text{W}$

10. A 75-W lamp is connected to 125 V.

a. What is the current through the lamp?

$I = \frac{P}{V} = \frac{75\ \text{W}}{125\ \text{V}} = 0.60\ \text{A}$

b. What is the resistance of the lamp?

$R = \frac{V}{I} = \frac{125\ \text{V}}{0.60\ \text{A}} = 2.1\times10^{2}\ \Omega$

11. A resistor is added to the lamp in the previous problem to reduce the current to half of its original value.

a. What is the potential difference across the lamp?

The new value of the current is

$$\frac{0.60\ \text{A}}{2} = 0.30\ \text{A}$$

$$V = IR = (0.30\ \text{A})(2.1\times10^{2}\ \Omega)$$
$$= 6.3\times10^{1}\ \text{V}$$

b. How much resistance was added to the circuit?

The total resistance of the circuit is now

$$R_{\text{total}} = \frac{V}{I} = \frac{125\ \text{V}}{0.30\ \text{A}} = 4.2\times10^{2}\ \Omega$$

Therefore,

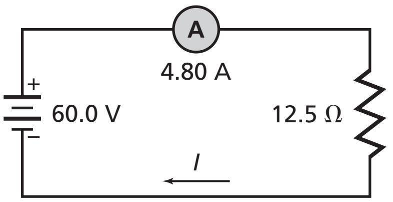
$$R_{\text{res}} = R_{\text{total}} - R_{\text{lamp}}$$
$$= 4.2\times10^{2}\ \Omega - 2.1\times10^{2}\ \Omega$$
$$= 2.1\times10^{2}\ \Omega$$

c. How much power is now dissipated in the lamp?

$$P = IV = (0.30\ \text{A})(6.3\times10^{1}\ \text{V}) = 19\ \text{W}$$

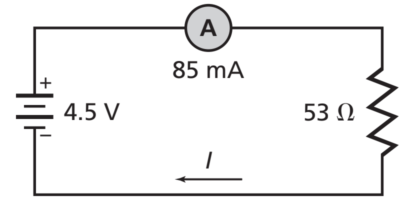
page 600

12. Draw a circuit diagram to include a 60.0-V battery, an ammeter, and a resistance of 12.5 Ω in series. Indicate the ammeter reading and the direction of the current.



$$I = \frac{V}{R} = \frac{60.0\ \text{V}}{12.5\ \Omega} = 4.80\ \text{A}$$

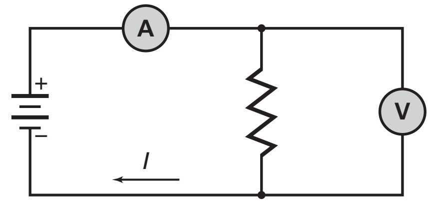
13. Draw a series-circuit diagram showing a 4.5-V battery, a resistor, and an ammeter that reads 85 mA. Determine the resistance and label the resistor. Choose a direction for the conventional current and indicate the positive terminal of the battery.



$$R = \frac{V}{I} = \frac{4.5\ \text{V}}{0.085\ \text{A}} = 53\ \Omega$$

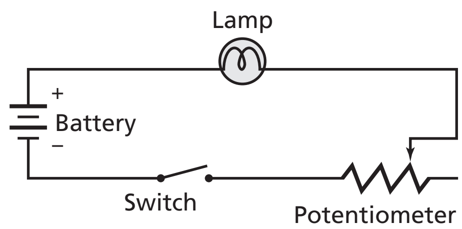
14. Add a voltmeter to measure the potential difference across the resistors in problems 12 and 13 and repeat the problems.

Both circuits will take the following form.

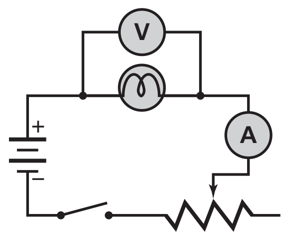


Because the ammeter resistance is assumed zero, the voltmeter readings will be 60.0 V for Practice Problem 12 and 4.5 V for Practice Problem 13.

15. Draw a circuit using a battery, a lamp, a potentiometer to adjust the lamp's brightness, and an on-off switch.



16. Repeat the previous problem, adding an ammeter and a voltmeter across the lamp.

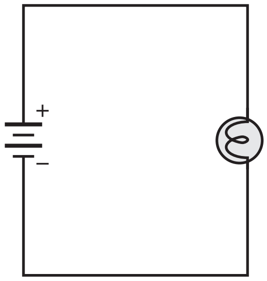


Section Review

22.1 Current and Circuits pages 591–600

page 600

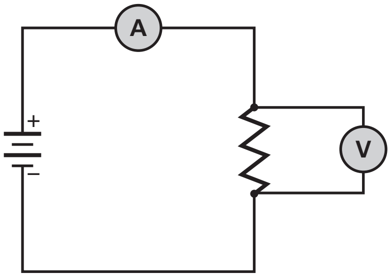
17. Schematic Draw a schematic diagram of a circuit that contains a battery and a lightbulb. Make sure the lightbulb will light in this circuit.



18. Resistance Joe states that because $R = V/I$, if he increases the voltage, the resistance will increase. Is Joe correct? Explain.

No, resistance depends on the device. When V increases, so will I.

19. Resistance You want to measure the resistance of a long piece of wire. Show how you would construct a circuit with a battery, a voltmeter, an ammeter, and the wire to be tested to make the measurement. Specify what you would measure and how you would compute the resistance.



Measure the current through the wire and the potential difference across it. Divide the potential difference by the current to obtain the wire resistance.

20. Power A circuit has 12 Ω of resistance and is connected to a 12-V battery. Determine the change in power if the resistance decreases to 9.0 Ω.

$$P_1 = V^2/R_1 = (12\text{ V})^2/12\ \Omega = 12\text{ W}$$

$$P_2 = V^2/R_2 = (12\text{ V})^2/9.0\ \Omega = 16\text{ W}$$

$$\Delta P = P_2 - P_1 = 16\text{ W} - 12\text{ W} = 4.0\text{ W}$$

4.0 W increase

21. Energy A circuit converts 2.2×10^3 J of energy when it is operated for 3.0 min. Determine the amount of energy it will convert when it is operated for 1 h.

$$E = \left(\frac{2.2\times10^3\text{ J}}{3.0\text{ min}}\right)(60.0\text{ min})$$

$$= 4.4\times10^4\text{ J}$$

22. Critical Thinking We say that power is "dissipated" in a resistor. To dissipate is to use, to waste, or to squander. What is "used" when charge flows through a resistor?

The potential energy of the charges decreases as they flow through the resistor. This decrease in potential energy is used to produce heat in the resistor.

Practice Problems

22.2 Using Electric Energy pages 601–605

page 603

23. A 15-Ω electric heater operates on a 120-V outlet.

a. What is the current through the heater?

$$I = \frac{V}{R} = \frac{120\text{ V}}{15\ \Omega} = 8.0\text{ A}$$

b. How much energy is used by the heater in 30.0 s?

$$E = I^2Rt = (8.0\text{ A})^2(15\ \Omega)(30.0\text{ s})$$

$$= 2.9\times10^4\text{ J}$$

c. How much thermal energy is liberated in this time?

2.9×10^4 J, because all electric energy is converted to thermal energy.

24. A 39-Ω resistor is connected across a 45-V battery.

a. What is the current in the circuit?

$$I = \frac{V}{R} = \frac{45\text{ V}}{39\ \Omega} = 1.2\text{ A}$$

b. How much energy is used by the resistor in 5.0 min?

$$E = \frac{V^2}{R}t$$

$$= \frac{(45\text{ V})^2}{(39\ \Omega)}(5.0\text{ min})(60\text{ s/min})$$

$$= 1.6\times10^4\text{ J}$$

25. A 100.0-W lightbulb is 22 percent efficient. This means that 22 percent of the electric energy is converted to light energy.

a. How many joules does the lightbulb convert into light each minute it is in operation?

$$E = Pt$$

$$= (0.22)(100.0\text{ J/s})(1.0\text{ min})(60\text{ s/min})$$

$$= 1.3\times10^3\text{ J}$$

b. How many joules of thermal energy does the lightbulb produce each minute?

$$E = Pt$$

$$= (0.78)(100.0\text{ J/s})(1.0\text{ min})(60.0\text{ s/min})$$

$$= 4.7\times10^3\text{ J}$$

26. The resistance of an electric stove element at operating temperature is 11 Ω.

a. If 220 V are applied across it, what is the current through the stove element?

$$I = \frac{V}{R} = \frac{220\text{ V}}{11\ \Omega} = 2.0\times10^1\text{ A}$$

b. How much energy does the element convert to thermal energy in 30.0 s?

$$E = I^2Rt = (2.0\times10^1\text{ A})^2(11\ \Omega)(30.0\text{ s})$$

$$= 1.3\times10^5\text{ J}$$

c. The element is used to heat a kettle containing 1.20 kg of water. Assume that 65 percent of the heat is absorbed by the water. What is the water's increase in temperature during the 30.0 s?

$Q = mC\Delta T$ **with** $Q = 0.65E$

$$\Delta T = \frac{0.65E}{mC} = \frac{(0.65)(1.3\times10^5\text{ J})}{(1.20\text{ kg})(4180\text{ J/kg}\cdot{}^\circ\text{C})}$$

$$= 17^\circ\text{C}$$

27. A 120-V water heater takes 2.2 h to heat a given volume of water to a certain temperature. How long would a 240-V unit operating with the same current take to accomplish the same task?

$$E = IVt = I(2V)\left(\frac{t}{2}\right)$$

For a given amount of energy, doubling the voltage will divide the time by 2.

$$t = \frac{2.2\text{ h}}{2} = 1.1\text{ h}$$

page 605

28. An electric space heater draws 15.0 A from a 120-V source. It is operated, on the average, for 5.0 h each day.

a. How much power does the heater use?

$$P = IV = (15.0\text{ A})(120\text{ V})$$

$$= 1800\text{ W} = 1.8\text{ kW}$$

b. How much energy in kWh does it consume in 30 days?

$$E = Pt = (1.8\text{ kW})(5.0\text{ h/day})(30\text{ days})$$

$$= 270\text{ kWh}$$

c. At \$0.12 per kWh, how much does it cost to operate the heater for 30 days?

Cost = (\$0.12/kWh)(270 kWh)

= \$32.40

29. A digital clock has a resistance of 12,000 Ω and is plugged into a 115-V outlet.

a. How much current does it draw?

$$I = \frac{V}{R} = \frac{115\text{ V}}{12{,}000\ \Omega} = 9.6\times10^{-3}\text{ A}$$

b. How much power does it use?

$$P = VI = (115\text{ V})(9.6\times10^{-3}\text{ A}) = 1.1\text{ W}$$

c. If the owner of the clock pays \$0.12 per kWh, how much does it cost to operate the clock for 30 days?

$$\text{Cost} = (1.1\times10^{-3}\text{ kWh})(\$0.12\text{/kWh})(30\text{ days})(24\text{ h/day})$$

$$= \$0.10$$

30. An automotive battery can deliver 55 A at 12 V for 1.0 h and requires 1.3 times as much energy for recharge due to its less-than-perfect efficiency. How long will it take to charge the battery using a current of 7.5 A? Assume that the charging voltage is the same as the discharging voltage.

$$E_{\text{charge}} = (1.3)IVt$$
$$= (1.3)(55\text{ A})(12\text{ V})(1.0\text{ h})$$
$$= 858\text{ Wh}$$
$$t = \frac{E}{IV} = \frac{858\text{ Wh}}{(7.5\text{ A})(12\text{ V})} = 9.5\text{ h}$$

31. Rework the previous problem by assuming that the battery requires the application of 14 V when it is recharging.

$$E_{\text{charge}} = (1.3)IVt$$
$$= (1.3)(55\text{ A})(12\text{ V})(1.0\text{ h})$$
$$= 858\text{ Wh}$$
$$t = \frac{E}{IV} = \frac{858\text{ Wh}}{(7.5\text{ A})(14\text{ V})} = 8.2\text{ h}$$

Section Review

22.2 Using Electric Energy pages 601–605

page 605

32. Energy A car engine drives a generator, which produces and stores electric charge in the car's battery. The headlamps use the electric charge stored in the car battery. List the forms of energy in these three operations.

Mechanical energy from the engine converted to electric energy in the generator; electric energy stored as chemical energy in the battery; chemical energy converted to electric energy in the battery and distributed to the headlamps; electric energy converted to light and thermal energy in headlamps.

33. Resistance A hair dryer operating from 120 V has two settings, hot and warm. In which setting is the resistance likely to be smaller? Why?

Hot draws more power, $P = IV$, so the fixed voltage current is larger. Because $I = V/R$ the resistance is smaller.

34. Power Determine the power change in a circuit if the applied voltage is decreased by one-half.

$$\frac{P_1}{P_2} = \frac{V_2^{\,2}/R}{V_1^{\,2}/R} = \frac{(0.5V_1)^2/R}{V_1^{\,2}} = 0.25$$

35. Efficiency Evaluate the impact of research to improve power transmission lines on society and the environment.

Research to improve power transmission lines would benefit society in cost of electricity. Also, if less power was lost during transmission, less coal and other power-producing resources would have to be used, which would improve the quality of our environment.

36. Voltage Why would an electric range and an electric hot-water heater be connected to a 240-V circuit rather than a 120-V circuit?

For the same power, at twice the voltage, the current would be halved. The I^2R loss in the circuit wiring would be dramatically reduced because it is proportional to the square of the current.

37. Critical Thinking When demand for electric power is high, power companies sometimes reduce the voltage, thereby producing a "brown-out." What is being saved?

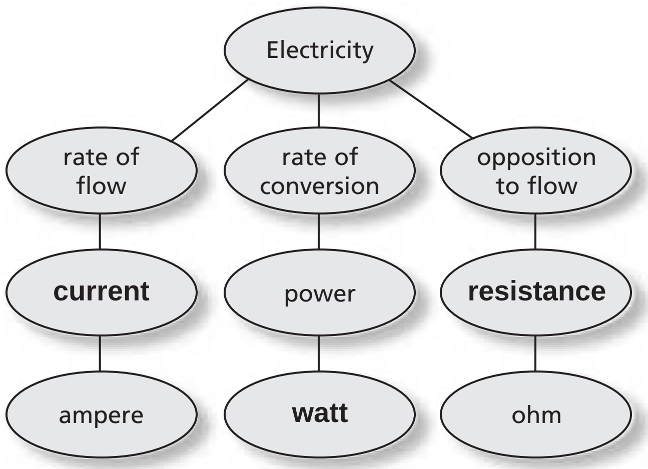
Power, not energy; most devices will have to run longer.

Chapter Assessment

Concept Mapping

page 610

38. Complete the concept map using the following terms: *watt, current, resistance.*



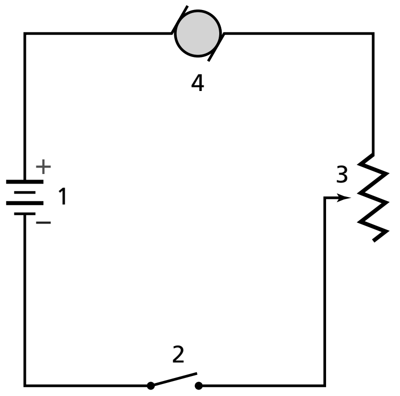
Mastering Concepts

page 610

39. Define the unit of electric current in terms of fundamental MKS units. (22.1)

1 A = 1 C/1 s

40. How should a voltmeter be connected in **Figure 22-12** to measure the motor's voltage? (22.1)



■ **Figure 22-12**

The positive voltmeter lead connects to the left-hand motor lead, and the negative voltmeter lead connects to the right-hand motor lead.

41. How should an ammeter be connected in Figure 22-12 to measure the motor's current? (22.1)

Break the circuit between the battery and the motor. Then connect the positive ammeter lead to the positive side of the break (the side connected to the positive battery terminal) and the negative ammeter lead to the negative side nearest the motor.

42. What is the direction of the conventional motor current in Figure 22-12? (22.1)

from left to right through the motor

43. Refer to Figure 22-12 to answer the following questions. (22.1)

a. Which device converts electric energy to mechanical energy?

4

b. Which device converts chemical energy to electric energy?

1

c. Which device turns the circuit on and off?

2

d. Which device provides a way to adjust speed?

3

44. Describe the energy conversions that occur in each of the following devices. (22.1)

a. an incandescent lightbulb

electric energy to heat and light

b. a clothes dryer

electric energy to heat and kinetic energy

c. a digital clock radio

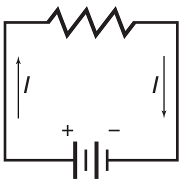
electric energy to light and sound

45. Which wire conducts electricity with the least resistance: one with a large cross-sectional diameter or one with a small cross-sectional diameter? (22.1)

A larger-diameter wire has a smaller resistance because there are more electrons to carry the charge.

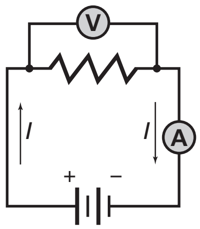
46. A simple circuit consists of a resistor, a battery, and connecting wires. (22.1)

a. Draw a circuit schematic of this simple circuit.



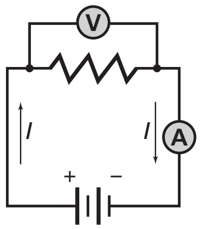
b. How must an ammeter be connected in a circuit for the current to be correctly read?

The ammeter must be connected in series.



c. How must a voltmeter be connected to a resistor for the potential difference across it to be read?

The voltmeter must be connected in parallel.



47. Why do lightbulbs burn out more frequently just as they are switched on rather than while they are operating? (22.2)

The low resistance of the cold filament allows a high current initially and a greater change in temperature, subjecting the filament to greater stress.

48. If a battery is short-circuited by a heavy copper wire being connected from one terminal to the other, the temperature of the copper wire rises. Why does this happen? (22.2)

The short circuit produces a high current, which causes more electrons to collide with the atoms of the wire. This raises the atoms' kinetic energies and the temperature of the wire.

49. What electric quantities must be kept small to transmit electric energy economically over long distances? (22.2)

the resistance of the wire and the current in the wire

50. Define the unit of power in terms of fundamental MKS units. (22.2)

$$\mathbf{W} = \frac{\mathbf{C}}{\mathbf{s}} \cdot \frac{\mathbf{J}}{\mathbf{C}} = \frac{\mathbf{J}}{\mathbf{s}} = \frac{\mathbf{kg} \cdot \frac{\mathbf{m}^2}{\mathbf{s}^2}}{\mathbf{s}} = \frac{\mathbf{kg} \cdot \mathbf{m}^2}{\mathbf{s}^3}$$

Applying Concepts

pages 610–611

51. Batteries When a battery is connected to a complete circuit, charges flow in the circuit almost instantaneously. Explain.

A potential difference is felt over the entire circuit as soon as the battery is connected to the circuit. The potential difference causes the charges to begin to flow. Note: The charges flow slowly compared to the change in potential difference.

52. Explain why a cow experiences a mild shock when it touches an electric fence.

By touching the fence and the ground, the cow encounters a difference in potential and conducts current, thus receiving a shock.

53. Power Lines Why can birds perch on high-voltage lines without being injured?

No potential difference exists along the wires, so there is no current through the birds' bodies.

54. Describe two ways to increase the current in a circuit.

Either increase the voltage or decrease the resistance.

55. Lightbulbs Two lightbulbs work on a 120-V circuit. One is 50 W and the other is 100 W. Which bulb has a higher resistance? Explain.

50-W bulb

$$P = \frac{V^2}{R}, \text{ so } R = \frac{V^2}{P}$$

Therefore, the lower *P* is caused by a higher *R*.

56. If the voltage across a circuit is kept constant and the resistance is doubled, what effect does this have on the circuit's current?

If the resistance is doubled, the current is halved.

57. What is the effect on the current in a circuit if both the voltage and the resistance are doubled? Explain.

No effect. $V = IR$, so $I = V/R$, and if the voltage and the resistance both are doubled, the current will not change.

58. **Ohm's Law** Sue finds a device that looks like a resistor. When she connects it to a 1.5-V battery, she measures only 45×10^{-6} A, but when she uses a 3.0-V battery, she measures 25×10^{-3} A. Does the device obey Ohm's law?

No. $V = IR$, so $R = V/I$. At 1.5 V,

$$R = \frac{1.5\text{ V}}{45\times10^{-6}} = 3.3\times10^{4}\ \Omega$$

At 3.0 V, $R = \frac{3.0\text{ V}}{25\times10^{-3}\text{ A}} = 120\ \Omega$

A device that obeys Ohm's law has a resistance that is independent of the applied voltage.

59. If the ammeter in Figure 22-4a on page 596 were moved to the bottom of the diagram, would the ammeter have the same reading? Explain.

Yes, because the current is the same everywhere in this circuit.

60. Two wires can be placed across the terminals of a 6.0-V battery. One has a high resistance, and the other has a low resistance. Which wire will produce thermal energy at a faster rate? Why?

the wire with the smaller resistance

$$P = \frac{V^2}{R}$$

Smaller R produces larger power P dissipated in the wire, which produces thermal energy at a faster rate.

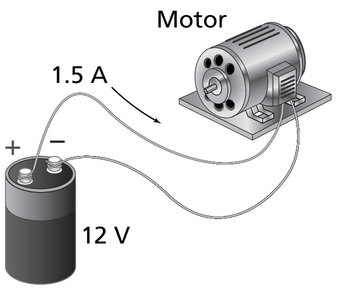
Mastering Problems

22.1 Current and Circuits

pages 611–612

Level 1

61. A motor is connected to a 12-V battery, as shown in **Figure 22-13.**



■ **Figure 22-13**

a. How much power is delivered to the motor?

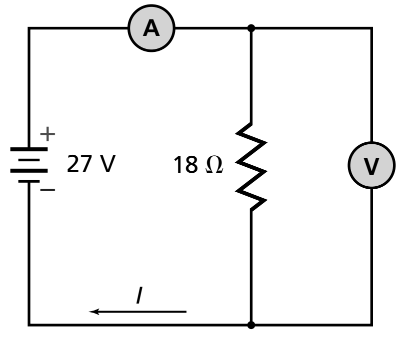
$P = VI = (12\text{ V})(1.5\text{ A}) = 18\text{ W}$

b. How much energy is converted if the motor runs for 15 min?

$E = Pt = (18\text{ W})(15\text{ min})(60\text{ s/min})$

$= 1.6\times10^{4}\text{ J}$

62. Refer to **Figure 22-14** to answer the following questions.



■ **Figure 22-14**

a. What should the ammeter reading be?

$I = V/R = \frac{27\text{ V}}{18\ \Omega} = 1.5\text{ A}$

b. What should the voltmeter reading be?

27 V

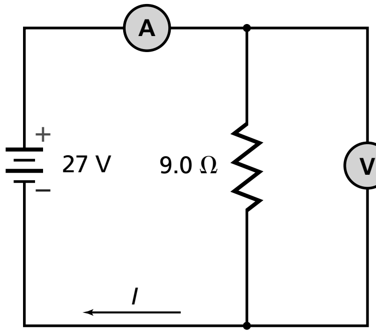
c. How much power is delivered to the resistor?

$P = VI = (27\text{ V})(1.5\text{ A}) = 41\text{ W}$

d. How much energy is delivered to the resistor per hour?

$E = Pt = (41\text{ W})(3600\text{ s}) = 1.5\times10^{5}\text{ J}$

63. Refer to **Figure 22-15** to answer the following questions.



■ **Figure 22-15**

a. What should the ammeter reading be?

$$I = V/R = \frac{27\text{ V}}{9.0\ \Omega} = 3.0\text{ A}$$

b. What should the voltmeter reading be?

27 V

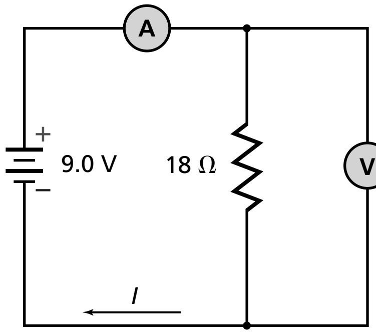
c. How much power is delivered to the resistor?

$P = VI = (27\text{ V})(3.0\text{ A}) = 81\text{ W}$

d. How much energy is delivered to the resistor per hour?

$E = Pt = (81\text{ W})(3600\text{ s}) = 2.9\times10^{5}\text{ J}$

64. Refer to **Figure 22-16** to answer the following questions.



■ **Figure 22-16**

a. What should the ammeter reading be?

$$I = V/R = \frac{9.0\text{ V}}{18\ \Omega} = 0.50\text{ A}$$

b. What should the voltmeter reading be?

9.0 V

c. How much power is delivered to the resistor?

$P = VI = (9.0\text{ V})(0.50\text{ A}) = 4.5\text{ W}$

d. How much energy is delivered to the resistor per hour?

$E = Pt = (4.5\text{ W})(3600\text{ s}) = 1.6\times10^{4}\text{ J}$

65. Toasters The current through a toaster that is connected to a 120-V source is 8.0 A. What power is dissipated by the toaster?

$P = IV = (8.0\text{ A})(120\text{ V}) = 9.6\times10^{2}\text{ W}$

66. Lightbulbs A current of 1.2 A is measured through a lightbulb when it is connected across a 120-V source. What power is dissipated by the bulb?

$P = IV = (1.2\text{ A})(120\text{ V}) = 1.4\times10^{2}\text{ W}$

67. A lamp draws 0.50 A from a 120-V generator.

a. How much power is delivered?

$P = IV = (0.50\text{ A})(120\text{ V}) = 6.0\times10^{1}\text{ W}$

b. How much energy is converted in 5.0 min?

The definition of power is $P = \frac{E}{t}$**, so**

$$E = Pt$$
$$= (6.0\times10^{1}\text{ W})\left(\frac{5.0\text{ min}}{1}\right)\left(\frac{60\text{ s}}{\text{min}}\right)$$
$$= 18{,}000\text{ J} = 1.8\times10^{4}\text{ J}$$

68. A 12-V automobile battery is connected to an electric starter motor. The current through the motor is 210 A.

a. How many joules of energy does the battery deliver to the motor each second?

$P = IV = (210\text{ A})(12\text{ V}) = 2500\text{ J/s}$ **or** $2.5\times10^{3}\text{ J/s}$

b. What power, in watts, does the motor use?

$P = 2.5\times10^{3}\text{ W}$

69. Dryers A 4200-W clothes dryer is connected to a 220-V circuit. How much current does the dryer draw?

$$P = IV$$
$$I = \frac{P}{V} = \frac{4200\text{ W}}{220\text{ V}} = 19\text{ A}$$

70. Flashlights A flashlight bulb is connected across a 3.0-V potential difference. The current through the bulb is 1.5 A.

a. What is the power rating of the bulb?

$P = IV = (1.5\ \text{A})(3.0\ \text{V}) = 4.5\ \text{W}$

b. How much electric energy does the bulb convert in 11 min?

The definition of power is $P = \frac{E}{t}$**, so**

$E = Pt$

$= (4.5\ \text{W})(11\ \text{min})\left(\frac{60\ \text{s}}{\text{min}}\right)$

$= 3.0\times10^3\ \text{J}$

71. Batteries A resistor of 60.0 Ω has a current of 0.40 A through it when it is connected to the terminals of a battery. What is the voltage of the battery?

$V = IR = (0.40\ \text{A})(60.0\ \Omega) = 24\ \text{V}$

72. What voltage is applied to a 4.0-Ω resistor if the current is 1.5 A?

$V = IR = (1.5\ \text{A})(4.0\ \Omega) = 6.0\ \text{V}$

73. What voltage is placed across a motor with a 15-Ω operating resistance if there is 8.0 A of current?

$V = IR = (8.0\ \text{A})(15\ \Omega) = 1.2\times10^2\ \text{V}$

74. A voltage of 75 V is placed across a 15-Ω resistor. What is the current through the resistor?

$V = IR$

$I = \frac{V}{R} = \frac{75\ \text{V}}{15\ \Omega} = 5.0\ \text{A}$

Level 2

75. Some students connected a length of nichrome wire to a variable power supply to produce between 0.00 V and 10.00 V across the wire. They then measured the current through the wire for several voltages. The students recorded the data for the voltages used and the currents measured, as shown in **Table 22-2.**

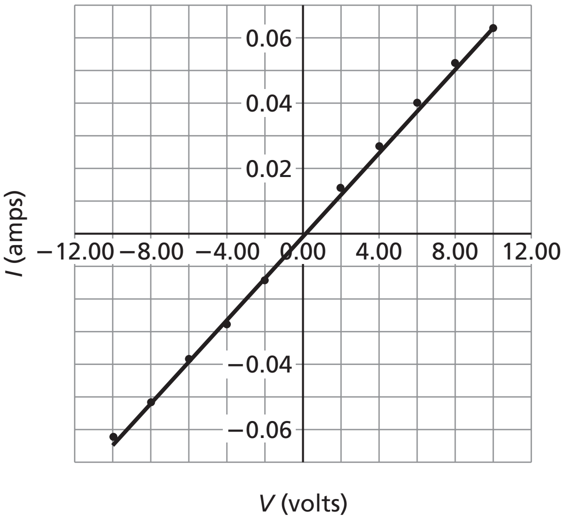
Table 22-2

Voltage, V (volts)	Current, I (amps)	Resistance, $R = V/I$ (amps)
2.00	0.0140	________
4.00	0.0270	________
6.00	0.0400	________
8.00	0.0520	________
10.00	0.0630	________
−2.00	−0.0140	________
−4.00	−0.0280	________
−6.00	−0.0390	________
−8.00	−0.0510	________
−10.00	−0.0620	________

a. For each measurement, calculate the resistance.

$R = 143\ \Omega$, $R = 148\ \Omega$, $R = 150\ \Omega$, $R = 154\ \Omega$, $R = 159\ \Omega$, $R = 143\ \Omega$, $R = 143\ \Omega$, $R = 154\ \Omega$, $R = 157\ \Omega$, $R = 161\ \Omega$

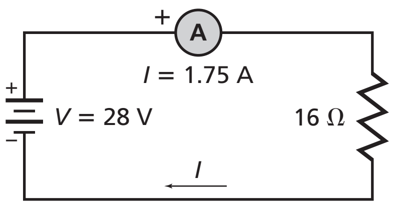
b. Graph I versus V.



c. Does the nichrome wire obey Ohm's law? If not, for all the voltages, specify the voltage range for which Ohm's law holds.

Ohm's law is obeyed when the resistance of a device is constant and independent of the potential difference. The resistance of the nichrome wire increases somewhat as the magnitude of the voltage increases, so the wire does not quite obey Ohm's law.

76. Draw a series circuit diagram to include a 16-Ω resistor, a battery, and an ammeter that reads 1.75 A. Indicate the positive terminal and the voltage of the battery, the positive terminal of the ammeter, and the direction of conventional current.



$$V = IR = (1.75\ \text{A})(16\ \Omega) = 28\ \text{V}$$

77. A lamp draws a 66-mA current when connected to a 6.0-V battery. When a 9.0-V battery is used, the lamp draws 75 mA.

a. Does the lamp obey Ohm's law?

No. The voltage is increased by a factor of $\frac{9.0}{6.0} = 1.5$, but the current is increased by a factor of $\frac{75}{66} = 1.1$

b. How much power does the lamp dissipate when it is connected to the 6.0-V battery?

$$P = IV = (66\times10^{-3}\ \text{A})(6.0\ \text{V}) = 0.40\ \text{W}$$

c. How much power does it dissipate at 9.0 V?

$$P = IV = (75\times10^{-3}\ \text{A})(9.0\ \text{V}) = 0.68\ \text{W}$$

78. **Lightbulbs** How much energy does a 60.0-W lightbulb use in half an hour? If the lightbulb converts 12 percent of electric energy to light energy, how much thermal energy does it generate during the half hour?

$$P = \frac{E}{t}$$

$$E = Pt = (60.0\ \text{W})(1800\ \text{s}) = 1.08\times10^{5}\ \text{J}$$

If the bulb is 12 percent efficient, 88 percent of the energy is lost to heat, so

$$Q = (0.88)(1.08\times10^{5}\ \text{J}) = 9.5\times10^{4}\ \text{J}$$

79. The current through a lamp connected across 120 V is 0.40 A when the lamp is on.

a. What is the lamp's resistance when it is on?

$$V = IR$$

$$R = \frac{V}{I} = \frac{120\ \text{V}}{0.40\ \text{A}} = 3.0\times10^{2}\ \Omega$$

b. When the lamp is cold, its resistance is $\frac{1}{5}$ as great as it is when the lamp is hot. What is the lamp's cold resistance?

$$\left(\frac{1}{5}\right)(3.0\times10^{2}\ \Omega) = 6.0\times10^{1}\ \Omega$$

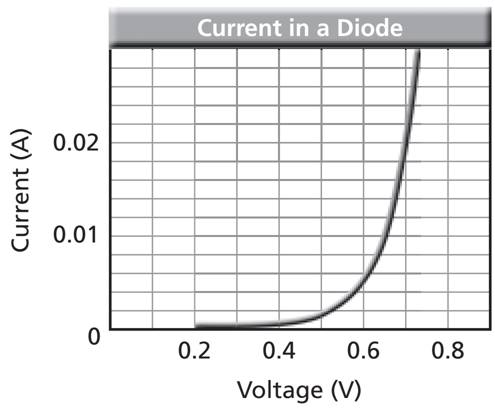
c. What is the current through the lamp as it is turned on if it is connected to a potential difference of 120 V?

$$V = IR$$

$$I = \frac{V}{R} = \frac{120\ \text{V}}{6.0\times10^{1}\ \Omega} = 2.0\ \text{A}$$

Level 3

80. The graph in **Figure 22-17** shows the current through a device called a silicon diode.



■ **Figure 22-17**

a. A potential difference of +0.70 V is placed across the diode. What is the resistance of the diode?

From the graph, I = 22 m/A, and $V = IR$, so

$$R = \frac{V}{I} = \frac{0.70\ \text{V}}{2.2\times10^{-2}\ \text{A}} = 32\ \Omega$$

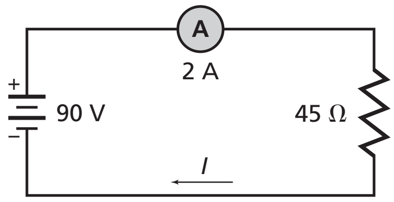
b. What is the diode's resistance when a +0.60-V potential difference is used?

$$R = \frac{V}{I} = \frac{0.60\ \text{V}}{5.2\times10^{-3}\ \text{A}} = 1.2\times10^{2}\ \Omega$$

c. Does the diode obey Ohm's law?

No. Resistance depends on voltage.

81. Draw a schematic diagram to show a circuit including a 90-V battery, an ammeter, and a resistance of 45 Ω connected in series. What is the ammeter reading? Draw arrows showing the direction of conventional current.



$V = IR$

$I = \frac{V}{R} = \frac{90\ \text{V}}{45\ \Omega} = 2\ \text{A}$

22.2 Using Electric Energy
pages 612–613
Level 1

82. Batteries A 9.0-V battery costs \$3.00 and will deliver 0.0250 A for 26.0 h before it must be replaced. Calculate the cost per kWh.

$E = IVt = (0.0250\ \text{A})(9.0\ \text{V})(26.0\ \text{h})$
$= 5.9\ \text{Wh} = 5.9\times10^{-3}\ \text{kWh}$

$\text{Rate} = \frac{\text{cost}}{E} = \frac{\$3.00}{5.9\times10^{-3}\ \text{kWh}}$
$= \$510/\text{kWh}$

83. What is the maximum current allowed in a 5.0-W, 220-Ω resistor?

$P = I^2R$

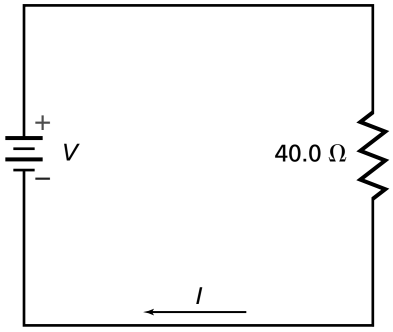
$I = \sqrt{\frac{P}{R}} = \sqrt{\frac{5.0\ \text{W}}{220\ \Omega}} = 0.15\ \text{A}$

84. A 110-V electric iron draws 3.0 A of current. How much thermal energy is developed in an hour?

$Q = E = VIt = (110\ \text{V})(3.0\ \text{A})(1.0\ \text{h})(3600\ \text{s/h})$
$= 1.2\times10^6\ \text{J}$

Level 2

85. For the circuit shown in **Figure 22-18,** the maximum safe power is 5.0×10^1 W. Use the figure to find the following:



■ **Figure 22-18**

a. the maximum safe current

$P = I^2R$

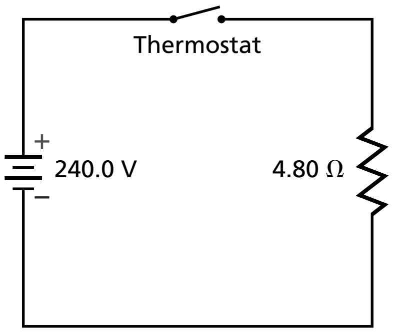
$I = \sqrt{\frac{P}{R}} = \sqrt{\frac{5.0\times10^1\ \text{W}}{40.0\ \Omega}} = 1\ \text{A}$

b. the maximum safe voltage

$P = V^2/R$

$V = \sqrt{PR} = \sqrt{(5.0\times10^1\ \text{W})(40.0\ \Omega)}$
$= 45\ \text{V}$

86. Utilities Figure 22-19 represents an electric furnace. Calculate the monthly (30-day) heating bill if electricity costs \$0.10 per kWh and the thermostat is on one-fourth of the time.



■ **Figure 22-19**

$E = \left(\frac{V^2}{R}\right)(t)$

$= \left(\frac{(240.0\ \text{V})^2}{4.80\ \Omega}\right)(30\ \text{d})(24\ \text{h/d})(0.25)$

$= 2160\ \text{kWh}$

$\text{Cost} = (2160\ \text{kWh})(\$0.100/\text{kWh}) = \$216$

87. Appliances A window air conditioner is estimated to have a cost of operation of \$50 per 30 days. This is based on the assumption that the air conditioner will run half of the time and that electricity costs \$0.090 per kWh. Determine how much current the air conditioner will take from a 120-V outlet.

$$\text{Cost} = (E)(\text{rate})$$

$$E = \frac{\text{Cost}}{\text{rate}} = \frac{\$50}{\$0.090/\text{kWh}}$$

$$= 556 \text{ kWh}$$

$$E = IVt$$

$$I = \frac{E}{Vt} = \frac{(556 \text{ kWh})(1000 \text{ W/kW})}{(120 \text{ V})(30 \text{ d})(24 \text{ h/d})(0.5)}$$

$$= 12.9 \text{ A}$$

88. **Radios** A transistor radio operates by means of a 9.0-V battery that supplies it with a 50.0-mA current.

a. If the cost of the battery is \$2.49 and it lasts for 300.0 h, what is the cost per kWh to operate the radio in this manner?

$$P = IV = (0.050 \text{ A})(9.0 \text{ V}) = 0.45 \text{ W}$$
$$= 4.5\times10^{-4} \text{ kW}$$

$$\text{Cost} = \frac{\$2.49}{(4.5\times10^{-4} \text{ kW})(300.0 \text{ h})}$$

$$= \$18.00/\text{kWh}$$

b. The same radio, by means of a converter, is plugged into a household circuit by a homeowner who pays \$0.12 per kWh. What does it now cost to operate the radio for 300.0 h?

$$\text{Cost} = (\$0.12/\text{kWh})(4.5\times10^{-4} \text{ kW})(300 \text{ h})$$

$$= \$0.02$$

Mixed Review

page 613

Level 1

89. If a person has \$5, how long could he or she play a 200 W stereo if electricity costs \$0.15 per kWh?

$$E = Pt = \frac{\text{Cost}}{\text{Rate}}$$

$$t = \frac{\text{Cost}}{(\text{Rate})(P)}$$

$$= \frac{\$5}{(\$0.15/\text{kWh})(200 \text{ W})\left(\frac{1 \text{ kW}}{1000 \text{ W}}\right)}$$

$$= 200 \text{ h}$$

90. A current of 1.2 A is measured through a 50.0-Ω resistor for 5.0 min. How much heat is generated by the resistor?

$$Q = E = I^2Rt$$

$$= (1.2 \text{ A})^2(50.0\ \Omega)(5.0 \text{ min})\left(\frac{60 \text{ s}}{\text{min}}\right)$$

$$= 2.2\times10^4 \text{ J}$$

91. A 6.0-Ω resistor is connected to a 15-V battery.

a. What is the current in the circuit?

$$V = IR$$

$$I = \frac{V}{R} = \frac{15 \text{ V}}{6.0\ \Omega} = 2.5 \text{ A}$$

b. How much thermal energy is produced in 10.0 min?

$$Q = E = I^2Rt$$

$$= (2.5 \text{ A})^2(6.0\ \Omega)(10.0 \text{ min})\left(\frac{60 \text{ s}}{\text{min}}\right)$$

$$= 2.3\times10^4 \text{ J}$$

Level 2

92. **Lightbulbs** An incandescent lightbulb with a resistance of 10.0 Ω when it is not lit and a resistance of 40.0 Ω when it is lit has 120 V placed across it.

a. What is the current draw when the bulb is lit?

$$I = \frac{V}{R} = \frac{120 \text{ V}}{40.0\ \Omega} = 3.0 \text{ A}$$

b. What is the current draw at the instant the bulb is turned on?

$$I = \frac{V}{R} = \frac{120 \text{ V}}{10.0\ \Omega} = 12 \text{ A}$$

c. When does the lightbulb use the most power?

the instant it is turned on

93. A 12-V electric motor's speed is controlled by a potentiometer. At the motor's slowest setting, it uses 0.02 A. At its highest setting, the motor uses 1.2 A. What is the range of the potentiometer?

The slowest speed's resistance is $R = V/I = 12 \text{ V}/0.02 \text{ A} = 600\ \Omega$. The fastest speed's resistance is $R = V/I = 12 \text{ V}/1.2 \text{ A} = 1.0\times10^1\ \Omega$. The range is $1.0\times10^1\ \Omega$ to $600\ \Omega$.

Level 3

94. An electric motor operates a pump that irrigates a farmer's crop by pumping 1.0×10^4 L of water a vertical distance of 8.0 m into a field each hour. The motor has an operating resistance of 22.0 Ω and is connected across a 110-V source.

a. What current does the motor draw?

$$V = IR$$

$$I = \frac{V}{R} = \frac{110\ \text{V}}{22.0\ \Omega} = 5.0\ \text{A}$$

b. How efficient is the motor?

$$E_W = mgd$$

$$= (1\times10^4\ \text{kg})(9.80\ \text{m/s}^2)(8.0\ \text{m})$$

$$= 8\times10^5\ \text{J}$$

$$E_m = IVt = (5.0\ \text{A})(110\ \text{V})(3600\ \text{s})$$

$$= 2.0\times10^6\ \text{J}$$

$$\text{Efficiency} = \frac{E_w}{E_m}\times 100$$

$$= \frac{8\times10^5\ \text{J}}{2.0\times10^6\ \text{J}}\times 100$$

$$= 40\%$$

95. A heating coil has a resistance of 4.0 Ω and operates on 120 V.

a. What is the current in the coil while it is operating?

$$V = IR$$

$$I = \frac{V}{R} = \frac{120\ \text{V}}{4.0\ \Omega} = 3.0\times10^1\ \text{A}$$

b. What energy is supplied to the coil in 5.0 min?

$$E = I^2Rt$$

$$= (3.0\times10^1\ \text{A})^2(4.0\ \Omega)(5.0\ \text{min})\left(\frac{60\ \text{s}}{\text{min}}\right)$$

$$= 1.1\times10^6\ \text{J}$$

c. If the coil is immersed in an insulated container holding 20.0 kg of water, what will be the increase in the temperature of the water? Assume 100 percent of the heat is absorbed by the water.

$$Q = mC\Delta T$$

$$\Delta T = \frac{Q}{mC}$$

$$= \frac{1.1\times10^6\ \text{J}}{(20.0\ \text{kg})(4180\ \text{J/kg·C°})}$$

$$= 13°\text{C}$$

d. At $0.08 per kWh, how much does it cost to operate the heating coil 30 min per day for 30 days?

$$\text{Cost} = \left(\frac{1.1\times10^6\ \text{J}}{5\ \text{min}}\right)\left(\frac{30\ \text{min}}{\text{day}}\right)(30\ \text{days})\left(\frac{1\ \text{kWh}}{3.6\times10^6\ \text{J}}\right)\left(\frac{\$0.08}{\text{kWh}}\right)$$

$$= \$4.40$$

96. Appliances An electric heater is rated at 500 W.

a. How much energy is delivered to the heater in half an hour?

$$E = Pt = (5\times10^2\ \text{W})(1800\ \text{s})$$

$$= 9\times10^5\ \text{J}$$

b. The heater is being used to heat a room containing 50 kg of air. If the specific heat of air is 1.10 kJ/kg·°C, and 50 percent of the thermal energy heats the air in the room, what is the change in air temperature in half an hour?

$$Q = mC\Delta T$$

$$\Delta T = \frac{Q}{mC}$$

$$= \frac{(0.5)(9\times10^5\ \text{J})}{(50.0\ \text{kg})(1100\ \text{J/kg·C°})}$$

$$= 8°\text{C}$$

c. At $0.08 per kWh, how much does it cost to run the heater 6.0 h per day for 30 days?

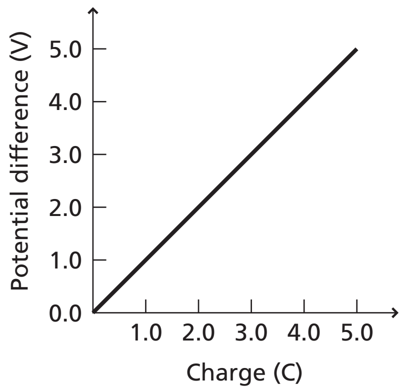
$$\text{Cost} = \left(\frac{500\ \text{J}}{\text{s}}\right)\left(\frac{6.0\ \text{h}}{\text{day}}\right)\left(\frac{3600\ \text{s}}{\text{h}}\right)(30\ \text{days})\left(\frac{1\text{kWH}}{3.6\times10^6\ \text{J}}\right)\left(\frac{\$0.08}{\text{kWh}}\right)$$

$$= \$7$$

Thinking Critically

page 614

97. Formulate Models How much energy is stored in a capacitor? The energy needed to increase the potential difference of a charge, *q*, is represented by $E = qV$. But in a capacitor, $V = q/C$. Thus, as charge is added, the potential difference increases. As more charge is added, however, it takes more energy to add the additional charge. Consider a 1.0-F "supercap" used as an energy storage device in a personal computer. Plot a graph of V as the capacitor is charged by adding 5.0 C to it. What is the voltage across the capacitor? The area under the curve is the energy stored in the capacitor. Find the energy in joules. Is it equal to the total charge times the final potential difference? Explain.



Voltage $V = \frac{q}{C} = \frac{5.0\ \text{C}}{1.0\ \text{F}} = 5.0\ \text{V}$

Energy E **= area under curve**

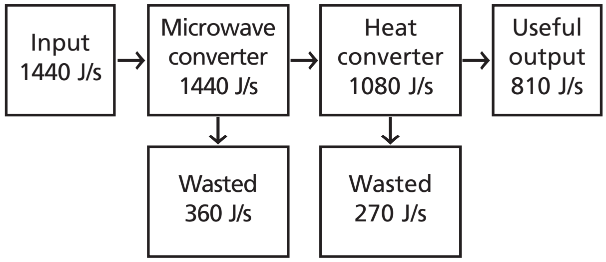
$$= \frac{1}{2}(5.0\ \text{V})(5.0\ \text{C})$$

$$= 13\ \text{J}$$

No. Graphically, total change times final potential difference is exactly twice the area under the curve. Physically, it means that each coulomb would require the same maximum amount of energy to place it on the capacitor. Actually, the amount of energy needed to add each charge increases as charge accumulates on the capacitor.

98. **Apply Concepts** A microwave oven operates at 120 V and requires 12 A of current. Its electric efficiency (converting AC to microwave radiation) is 75 percent, and its conversion efficiency from microwave radiation to heating water is also 75 percent.

a. Draw a block power diagram similar to the energy diagram shown in Figure 22-2b on page 593. Label the function of each block according to total joules per second.



b. Derive an equation for the rate of temperature increase ($\Delta T/s$) from the information presented in Chapter 12. Solve for the rate of temperature rise given the rate of energy input, the mass, and the specific heat of a substance.

$$\frac{\Delta T}{\Delta t} = \frac{1}{mC}\left(\frac{\Delta Q}{\Delta t}\right)$$

c. Use your equation to solve for the rate of temperature rise in degrees Celsius per second when using this oven to heat 250 g of water above room temperature.

$$\frac{\Delta T}{\Delta t} = \frac{1}{mC}\left(\frac{\Delta Q}{\Delta t}\right)$$

$$= \frac{810\ \text{J/s}}{(0.25\ \text{kg})(4180\ \text{J/kg}\cdot{}^\circ\text{C})}$$

$$= 0.78^\circ\text{C/s}$$

d. Review your calculations carefully for the units used and discuss why your answer is in the correct form.

The kg unit cancels and the J unit cancels, leaving °C/s.

e. Discuss, in general terms, different ways in which you could increase the efficiency of microwave heating.

The efficiency of conversion from electric energy to microwave energy is 75 percent. It might be possible to find a way to convert electric energy to radiation using a different approach that would be more efficient. The efficiency of conversion from microwave radiation to thermal energy in water is 75 percent. It might be possible to use a different frequency of electromagnetic radiation to improve this rating. Or, it might be possible to find a new

geometry of radiating objects to be heated to improve the efficiency.

f. Discuss, in efficiency terms, why microwave ovens are not useful for heating everything.

The conversion efficiency from microwave energy to thermal energy is good for water. It's not as good for other materials. The containers and dishes designed for use with microwave ovens convert little of the energy.

g. Discuss, in general terms, why it is not a good idea to run microwave ovens when they are empty.

The empty oven means that the microwave energy has to be dissipated in the oven. This can lead to overheating of the oven components and to their failure.

99. Analyze and Conclude A salesclerk in an appliance store states that microwave ovens are the most electrically efficient means of heating objects.

a. Formulate an argument to refute the clerk's claim. *Hint: Think about heating a specific object.*

In the case of heating a cup of water, an immersion heater uses only resistance for energy conversion and is nearly 100 percent efficient. A microwave oven uses two energy conversions (electricity to microwave radiation to heat) and is typically around 50 percent efficient.

b. Formulate an argument to support the clerk's claim. *Hint: Think about heating a specific object.*

In the case of heating a potato, a microwave oven heats mostly the potato and is more efficient than an electric oven or skillet, which also heats the air, cabinets, racks, etc.

c. Formulate a diplomatic reply to the clerk.

"It can be true, but it depends on the specific application."

100. Apply Concepts The sizes of 10-Ω resistors range from a pinhead to a soup can. Explain.

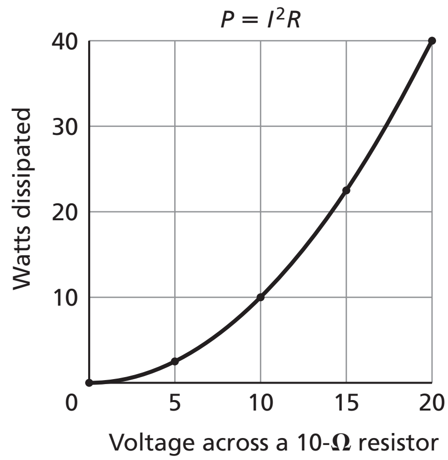
The physical size of a resistor is determined by its power rating. Resistors rated at 100 W are much larger than those rated at 1 W.

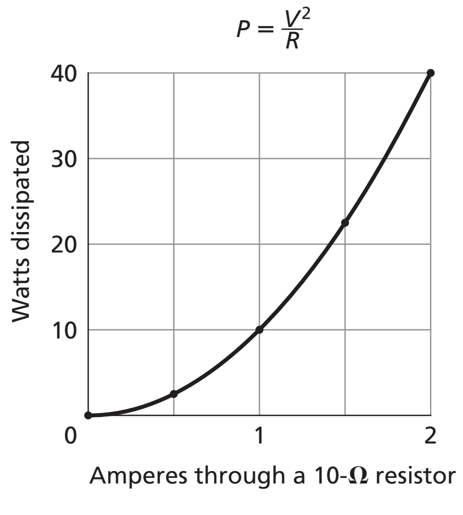
101. Make and Use Graphs The diode graph shown in Figure 22-17 on page 612 is more useful than a similar graph for a resistor that obeys Ohm's law. Explain.

The volt–ampere graph for a resistor obeying Ohm's law is a straight line and is seldom necessary.

102. Make and Use Graphs Based on what you have learned in this chapter, identify and prepare two parabolic graphs.

voltage–power and current–power





Writing in Physics

page 614

103. There are three kinds of equations encountered in science: (1) definitions, (2) laws, and (3) derivations. Examples of these are: (1) an ampere is equal to one coulomb per second, (2) force is equal to mass times acceleration, (3) power is equal to voltage squared divided by resistance. Write a one-page explanation of where "resistance is equal to voltage divided by current" fits. Before you begin to write, first research the three categories given above.

The student's answer should include the idea (1) that, for devices obeying Ohm's law, the voltage drop is proportional to current through the device and (2) that the formula $R = V/I$, the definition of resistance, is a derivation from Ohm's law.

104. In Chapter 13, you learned that matter expands when it is heated. Research the relationship between thermal expansion and high-voltage transmission lines.

Answers will vary, but students should determine that transmission lines can become hot enough to expand and sag when they have high currents. Sagging lines can be dangerous if they touch objects beneath them, such as trees or other power lines.

Cumulative Review

page 614

105. A person burns energy at the rate of about 8.4×10^6 J per day. How much does she increase the entropy of the universe in that day? How does this compare to the entropy increase caused by melting 20 kg of ice? (Chapter 12)

$\Delta S = Q/T$ **where** T **is the body temperature of 310 K.**

$$\Delta S = (8.4\times10^6\text{ J})/(310\text{ K})$$
$$= 2.7\times10^4\text{ J/K}$$

For melting ice

$$\Delta S = (20\text{ kg})(3.34\times10^5\text{ J/kg})/(273\text{ K})$$
$$= 2.4\times10^4\text{ J/K}$$

106. When you go up the elevator of a tall building, your ears might pop because of the rapid change in pressure. What is the pressure change caused by riding in an elevator up a 30-story building (150 m)? The density of air is about 1.3 kg/m^3 at sea level. (Chapter 13)

$$\Delta P = \rho g h$$
$$= (1.3\text{ kg/m}^3)(9.80\text{ m/s}^2)(150\text{ m})$$
$$= 1.9\text{ kPa or about 2/100 of the total air pressure}$$

107. What is the wavelength in air of a 17-kHz sound wave, which is at the upper end of the frequency range of human hearing? (Chapter 15)

$$v = \lambda f$$
$$\lambda = \frac{v}{f} = \frac{343\text{ m/s}}{17{,}000\text{ Hz}} = 0.020\text{ m} = 2.0\text{ cm}$$

108. Light of wavelength 478 nm falls on a double slit. First-order bright bands appear 3.00 mm from the central bright band. The screen is 0.91 m from the slits. How far apart are the slits? (Chapter 19)

$$\lambda = \frac{xd}{L}$$
$$d = \frac{\lambda L}{x}$$
$$= \frac{(478\times10^{-9}\text{ m})(0.91\text{ m})}{(3.00\times10^{-3}\text{ m})}$$
$$= 1.4\times10^{-4}\text{ m}$$

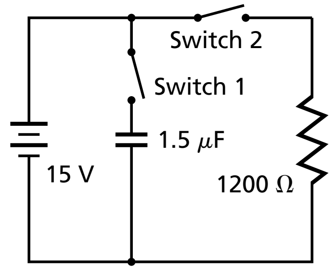
109. A charge of $+3.0\times10^{-6}$ C is 2.0 m from a second charge of $+6.0\times10^{-5}$ C. What is the magnitude of the force between them? (Chapter 20)

$$F = K\frac{q_A q_B}{d^2}$$
$$= (9.0\times10^9\text{ N·m}^2/\text{C}^2)\frac{(3.0\times10^{-6}\text{ C})(6.0\times10^{-5}\text{ C})}{(2.0\text{ m})^2}$$
$$= 0.41\text{ N}$$

Challenge Problem

page 604

Use the figure to the right to help you answer the questions below.



1. Initially, the capacitor is uncharged. Switch 1 is closed, and Switch 2 remains open. What is the voltage across the capacitor?

15 V

2. Switch 1 is now opened, and Switch 2 remains open. What is the voltage across the capacitor? Why?

It remains 15 V because there is no path for the charge to be removed.

3. Next, Switch 2 is closed, while Switch 1 remains open. What is the voltage across the capacitor and the current through the resistor immediately after Switch 2 is closed?

15 V and 13 mA

4. As time goes on, what happens to the voltage across the capacitor and the current through the resistor?

The capacitor voltage remains at 15 V because there is no path to discharge the capacitor; the current remains at 13 mA because the battery voltage is constant at 15 V. However, if the battery and capacitor were real components instead of ideal circuit components, the capacitor voltage eventually would become zero due to leakage, and the current eventually would become zero due to battery depletion.

CHAPTER

23 Series and Parallel Circuits

Practice Problems

23.1 Simple Circuits pages 617–626

page 619

1. Three 20-Ω resistors are connected in series across a 120-V generator. What is the equivalent resistance of the circuit? What is the current in the circuit?

$$R = R_1 + R_2 + R_3$$
$$= 20\ \Omega + 20\ \Omega + 20\ \Omega$$
$$= 60\ \Omega$$
$$I = \frac{V}{R} = \frac{120\ \text{V}}{60\ \Omega} = 2\ \text{A}$$

2. A 10-Ω, 15-Ω, and 5-Ω resistor are connected in a series circuit with a 90-V battery. What is the equivalent resistance of the circuit? What is the current in the circuit?

$$R = R_1 + R_2 + R_3$$
$$= 10\ \Omega + 15\ \Omega + 5\ \Omega = 30\ \Omega$$
$$I = \frac{V}{R} = \frac{90\ \text{V}}{30\ \Omega} = 3\ \text{A}$$

3. A 9-V battery is in a circuit with three resistors connected in series.

a. If the resistance of one of the resistors increases, how will the equivalent resistance change?

It will increase.

b. What will happen to the current?

$I = \frac{V}{R}$, **so it will decrease.**

c. Will there be any change in the battery voltage?

No. It does not depend on the resistance.

4. A string of holiday lights has ten bulbs with equal resistances connected in series. When the string of lights is connected to a 120-V outlet, the current through the bulbs is 0.06 A.

a. What is the equivalent resistance of the circuit?

$$R = \frac{V}{I} = \frac{120\ \text{V}}{0.06\ \text{A}} = 2\times10^3\ \Omega$$

b. What is the resistance of each bulb?

$$R_{\text{bulb}} = \frac{R}{10} = \frac{2\times10^3\ \Omega}{10} = 2\times10^2\ \Omega$$

5. Calculate the voltage drops across the three resistors in problem 2, and verify that their sum equals the voltage of the battery.

$$V_1 = IR_1 = (3\ \text{A})(10\ \Omega) = 30\ \text{V}$$
$$V_2 = IR_2 = (3\ \text{A})(15\ \Omega) = 45\ \text{V}$$
$$V_3 = IR_3 = (3\ \text{A})(5\ \Omega) = 15\ \text{V}$$
$$V_1 + V_2 + V_3 = 30\ \text{V} + 45\ \text{V} + 15\ \text{V}$$
$$= 90\ \text{V}$$
$$= \text{voltage of battery}$$

page 622

6. The circuit shown in Example Problem 1 is producing these symptoms: the ammeter reads 0 A, V_A reads 0 V, and V_B reads 45 V. What has happened?

R_B has failed. It has infinite resistance, and the battery voltage appears across it.

7. Suppose the circuit shown in Example Problem 1 has these values: $R_A = 255\ \Omega$, $R_B = 292\ \Omega$, and $V_A = 17.0$ V. No other information is available.

a. What is the current in the circuit?

$$I = \frac{V}{R} = \frac{17.0\ \text{V}}{255.0\ \Omega} = 66.7\ \text{mA}$$

b. What is the battery voltage?

First, find the total resistance, then solve for voltage.

$$R = R_A + R_B$$
$$= 255\ \Omega + 292\ \Omega$$
$$= 547\ \Omega$$
$$V = IR = (66.7\ \text{mA})(547\ \Omega) = 36.5\ \text{V}$$

c. What are the total power dissipation and the individual power dissipations?

$P = IV = (66.7\text{ mA})(36.5\text{ V}) = 2.43\text{ W}$

$P_A = I^2R_A$

$= (66.7\text{ mA})^2(255\ \Omega)$

$= 1.13\text{ W}$

$P_B = I^2R_B$

$= (66.7\text{ mA})^2(292\ \Omega)$

$= 1.30\text{ W}$

d. Does the sum of the individual power dissipations in the circuit equal the total power dissipation in the circuit? Explain.

Yes. The law of conservation of energy states that energy cannot be created or destroyed; therefore, the rate at which energy is converted, or power dissipated, will equal the sum of all parts.

8. Holiday lights often are connected in series and use special lamps that short out when the voltage across a lamp increases to the line voltage. Explain why. Also explain why these light sets might blow their fuses after many bulbs have failed.

If not for the shorting mechanism, the entire set would go out when one lamp burns out. After several lamps fail and then short, the total resistance of the remaining working lamps results in an increased current that is sufficient to blow the fuse.

9. The circuit in Example Problem 1 has unequal resistors. Explain why the resistor with the lower resistance will operate at a lower temperature.

The resistor with the lower resistance will dissipate less power, and thus will be cooler.

10. A series circuit is made up of a 12.0-V battery and three resistors. The voltage across one resistor is 1.21 V, and the voltage across another resistor is 3.33 V. What is the voltage across the third resistor?

$V_{source} = V_A + V_B + V_C$

$V_C = V_{source} - (V_A + V_B)$

$= 12.0\text{ V} - (1.21\text{ V} + 3.33\text{ V}) = 7.46\text{ V}$

page 623

11. A 22-Ω resistor and a 33-Ω resistor are connected in series and placed across a 120-V potential difference.

a. What is the equivalent resistance of the circuit?

$R = R_1 + R_2 = 22\ \Omega + 33\ \Omega = 55\ \Omega$

b. What is the current in the circuit?

$I = \frac{V}{R} = \frac{120\text{ V}}{55\ \Omega} = 2.2\text{ A}$

c. What is the voltage drop across each resistor?

$V_1 = IR_1$

$= \left(\frac{V}{R}\right)R_1$

$= \left(\frac{120\text{ V}}{55\ \Omega}\right)(22\ \Omega)$

$= 48\text{ V}$

$V_2 = IR_2 = \left(\frac{120\text{ V}}{55\ \Omega}\right)(33\ \Omega) = 72\text{ V}$

d. What is the voltage drop across the two resistors together?

$V = 48\text{ V} + 72\text{ V} = 1.20\times10^2\text{ V}$

12. Three resistors of 3.3 kΩ, 4.7 kΩ, and 3.9 kΩ are connected in series across a 12-V battery.

a. What is the equivalent resistance?

$R = 3.3\text{ k}\Omega + 4.7\text{ k}\Omega + 3.9\text{ k}\Omega$

$= 1.2\times10^1\text{ k}\Omega$

b. What is the current through the resistors?

$I = \frac{V}{R} = \frac{12\text{ V}}{12\times10^4\ \Omega}$

$= 1.0\text{ mA} = 1.0\times10^{-3}\text{ A}$

c. What is the voltage drop across each resistor?

$V = IR$

$V_1 = (3.3\text{ k}\Omega)(1.0\times10^{-3}\text{ A}) = 3.3\text{ V}$

$V_2 = (4.7\text{ k}\Omega)(1.0\times10^{-3}\text{ A}) = 4.7\text{ V}$

$V_3 = (3.9\ \text{k}\Omega)(1.0\times10^{-3}\ \text{A}) = 3.9\ \text{V}$

so $V = 3.3$ V, 4.7 V, and 3.9 V

d. Find the total voltage drop across the three resistors.

$V = 3.3\ \text{V} + 4.7\ \text{V} + 3.9\ \text{V} = 11.9\ \text{V}$

13. A student makes a voltage divider from a 45-V battery, a 475-kΩ resistor, and a 235-kΩ resistor. The output is measured across the smaller resistor. What is the voltage?

$$V_B = \frac{VR_B}{R_A + R_B} = \frac{(45\ \text{V})(235\ \text{k}\Omega)}{475\ \text{k}\Omega + 235\ \text{k}\Omega} = 15\ \text{V}$$

14. Select a resistor to be used as part of a voltage divider along with a 1.2-kΩ resistor. The drop across the 1.2-kΩ resistor is to be 2.2 V when the supply is 12 V.

$$V_B = \frac{VR_B}{R_A + R_B}$$

$$R_A = \frac{VR_B}{V_B} - R_B$$

$$= \frac{(12.0\ \text{V})(1.2\ \text{k}\Omega)}{2.2\ \text{V}} - 1.2\ \text{k}\Omega$$

$$= 5.3\ \text{k}\Omega$$

page 626

15. Three 15.0-Ω resistors are connected in parallel and placed across a 30.0-V battery.

a. What is the equivalent resistance of the parallel circuit?

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

$$= \frac{1}{15.0\ \Omega} + \frac{1}{15.0\ \Omega} + \frac{1}{15.0\ \Omega}$$

$$= \frac{3}{15.0\ \Omega}$$

$R = 5.00\ \Omega$

b. What is the current through the entire circuit?

$$I = \frac{V}{R} = \frac{30.0\ \text{V}}{5.00\ \Omega} = 6.00\ \text{A}$$

c. What is the current through each branch of the circuit?

$$I = \frac{V}{R_1} = \frac{30.0\ \text{V}}{15.0\ \Omega} = 2.00\ \text{A}$$

16. A 120.0-Ω resistor, a 60.0-Ω resistor, and a 40.0-Ω resistor are connected in parallel and placed across a 12.0-V battery.

a. What is the equivalent resistance of the parallel circuit?

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

$$= \frac{1}{120.0\ \Omega} + \frac{1}{60.0\ \Omega} + \frac{1}{40.0\ \Omega}$$

$R = 20.0\ \Omega$

b. What is the current through the entire circuit?

$$I = \frac{V}{R} = \frac{12.0\ \text{V}}{20.0\ \Omega} = 0.600\ \text{A}$$

c. What is the current through each branch of the circuit?

$$I_1 = \frac{V}{R_1} = \frac{12.0\ \text{V}}{120.0\ \Omega} = 0.100\ \text{A}$$

$$I_2 = \frac{V}{R_2} = \frac{12.0\ \text{V}}{60.0\ \Omega} = 0.200\ \text{A}$$

$$I_3 = \frac{V}{R_3} = \frac{12.0\ \text{V}}{40.0\ \Omega} = 0.300\ \text{A}$$

17. Suppose that one of the 15.0-Ω resistors in problem 15 is replaced by a 10.0-Ω resistor.

a. Does the equivalent resistance change? If so, how?

Yes, it gets smaller.

b. Does the amount of current through the entire circuit change? If so, in what way?

Yes, it gets larger.

c. Does the amount of current through the other 15.0-Ω resistors change? If so, how?

No, it remains the same. Currents are independent.

18. A 150-Ω branch in a circuit must be reduced to 93 Ω. A resistor will be added to this branch of the circuit to make this change. What value of resistance should be used and how must the resistor be connected?

A parallel resistor will be required to reduce the resistance.

$$\frac{1}{R} = \frac{1}{R_A} + \frac{1}{R_B}$$

$$\frac{1}{R_A} = \frac{1}{R} - \frac{1}{R_B} = \frac{1}{93\ \Omega} - \frac{1}{150\ \Omega}$$

$R_A = 2.4\times10^2\ \Omega$

$2.4\times10^2\ \Omega$ in parallel with the 150-Ω resistance

19. A 12-Ω, 2-W resistor is connected in parallel with a 6.0-Ω, 4-W resistor. Which will become hotter if the voltage across them keeps increasing?

Neither. They both reach maximum dissipation at the same voltage.

$P = \frac{V^2}{R}$

$V = \sqrt{PR}$

The voltage is equal across parallel resistors, so:

$V = \sqrt{P_1R_1} = \sqrt{P_2R_2}$

$= \sqrt{(2\text{ W})(12\ \Omega)}$

$= \sqrt{(4\text{ W})(6.0\ \Omega)}$

= 5 V maximum

Section Review

23.1 Simple Circuits pages 617–626

page 626

20. Circuit Types Compare and contrast the voltages and the currents in series and parallel circuits.

The student's answer should include the following ideas:

(1) In a series circuit, the current in each of the devices is the same, and the sum of the device voltage drops equals the source voltage.

(2) In a parallel circuit, the voltage drop across each device is the same and the sum of the currents through each loop equals the source current.

21. Total Current A parallel circuit has four branch currents: 120 mA, 250 mA, 380 mA, and 2.1 A. How much current is supplied by the source?

$I_T = I_1 + I_2 + I_3 + I_4$

$= 120\text{ mA} + 250\text{ mA} + 380\text{ mA} + 2.1\text{ A}$

$= 0.12\text{ A} + 0.25\text{ A} + 0.38\text{ A} + 2.1\text{ A}$

= 2.9 A

22. Total Current A series circuit has four resistors. The current through one resistor is 810 mA. How much current is supplied by the source?

810 mA. Current is the same everywhere in a series circuit.

23. Circuits A switch is connected in series with a 75-W bulb to a source of 120 V.

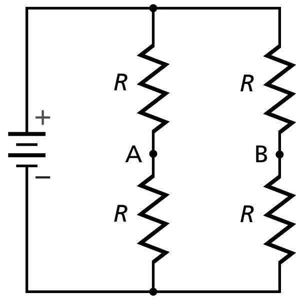
a. What is the potential difference across the switch when it is closed (turned on)?

0 V; $V = IR$ with $R = 0$

b. What is the potential difference across the switch if another 75-W bulb is added in series?

0 V; $V = IR$ with $R = 0$

24. Critical Thinking The circuit in **Figure 23-8** has four identical resistors. Suppose that a wire is added to connect points A and B. Answer the following questions, and explain your reasoning.



■ **Figure 23-8**

a. What is the current through the wire?

0 A; the potentials of points A and B are the same.

b. What happens to the current through each resistor?

nothing

c. What happens to the current drawn from the battery?

nothing

d. What happens to the potential difference across each resistor?

nothing

Practice Problems

23.2 Applications of Circuits pages 627–631

page 630

25. A series-parallel circuit has three resistors: one dissipates 2.0 W, the second 3.0 W, and the third 1.5 W. How much current does the circuit require from a 12-V battery?

By conservation of energy (and power):

$$P_T = P_1 + P_2 + P_3$$
$$= 2.0\text{ W} + 3.0\text{ W} + 1.5\text{ W}$$
$$= 6.5\text{ W}$$
$$P_T = IV$$
$$I = \frac{P_T}{V} = \frac{6.5\text{ W}}{12\text{ V}} = 0.54\text{ A}$$

26. There are 11 lights in series, and they are in series with two lights in parallel. If the 13 lights are identical, which of them will burn brightest?

The 11 lights in series will burn brighter. The parallel lights each will conduct half of the current of the series lights and they will burn at one-fourth the intensity of the series lights since $P = I^2R$.

27. What will happen to the circuit in problem 26 if one of the parallel lights burns out?

Then, all of the working lights are in series. The 12 working lights will burn with equal intensity.

28. What will happen to the circuit in problem 26 if one of the parallel lights shorts out?

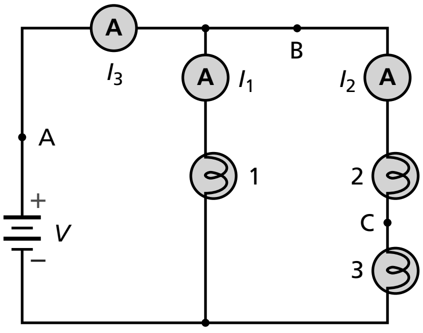
Then, the shorted light will reduce the voltage across itself and its parallel companion to 0. The 11 series lights will burn with equal, but increased, intensity and the two parallel lights will go out.

Section Review

23.2 Applications of Circuits pages 627–631

page 631

*Refer to **Figure 23-13** for questions 29–33, and 35. The bulbs in the circuit are identical.*



■ **Figure 23-13**

29. Brightness How do the bulb brightnesses compare?

Bulbs 2 and 3 are equal in brightness but dimmer than bulb 1.

30. Current If I_3 measures 1.7 A and I_1 measures 1.1 A, how much current is flowing in bulb 2?

$$I_3 = I_1 + I_2$$
$$I_2 = I_3 - I_1 = 1.7\text{ A} - 1.1\text{ A} = 0.6\text{ A}$$

31. Circuits in Series The wire at point C is broken and a small resistor is inserted in series with bulbs 2 and 3. What happens to the brightnesses of the two bulbs? Explain.

Both dim equally. The current in each is reduced by the same amount.

32. Battery Voltage A voltmeter connected across bulb 2 measures 3.8 V, and a voltmeter connected across bulb 3 measures 4.2 V. What is the battery voltage?

These bulbs are in series, so:

$$V_T = V_1 + V_2 = 3.8\text{ V} + 4.2\text{ V} = 8.0\text{ V}$$

33. Circuits Using the information from problem 32, determine if bulbs 2 and 3 are identical.

No. Identical bulbs in series would have identical voltage drops since their currents are the same.

34. Circuit Protection Describe three common safety devices associated with household wiring.

fuses, circuit breakers, ground-fault circuit interrupters

35. Critical Thinking Is there a way to make the three bulbs in Figure 23-13 burn with equal intensity without using any additional resistors? Explain.

Yes. Because intensity is proportional to power, it would be necessary to use a bulb at location 1 that has four times the operating resistance of each of those at locations 2 and 3.

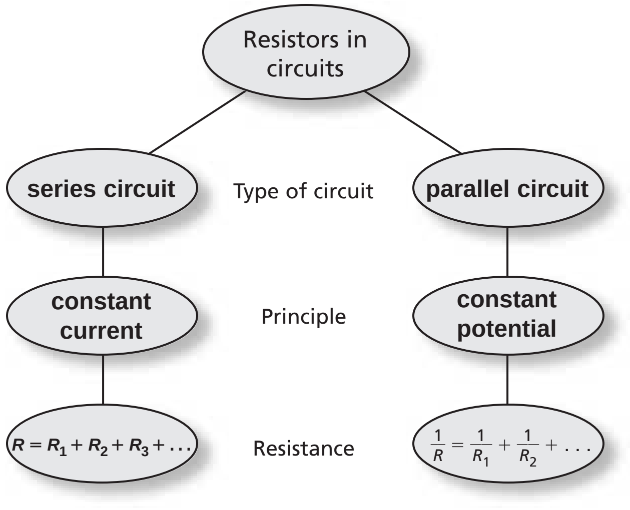
$V^2/4R = (V/2)^2/R$

Chapter Assessment

Concept Mapping

page 636

36. Complete the concept map using the following terms: *series circuit*, $R = R_1 + R_2 + R_3$, *constant current, parallel circuit, constant potential.*



Mastering Concepts

page 636

37. Why is it frustrating when one bulb burns out on a string of holiday tree lights connected in series? (23.1)

When one bulb burns out, the circuit is open and all the bulbs go out.

38. Why does the equivalent resistance decrease as more resistors are added to a parallel circuit? (23.1)

Each new resistor provides an additional path for the current.

39. Several resistors with different values are connected in parallel. How do the values of the individual resistors compare with the equivalent resistance? (23.1)

The equivalent resistance will be less than that of any of the resistors.

40. Why is household wiring constructed in parallel instead of in series? (23.1)

Appliances in parallel can be run independently of one another.

41. Why is there a difference in equivalent resistance between three 60-Ω resistors connected in series and three 60-Ω resistors connected in parallel? (23.1)

In a series circuit, the current is opposed by each resistance in turn. The total resistance is the sum of the resistors. In a parallel circuit, each resistance provides an additional path for current. The result is a decrease in total resistance.

42. Compare the amount of current entering a junction in a parallel circuit with that leaving the junction. (A junction is a point where three or more conductors are joined.) (23.1)

The amount of current entering a junction is equal to the amount of current leaving.

43. Explain how a fuse functions to protect an electric circuit. (23.2)

The purpose of a fuse is to prevent conductors from being overloaded with current, causing fires due to overheating. A fuse is simply a short length of wire that will melt from the heating effect if the current exceeds a certain maximum.

44. What is a short circuit? Why is a short circuit dangerous? (23.2)

A short circuit is a circuit that has extremely low resistance. A short circuit is dangerous because any potential difference will produce a large current. The heating effect of the current can cause a fire.

45. Why is an ammeter designed to have a very low resistance? (23.2)

An ammeter must have low resistance because it is placed in series in the circuit. If its resistance were high, it would significantly change the total resistance of the circuit and thus serve to reduce the current in the circuit, thereby changing the current it is meant to measure.

46. Why is a voltmeter designed to have a very high resistance? (23.2)

A voltmeter is placed in parallel with the portion of the circuit whose difference in potential is to be measured. A voltmeter must have very high resistance for the same reason that an ammeter has low resistance. If the voltmeter had low resistance, it would lower the resistance of the portion of the circuit it is across and increase the current in the circuit. This would produce a higher voltage drop across the part of the circuit where the voltmeter is located, changing the voltage it is measuring.

47. How does the way in which an ammeter is connected in a circuit differ from the way in which a voltmeter is connected? (23.2)

An ammeter is connected in series; a voltmeter is connected in parallel.

Applying Concepts

page 636

48. What happens to the current in the other two lamps if one lamp in a three-lamp series circuit burns out?

If one of the lamp filaments burns out, the current will cease and all the lamps will go out.

49. Suppose the resistor, R_A, in the voltage divider in Figure 23-4 is made to be a variable resistor. What happens to the voltage output, V_B, of the voltage divider if the resistance of the variable resistor is increased?

$V_B = VR_B/(R_A + R_B)$**. As** R_A **increases,** V_B **will decrease.**

50. Circuit A contains three 60-Ω resistors in series. Circuit B contains three 60-Ω resistors in parallel. How does the current in the second 60-Ω resistor of each circuit change if a switch cuts off the current to the first 60-Ω resistor?

Circuit A: There will be no current in the resistor.

Circuit B: The current in the resistor will remain the same

51. What happens to the current in the other two lamps if one lamp in a three-lamp parallel circuit burns out?

If one of the filaments burns out, the resistance and the potential difference across the other lamps will not change; therefore, their currents will remain the same.

52. An engineer needs a 10-Ω resistor and a 15-Ω resistor, but there are only 30-Ω resistors in stock. Must new resistors be purchased? Explain.

No, the 30-Ω resistors can be used in parallel. Three 30-Ω resistors in parallel will give a 10-Ω resistance. Two 30-Ω resistors in parallel will give a 15-Ω resistance.

53. If you have a 6-V battery and many 1.5-V bulbs, how could you connect them so that they light but do not have more than 1.5 V across each bulb?

Connect four of the bulbs in series. The voltage drop across each will be (6.0 V)/4 = 1.5 V.

54. Two lamps have different resistances, one larger than the other.

a. If the lamps are connected in parallel, which is brighter (dissipates more power)?

The lamp with the lower resistance: $P = IV$ and $I = V/R$, so $P = V^2/R$. Because the voltage drop is the same across both lamps, the smaller R means larger P, and thus will be brighter.

b. When the lamps are connected in series, which lamp is brighter?

The lamp with the higher resistance; $P = IV$ and $V = IR$, so $P = I^2R$. Because the current is the same in both lamps, the larger R means larger P, and thus will be brighter.

55. For each of the following, write the form of circuit that applies: series or parallel.

a. The current is the same everywhere throughout the entire circuit.

series

b. The total resistance is equal to the sum of the individual resistances.

series

c. The voltage drop across each resistor in the circuit is the same.

parallel

d. The voltage drop in the circuit is proportional to the resistance.

series

e. Adding a resistor to the circuit decreases the total resistance.

parallel

f. Adding a resistor to the circuit increases the total resistance.

series

g. If the current through one resistor in the circuit goes to zero, there is no current in the entire circuit.

series

h. If the current through one resistor in the circuit goes to zero, the current through all other resistors remains the same.

parallel

i. This form is suitable for house wiring.

parallel

56. Household Fuses Why is it dangerous to replace the 15-A fuse used to protect a household circuit with a fuse that is rated at 30 A?

The 30-A fuse allows more current to flow through the circuit, generating more heat in the wires, which can be dangerous.

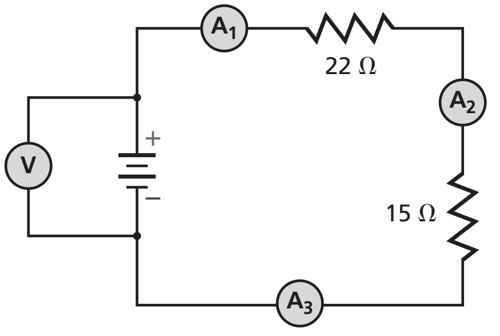
Mastering Problems

23.1 Simple Circuits

pages 637–638

Level 1

57. Ammeter 1 in **Figure 23-14** reads 0.20 A.



■ **Figure 23-14**

a. What should ammeter 2 indicate?

0.20 A, because current is constant in a series circuit.

b. What should ammeter 3 indicate?

0.20 A, because current is constant in a series circuit.

58. Calculate the equivalent resistance of these series-connected resistors: 680 Ω, 1.1 kΩ, and 10 kΩ.

$$R = 680\ \Omega + 1100\ \Omega + 10{,}000\ \Omega$$
$$= 12\ \text{k}\Omega$$

59. Calculate the equivalent resistance of these parallel-connected resistors: 680 Ω, 1.1 kΩ, and 10.2 kΩ.

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

$$R = \frac{1}{\left(\frac{1}{0.68\ \text{k}\Omega} + \frac{1}{1.1\ \text{k}\Omega} + \frac{1}{10.2\ \text{k}\Omega}\right)}$$
$$= 0.40\ \text{k}\Omega$$

60. A series circuit has two voltage drops: 5.50 V and 6.90 V. What is the supply voltage?

$$V = 5.50\ \text{V} + 6.90\ \text{V} = 12.4\ \text{V}$$

61. A parallel circuit has two branch currents: 3.45 A and 1.00 A. What is the current in the energy source?

$$I = 3.45\ \text{A} + 1.00\ \text{A} = 4.45\ \text{A}$$

Level 2

62. Ammeter 1 in Figure 23-14 reads 0.20 A.

a. What is the total resistance of the circuit?

$$R = R_1 + R_2 = 15\ \Omega + 22\ \Omega = 37\ \Omega$$

b. What is the battery voltage?

$$V = IR = (0.20\ \text{A})(37\ \Omega) = 7.4\ \text{V}$$

c. How much power is delivered to the 22-Ω resistor?

$$P = I^2R = (0.20\ \text{A})^2(22\ \Omega) = 0.88\ \text{W}$$

d. How much power is supplied by the battery?

$$P = IV = (0.20\ \text{A})(7.4\ \text{V}) = 1.5\ \text{W}$$

63. Ammeter 2 in Figure 23-14 reads 0.50 A.

a. Find the voltage across the 22-Ω resistor.

$$V = IR = (0.50\ \text{A})(22\ \Omega) = 11\ \text{V}$$

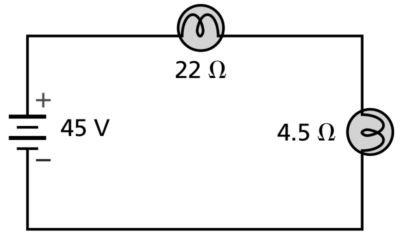
b. Find the voltage across the 15-Ω resistor.

$$V = IR = (0.50\ \text{A})(15\ \Omega) = 7.5\ \text{V}$$

c. What is the battery voltage?

$$V = V_1 + V_2 = (11\ \text{V}) + (7.5\ \text{V}) = 19\ \text{V}$$

64. A 22-Ω lamp and a 4.5-Ω lamp are connected in series and placed across a potential difference of 45 V as shown in **Figure 23-15.**



■ **Figure 23-15**

a. What is the equivalent resistance of the circuit?

$$22\ \Omega + 4.5\ \Omega = 26\ \Omega$$

b. What is the current in the circuit?

$$I = \frac{V}{R} = \frac{45\ \text{V}}{27\ \Omega} = 1.7\ \text{A}$$

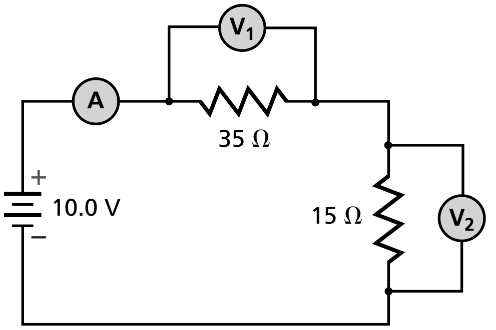
c. What is the voltage drop across each lamp?

$$V = IR = (1.7\ \text{A})(22\ \Omega) = 37\ \text{V}$$
$$V = IR = (1.7\ \text{A})(4.5\ \Omega) = 7.7\ \text{V}$$

d. What is the power dissipated in each lamp?

$$P = IV = (1.7\ \text{A})(37\ \text{V}) = 63\ \text{W}$$
$$P = IV = (1.7\ \text{A})(7.7\ \text{V}) = 13\ \text{W}$$

65. Refer to **Figure 23-16** to answer the following questions.



■ **Figure 23-16**

a. What should the ammeter read?

$$R = R_1 + R_2 = 35\ \Omega + 15\ \Omega$$
$$I = V/R$$
$$= (10.0\ \text{V})/(35\ \Omega + 15\ \Omega)$$
$$= 0.20\ \text{A}$$

b. What should voltmeter 1 read?

$$V = IR = (0.20\ \text{A})(35\ \Omega) = 7.0\ \text{V}$$

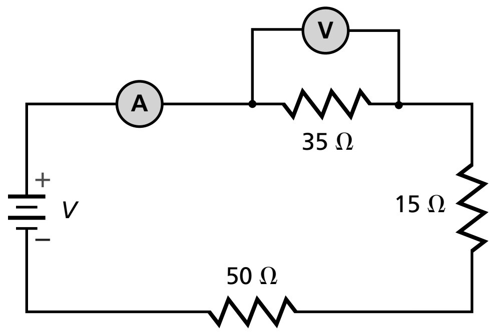
c. What should voltmeter 2 read?

$V = IR = (0.20\ \text{A})(15\ \Omega) = 3.0\ \text{V}$

d. How much energy is supplied by the battery per minute?

$$\begin{aligned} E &= Pt \\ &= VIt \\ &= (10.0\ \text{V})(0.20\ \text{A})(1\ \text{min})(60\ \text{s/min}) \\ &= 120\ \text{J} \end{aligned}$$

66. For **Figure 23-17,** the voltmeter reads 70.0 V.



■ **Figure 23-17**

a. Which resistor is the hottest?

50 Ω. Since $P = I^2R$ and I is constant in a series circuit, the largest value of resistance will produce the most power.

b. Which resistor is the coolest?

15 Ω. Since $P = I^2R$ and I is constant in a series circuit, the smallest value of resistance will produce the least power.

c. What will the ammeter read?

Use Ohm's law: $I = V/R$

$$\begin{aligned} &= (70.0\ \text{V})/(35\ \Omega) \\ &= 2.0\ \text{A} \end{aligned}$$

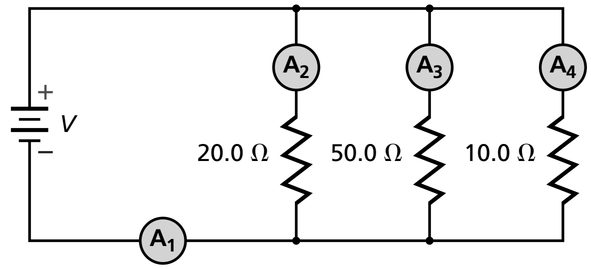
d. What is the power supplied by the battery?

First, find the total resistance:

$$\begin{aligned} R &= R_1 + R_2 + R_3 \\ &= 35\ \Omega + 15\ \Omega + 50\ \Omega \\ &= 0.1\ \text{k}\Omega \end{aligned}$$

$$\begin{aligned} P &= I^2R \\ &= (2.0\ \text{A})^2(0.1\ \text{k}\Omega)(1000\ \Omega/\text{k}\Omega) \\ &= 4\times10^2\ \text{W} \end{aligned}$$

67. For **Figure 23-18,** the battery develops 110 V.



■ **Figure 23-18**

a. Which resistor is the hottest?

10.0 Ω. Since $P = V^2/R$ and V is constant in a parallel circuit, the smallest resistor will dissipate the most power.

b. Which resistor is the coolest?

50.0 Ω. Since $P = V^2/R$ and V is constant in a parallel circuit, the largest resistor will dissipate the least power.

c. What will ammeter 1 read?

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

$$\begin{aligned} R &= \frac{1}{\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right)} \\ &= \frac{1}{\left(\frac{1}{20.0\ \Omega} + \frac{1}{50.0\ \Omega} + \frac{1}{10.0\ \Omega}\right)} \\ &= 5.88\ \Omega \end{aligned}$$

$$I = \frac{V}{R} = \frac{1.1\times10^2\ \text{V}}{5.88\ \Omega} = 19\text{A}$$

d. What will ammeter 2 read?

$$I = \frac{V}{R} = \frac{1.1\times10^2\ \text{V}}{20.0\ \Omega} = 5.5\ \text{A}$$

e. What will ammeter 3 read?

$$I = \frac{V}{R} = \frac{1.1\times10^2\ \text{V}}{50.0\ \Omega} = 2.2\ \text{A}$$

f. What will ammeter 4 read?

$$I = \frac{V}{R} = \frac{1.1\times10^2\ \text{V}}{10.0\ \Omega} = 11\ \text{A}$$

68. For Figure 23-18, ammeter 3 reads 0.40 A.

a. What is the battery voltage?

$V = IR = (0.40\ \text{A})(50.0\ \Omega) = 2.0\times10^1\ \text{V}$

b. What will ammeter 1 read?

Find the equivalent resistance:

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

$$R = \frac{1}{\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right)}$$

$$= \frac{1}{\left(\frac{1}{20.0\ \Omega} + \frac{1}{50.0\ \Omega} + \frac{1}{10.0\ \Omega}\right)}$$

$$= \frac{1}{0.17\ \Omega}$$

$$= 5.88\ \Omega$$

$$I = \frac{V}{R} = \frac{2.0\times10^1\ \text{V}}{5.88\ \Omega} = 3.4\ \text{A}$$

c. What will ammeter 2 read?

$$I = \frac{V}{R} = \frac{2.0\times10^1\ \text{V}}{20.0\ \Omega} = 1.0\ \text{A}$$

d. What will ammeter 4 read?

$$I = \frac{V}{R} = \frac{2.0\times10^1\ \text{V}}{10.0\ \Omega} = 2.0\ \text{A}$$

69. What is the direction of the conventional current in the 50.0-Ω resistor in Figure 23-18?

down

70. The load across a battery consists of two resistors, with values of 15 Ω and 47 Ω, connected in series.

a. What is the total resistance of the load?

$$R = R_1 + R_2 = 15\ \Omega + 47\ \Omega$$

$$= 62\ \Omega$$

b. What is the voltage of the battery if the current in the circuit is 97 mA?

$$V = IR = (97\ \text{mA})(62\ \Omega) = 6.0\ \text{V}$$

71. Holiday Lights A string of 18 identical holiday tree lights is connected in series to a 120-V source. The string dissipates 64 W.

a. What is the equivalent resistance of the light string?

$$P = \frac{V^2}{R_{eq}}$$

$$R_{eq} = \frac{V^2}{P} = \frac{(120\ \text{V})^2}{64\ \text{W}} = 2.3\times10^2\ \Omega$$

b. What is the resistance of a single light?

R **is the sum of the resistances of 18 lamps, so each resistance is**

$$\frac{2.3\times10^2\ \Omega}{18} = 13\ \Omega$$

c. What power is dissipated by each light?

$$\frac{64\ \text{W}}{18} = 3.6\ \text{W}$$

72. One of the lights in problem 71 burns out. The light shorts out the bulb filament when it burns out. This drops the resistance of the lamp to zero.

a. What is the resistance of the light string now?

There are now 17 lamps in series instead of 18 lamps. The resistance is $\left(\frac{17}{18}\right)(2.3\times10^2\ \Omega) = 2.2\times10^2\ \Omega$

b. Find the power dissipated by the string.

$$P = \frac{V^2}{R} = \frac{(120\ \text{V})^2}{2.2\times10^2\ \Omega} = 65\ \text{W}$$

c. Did the power increase or decrease when the bulb burned out?

It increased.

73. A 16.0-Ω and a 20.0-Ω resistor are connected in parallel. A difference in potential of 40.0 V is applied to the combination.

a. Compute the equivalent resistance of the parallel circuit.

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$$

$$R = \frac{1}{\left(\frac{1}{R_1} + \frac{1}{R_2}\right)}$$

$$= \frac{1}{\left(\frac{1}{16.0\ \Omega} + \frac{1}{20.0\ \Omega}\right)}$$

$$= 8.89\ \Omega$$

b. What is the total current in the circuit?

$$I = \frac{V}{R} = \frac{40.0\ \text{V}}{8.89\ \Omega} = 4.50\ \text{A}$$

c. What is the current in the 16.0-Ω resistor?

$$I_1 = \frac{V}{R_1} = \frac{40.0\ \text{V}}{16.0\ \Omega} = 2.50\ \text{A}$$

74. Amy needs 5.0 V for an integrated-circuit experiment. She uses a 6.0-V battery and two resistors to make a voltage divider. One resistor is 330 Ω. She decides to make the other resistor smaller. What value should it have?

$$V_2 = \frac{VR_2}{R_1 + R_2}$$

$$R_1 = \frac{VR_2}{V_2} - R_2$$

$$= \frac{(6.0\ \text{V})(330\ \Omega)}{5.0\ \text{V}} - 330\ \Omega = 66\ \Omega$$

75. Pete is designing a voltage divider using a 12-V battery and a 82-Ω resistor as R_B. What resistor should be used as R_A if the output voltage across R_B is to be 4.0 V?

$$V_B = \frac{VR_B}{R_A + R_B}$$

$$R_A + R_B = \frac{VR_B}{V_B}$$

$$R_A = \frac{VR_B}{V_B} - R_B$$

$$= \frac{(12\ \text{V})(82\ \Omega)}{4.0\ \text{V}} - 82\ \Omega$$

$$= 1.6\times10^2\ \Omega$$

Level 3

76. Television A typical television dissipates 275 W when it is plugged into a 120-V outlet.

a. Find the resistance of the television.

$P = IV$ and $I = \frac{V}{R}$, so $P = \frac{V^2}{R}$, or

$$R = \frac{V^2}{P} = \frac{(120\ \text{V})^2}{275\ \text{W}} = 52\ \Omega$$

b. The television and 2.5-Ω wires connecting the outlet to the fuse form a series circuit that works like a voltage divider. Find the voltage drop across the television.

$$V_A = \frac{VR_A}{R_A + R_B}$$

$$= \frac{(120\ \text{V})(52\ \Omega)}{52\ \Omega + 2.5\ \Omega}$$

$$= 110\ \text{V}$$

c. A 12-Ω hair dryer is plugged into the same outlet. Find the equivalent resistance of the two appliances.

$$\frac{1}{R} = \frac{1}{R_A} + \frac{1}{R_B}$$

$$R = \frac{1}{\left(\frac{1}{R_A} + \frac{1}{R_B}\right)}$$

$$= \frac{1}{\left(\frac{1}{52\ \Omega} + \frac{1}{12\ \Omega}\right)}$$

$$= 9.8\ \Omega$$

d. Find the voltage drop across the television and the hair dryer.

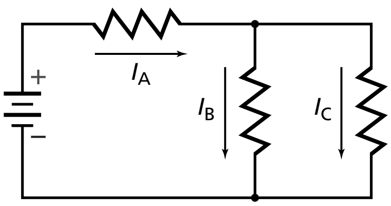
$$V_1 = \frac{VR_A}{R_A + R_B} = \frac{(120\ \text{V})(9.8\ \Omega)}{9.8\ \Omega + 2.5\ \Omega} = 96\ \text{V}$$

23.2 Applications of Circuits

pages 638–639

Level 1

77. Refer to **Figure 23-19** and assume that all the resistors are 30.0 Ω. Find the equivalent resistance.



■ **Figure 23-19**

The parallel combination of the two 30.0-Ω resistors has an equivalent resistance of 15.0 Ω.

So $R = 30.0\ \Omega + 15.0\ \Omega = 45.0\ \Omega$

78. Refer to Figure 23-19 and assume that each resistor dissipates 120 mW. Find the total dissipation.

$P = 3(120\ \text{mW}) = 360\ \text{mW}$

79. Refer to Figure 23-19 and assume that I_A = 13 mA and I_B = 1.7 mA. Find I_C.

$$I_C = I_A - I_B$$

$$= 13\ \text{mA} - 1.7\ \text{mA}$$

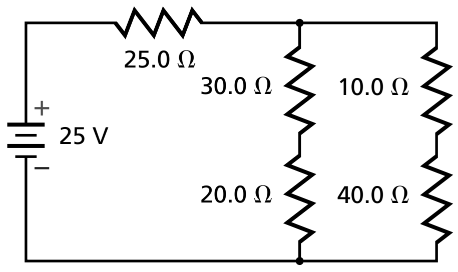
$$= 11\ \text{mA}$$

80. Refer to Figure 23-19 and assume that $I_B = 13$ mA and $I_C = 1.7$ mA. Find I_A.

$$\mathbf{I_A = I_B + I_C}$$
$$\mathbf{= 13\text{ mA} + 1.7\text{ mA}}$$
$$\mathbf{= 15\text{ mA}}$$

Level 2

81. Refer to **Figure 23-20** to answer the following questions.



■ **Figure 23-20**

a. Determine the total resistance.

The 30.0-Ω and 20.0-Ω resistors are in series.

$$\mathbf{R_1 = 30.0\ \Omega + 20.0\ \Omega = 50.0\ \Omega}$$

The 10.0-Ω and 40.0-Ω resistors are in series.

$$\mathbf{R_2 = 10.0\ \Omega + 40.0\ \Omega = 50.0\ \Omega}$$

R_1 and R_2 are in parallel.

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$$

$$R = \frac{1}{\left(\frac{1}{R_1} + \frac{1}{R_2}\right)}$$

$$= \frac{1}{\left(\frac{1}{50.0\ \Omega} + \frac{1}{50.0\ \Omega}\right)}$$

= 25.0 Ω and is in series with the 25.0-Ω resistor

$$\mathbf{R_{Total} = 25.0\ \Omega + 25.0\ \Omega = 50.0\ \Omega}$$

b. Determine the current through the 25-Ω resistor.

use Ohm's law and R_{Total}

$$I = \frac{V}{R_{Total}} = \frac{25\text{ V}}{50.0\ \Omega} = 0.50\text{ A}$$

c. Which resistor is the hottest? Coolest?

$$P = I^2R = (0.50\text{ A})^2(25.0\ \Omega) = 6.25\text{ W}$$

Half the total current is in each parallel branch because the sum of the resistances in each branch are equal.

$$P = I^2R = (0.25\text{ A})^2(30.0\ \Omega) = 1.9\text{ W}$$

$$P = I^2R = (0.25\text{ A})^2(20.0\ \Omega) = 1.2\text{ W}$$

$$P = I^2R = (0.25\text{ A})^2(10.0\ \Omega) = 0.62\text{ W}$$

$$P = I^2R = (0.25\text{ A})^2(40.0\ \Omega) = 2.5\text{ W}$$

The 25.0-Ω resistor is the hottest.

The 10.0-Ω resistor is the coolest.

82. A circuit contains six 60-W lamps with a resistance of 240-Ω each and a 10.0-Ω heater connected in parallel. The voltage across the circuit is 120 V. Find the current in the circuit for the following situations.

a. Four lamps are turned on.

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4}$$

$$= \frac{1}{240\ \Omega} + \frac{1}{240\ \Omega} + \frac{1}{240\ \Omega} + \frac{1}{240\ \Omega}$$

$$= \frac{4}{240\ \Omega}$$

$$R = \frac{240\ \Omega}{4} = 0.060\text{ k}\Omega$$

$$I = \frac{V}{R} = \frac{120\text{ V}}{0.060\text{ k}\Omega} = 2.0\text{ A}$$

b. All of the lamps are turned on.

$$\frac{1}{R} = \frac{6}{240\ \Omega}$$

$$R = \frac{240\ \Omega}{6} = 0.040\text{ k}\Omega$$

$$I = \frac{V}{R} = \frac{120\text{ V}}{0.040\text{ k}\Omega} = 3.0\text{ A}$$

c. Six lamps and the heater are operating.

$$\frac{1}{R} = \frac{1}{0.040\text{ k}\Omega} + \frac{1}{10.0\ \Omega}$$

$$= \frac{5}{4.0\times10^1\ \Omega}$$

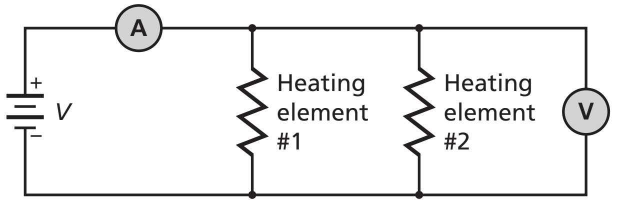
$$R = \frac{4.0\times10^1\ \Omega}{5} = 8.0\ \Omega$$

$$I = \frac{V}{R} = \frac{120\text{ V}}{8.0\ \Omega} = 15\text{ A}$$

83. If the circuit in problem 82 has a 12-A fuse, will the fuse melt if all the lamps and the heater are on?

Yes. The 15-A current will melt the 12-A fuse.

84. During a laboratory exercise, you are supplied with a battery of potential difference *V*, two heating elements of low resistance that can be placed in water, an ammeter of very small resistance, a voltmeter of extremely high resistance, wires of negligible resistance, a beaker that is well insulated and has negligible heat capacity, and 0.10 kg of water at 25°C. By means of a diagram and standard symbols, show how these components should be connected to heat the water as rapidly as possible.



85. If the voltmeter used in problem 84 holds steady at 45 V and the ammeter reading holds steady at 5.0 A, estimate the time in seconds required to completely vaporize the water in the beaker. Use 4.2 kJ/kg·°C as the specific heat of water and 2.3×10^6 J/kg as the heat of vaporization of water.

$\Delta Q = mC\Delta T$

$= (0.10 \text{ kg})(4.2 \text{ kJ/kg·°C})(75°\text{C})$

$= 32$ **kJ (energy needed to raise temperature of water to 100°C)**

$\Delta Q = mH_v = (0.10 \text{ kg})(2.3\times10^6 \text{ J/kg})$

$= 2.3\times10^2$ **kJ (energy needed to vaporize the water)**

$\Delta Q_{total} = 32 \text{ kJ} + 2.3\times10^2 \text{ kJ}$

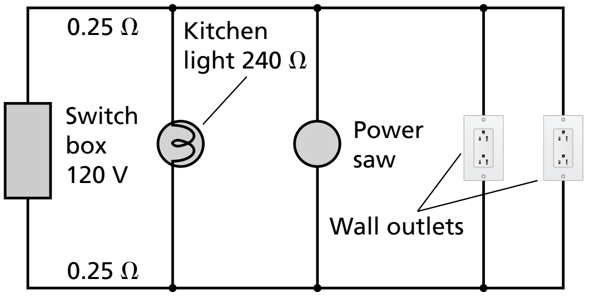
$= 2.6\times10^2$ **kJ (total energy needed) Energy is provided at the rate of**

$P = IV = (5.0 \text{ A})(45 \text{ V}) = 0.23 \text{ kJ/s}.$

The time required is

$$t = \frac{2.6\times10^2 \text{ kJ}}{0.23 \text{ kJ/s}} = 1.1\times10^3 \text{ s}$$

86. Home Circuit A typical home circuit is shown in **Figure 23-21.** The wires to the kitchen lamp each have a resistance of 0.25 Ω. The lamp has a resistance of 0.24 kΩ. Although the circuit is parallel, the lead lines are in series with each of the components of the circuit.



■ **Figure 23-21**

a. Compute the equivalent resistance of the circuit consisting of just the lamp and the lead lines to and from the lamp.

$R = 0.25\ \Omega + 0.25\ \Omega + 0.24\ \text{k}\Omega$

$= 0.24\ \text{k}\Omega$

b. Find the current to the lamp.

$$I = \frac{V}{R} = \frac{120 \text{ V}}{0.24\ \text{k}\Omega} = 0.50 \text{ A}$$

c. Find the power dissipated in the lamp.

$P = IV = (0.50 \text{ A})(120 \text{ V}) = 6.0\times10^1 \text{ W}$

Mixed Review

page 639

Level 1

87. A series circuit has two voltage drops: 3.50 V and 4.90 V. What is the supply voltage?

$V = 3.50 \text{ V} + 4.90 \text{ V} = 8.40 \text{ V}$

88. A parallel circuit has two branch currents: 1.45 A and 1.00 A. What is the current in the energy source?

$I = 1.45 \text{ A} + 1.00 \text{ A} = 2.45 \text{ A}$

89. A series-parallel circuit has three resistors, dissipating 5.50 W, 6.90 W, and 1.05 W, respectively. What is the supply power?

$P = 5.50 \text{ W} + 6.90 \text{ W} + 1.05 \text{ W} = 13.45 \text{ W}$

Level 2

90. Determine the maximum safe power in each of three 150-Ω, 5-W resistors connected in series.

All will dissipate the same power.

$P = (3)(5\ \text{W}) = 15\ \text{W}$

91. Determine the maximum safe power in each of three 92-Ω, 5-W resistors connected in parallel.

Each resistor will develop the same power.

$P = (3)(5\ \text{W}) = 15\ \text{W}$

92. A voltage divider consists of two 47-kΩ resistors connected across a 12-V battery. Determine the measured output for the following.

a. an ideal voltmeter

$$V_B = \frac{VR_B}{R_A + R_B}$$

$$= \frac{(12\ \text{V})(47\ \text{k}\Omega)}{47\ \text{k}\Omega + 47\ \text{k}\Omega}$$

$$= 6.0\ \text{V}$$

b. a voltmeter with a resistance of 85 kΩ

The voltmeter resistance acts in parallel:

$$\frac{1}{R_B} = \frac{1}{R_1} + \frac{1}{R_2}$$

$$= \frac{1}{47\ \text{k}\Omega} + \frac{1}{85\ \text{k}\Omega}$$

$$= \frac{1}{3.3\times10^{-5}\ \Omega}$$

$$R_B = 3.0\times10^{1}\ \text{k}\Omega$$

$$V_B = \frac{VR_B}{R_A + R_B}$$

$$= \frac{(12\ \text{V})(3.0\times10^{1}\ \text{k}\Omega)}{47\ \text{k}\Omega + 3.0\times10^{1}\ \text{k}\Omega}$$

$$= 4.7\ \text{V}$$

c. a voltmeter with a resistance of $10\times10^{6}\ \Omega$

The voltmeter resistance acts in parallel:

$$\frac{1}{R_B} = \frac{1}{R_1} + \frac{1}{R_2}$$

$$= \frac{1}{47\times10^{3}\ \Omega} + \frac{1}{10\times10^{6}\ \Omega}$$

$$= \frac{1}{2.1\times10^{-5}\ \Omega}$$

$$R_B = 47\ \text{k}\Omega$$

$$V_B = \frac{VR_B}{R_A + R_B}$$

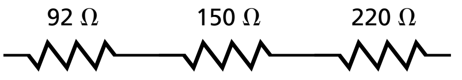
$$= \frac{(12\ \text{V})(47\ \text{k}\Omega)}{47\ \text{k}\Omega + 47\ \text{k}\Omega}$$

$$= 6.0\ \text{V}$$

The meter approaches the ideal voltmeter.

Level 3

93. Determine the maximum safe voltage that can be applied across the three series resistors in **Figure 23-22** if all three are rated at 5.0 W.



■ **Figure 23-22**

Current is constant in a series circuit, so the largest resistor will develop the most power.

$$P = I^2R$$

$$I = \sqrt{\frac{P}{R}} = \sqrt{\frac{5.0\ \text{W}}{220\ \Omega}} = 0.151\ \text{A}$$

The total resistance is now needed.

$$R_{Total} = 92\ \Omega + 150\ \Omega + 220\ \Omega$$

$$= 462\ \Omega$$

Use Ohm's law to find the voltage.

$$V = IR$$

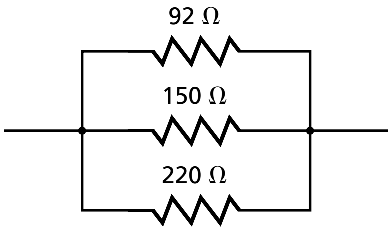
$$= (0.151\ \text{A})(462\ \Omega)$$

$$= 7.0\times10^{1}\ \text{V}$$

94. Determine the maximum safe total power for the circuit in problem 93.

$$P = V^2/R = \frac{(7.0\times10^{1}\ \text{V})^2}{462\ \Omega} = 11\ \text{W}$$

95. Determine the maximum safe voltage that can be applied across three parallel resistors of 92 Ω, 150 Ω, and 220 Ω, as shown in **Figure 23-23,** if all three are rated at 5.0 W.



■ **Figure 23-23**

The 92-Ω resistor will develop the most power because it will conduct the most current.

$$P = \frac{V^2}{R}$$

$$V = \sqrt{PR} = \sqrt{(5.0\ \text{W})(92\ \Omega)} = 21\ \text{V}$$

Thinking Critically

pages 639–640

96. Apply Mathematics Derive equations for the resistance of two equal-value resistors in parallel, three equal-value resistors in parallel, and *N* equal-value resistors in parallel.

$$\frac{1}{R_{eq2}} = \frac{1}{R} + \frac{1}{R} = \frac{2}{R}$$

$$R_{eq2} = \frac{R}{2}$$

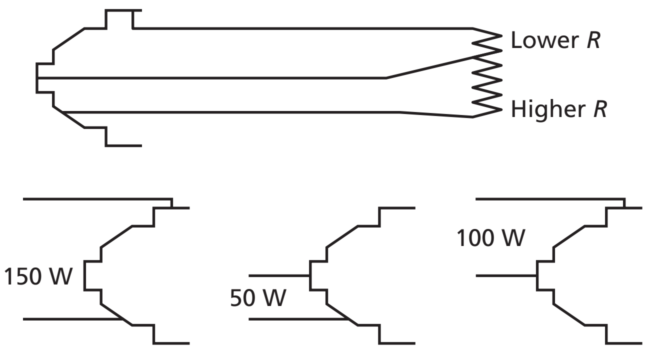
$$\frac{1}{R_{eq3}} = \frac{1}{R} + \frac{1}{R} + \frac{1}{R} = \frac{3}{R}$$

$$R_{eq3} = \frac{R}{3}$$

$$R_{eqN} = \frac{R}{N}$$

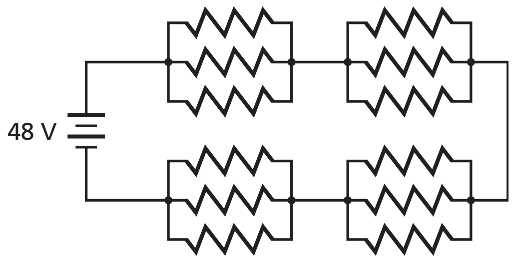
97. Apply Concepts Three-way lamps, of the type in **Figure 23-24,** having a rating of 50 W, 100 W, and 150 W, are common. Draw four partial schematic diagrams that show the lamp filaments and the switch positions for each brightness level, as well as the off position. (You do not need to show the energy source.) Label each diagram.

■ **Figure 23-24**

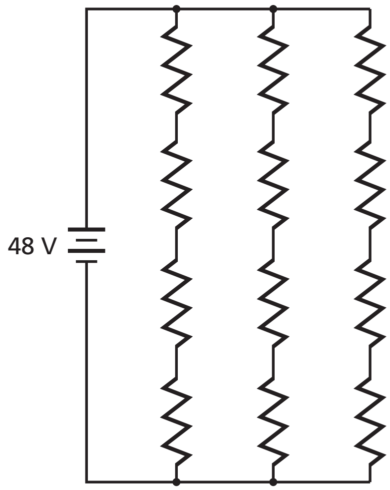


98. Apply Concepts Design a circuit that will light one dozen 12-V bulbs, all to the correct (same) intensity, from a 48-V battery.

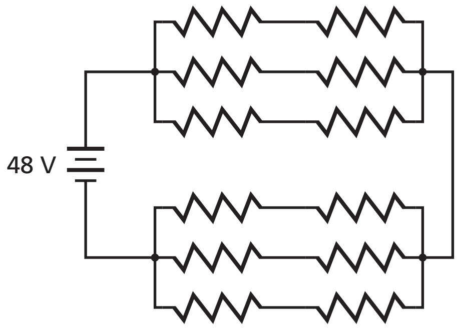
a. Design A requires that should one bulb burn out, all other bulbs continue to produce light.



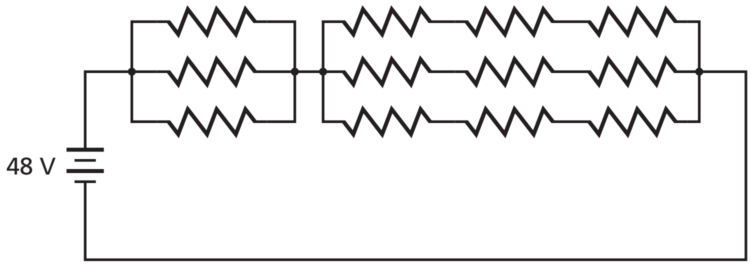
b. Design B requires that should one bulb burn out, those bulbs that continue working must produce the correct intensity.



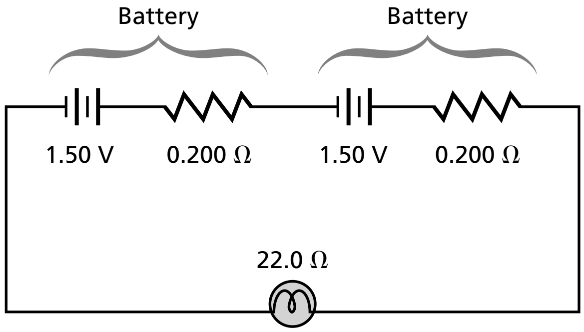
c. Design C requires that should one bulb burn out, one other bulb also will go out.



d. Design D requires that should one bulb burn out, either two others will go out or no others will go out.



99. Apply Concepts A battery consists of an ideal source of potential difference in series with a small resistance. The electric energy of the battery is produced by chemical reactions that occur in the battery. However, these reactions also result in a small resistance that, unfortunately, cannot be completely eliminated. A flashlight contains two batteries in series, as shown in **Figure 23-25.** Each has a potential difference of 1.50 V and an internal resistance of 0.200 Ω. The bulb has a resistance of 22.0 Ω.



■ **Figure 23-25**

a. What is the current through the bulb?

The circuit has two 1.50-V batteries in series with three resistors: 0.200 Ω, 0.200 Ω, and 22.0 Ω. The equivalent resistance is 22.4 Ω. The current is

$$I = \frac{V}{R}$$
$$= \frac{2(1.50)\text{ V}}{(2(0.200\ \Omega) + 22.0\ \Omega)}$$
$$= 0.134\text{ A}$$

b. How much power does the bulb dissipate?

The power dissipated is

$$P = I^2R$$
$$= (0.134\text{ A})^2(22.0\ \Omega)$$
$$= 0.395\text{ W}$$

c. How much greater would the power be if the batteries had no internal resistance?

$$P = IV = \frac{V^2}{R} = \frac{(3.00\text{ V})^2}{22.0\ \Omega} = 0.409\text{ W}$$

$$\Delta P = 0.409\text{ W} - 0.395\text{ W} = 0.014\text{ W}$$

Power would be 0.014 W greater.

100. Apply Concepts An ohmmeter is made by connecting a 6.0-V battery in series with an adjustable resistor and an ideal ammeter. The ammeter deflects full-scale with a current of 1.0 mA. The two leads are touched together and the resistance is adjusted so that 1.0 mA flows.

a. What is the resistance of the adjustable resistor?

$$V = IR$$

$$R = \frac{V}{I} = \frac{6.0\text{ V}}{1.0\times10^{-3}\text{ A}} = 6.0\text{ k}\Omega$$

b. The leads are now connected to an unknown resistance. What resistance would produce a current of half-scale, 0.50 mA? Quarter-scale, 0.25 mA? Three-quarters-scale, 0.75 mA?

$$R = \frac{V}{I} = \frac{6.0\text{ V}}{0.50\times10^{-3}\text{ A}} = 12\text{ k}\Omega$$

and $R_T = R_1 + R_e$, so

$$R_e = R_T - R_1$$
$$= 12\text{ k}\Omega - 6.0\text{ k}\Omega$$
$$= 6.0\text{ k}\Omega$$

$$R = \frac{V}{I} = \frac{6.0\text{ V}}{0.25\times10^{-3}\text{ A}} = 24\text{ k}\Omega$$

and $R_e = R_T - R_1$
$$= 24\text{ k}\Omega - 6.0\text{ k}\Omega$$
$$= 18\text{ k}\Omega$$

$$R = \frac{V}{I} = \frac{6.0\text{ V}}{0.75\times10^{-3}\text{ A}} = 8.0\text{ k}\Omega$$

and $R_e = R_T - R_1$
$$= 8.0\text{ k}\Omega - 6.0\text{ k}\Omega$$
$$= 2.0\text{ k}\Omega$$

c. Is the ohmmeter scale linear? Explain.

No. Zero ohms is at full-scale, 6 kΩ is at midscale, and infinite Ω (or open-circuit) is at zero-scale.

Writing in Physics

page 640

101. Research Gustav Kirchhoff and his laws. Write a one-page summary of how they apply to the three types of circuits presented in this chapter.

Key ideas are:

(1) Kirchhoff's Voltage Law (KVL) is conservation of energy applied to electric circuits.

(2) Kirchhoff's Current Law (KCL) is conservation of charge applied to electric circuits.

(3) KVL states that the algebraic sum of voltage drops around a closed loop is zero. In a series circuit there is one closed loop, and the sum of voltage drops in the resistances equals the source voltage. In a

parallel circuit, there is a closed loop for each branch, and KVL implies that the voltage drop in each branch is the same.

(4) KCL states that the algebraic sum of currents at a node is zero. In a series circuit, at every point the current in equals current out; therefore, the current is the same everywhere. In a parallel circuit, there is a common node at each end of the branches. KCL implies that the sum of the branch currents equals the source current.

Cumulative Review

page 640

102. Airplane An airplane flying through still air produces sound waves. The wave fronts in front of the plane are spaced 0.50 m apart and those behind the plane are spaced 1.50 m apart. The speed of sound is 340 m/s. (Chapter 15)

a. What would be the wavelength of the sound waves if the airplane were not moving?

1.00 m

b. What is the frequency of the sound waves produced by the airplane?

$f = v/\lambda = (340\text{ m/s})/(1.00\text{ m}) = 340\text{ Hz}$

c. What is the speed of the airplane?

The airplane moves forward 0.50 m for every 1.00 m that the sound waves move, so its speed is one-half the speed of sound, 170 m/s.

d. What is the frequency detected by an observer located directly in front of the airplane?

$$f = v/\lambda = (340\text{ m/s})/(0.50\text{ m}) = 680\text{ Hz, or}$$

$$f_d = f_s\left(\frac{v - v_d}{v - v_s}\right) = (340\text{ Hz})\left(\frac{340\text{ m/s} - 0}{340\text{ m/s} - 170\text{ m/s}}\right) = 680\text{ Hz}$$

e. What is the frequency detected by an observer located directly behind the airplane?

$$f = v/\lambda = (340\text{ m/s})/(1.50\text{ m}) = 230\text{ Hz, or}$$

$$f_d = f_s\left(\frac{v - v_d}{v - v_s}\right) = (340\text{ Hz})\left(\frac{340\text{ m/s} - 0}{340\text{ m/s} - (-170\text{ m/s})}\right) = 230\text{ Hz}$$

103. An object is located 12.6 cm from a convex mirror with a focal length of −18.0 cm. What is the location of the object's image? (Chapter 17)

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$d_i = \frac{d_o f}{d_o - f} = \frac{(12.6\text{ cm})(-18.0\text{ cm})}{12.6\text{ cm} - (-18.0\text{ cm})} = -7.41\text{ cm}$$

104. The speed of light in a special piece of glass is 1.75×10^8 m/s. What is its index of refraction? (Chapter 18)

$$n = \frac{c}{v} = \frac{3.00\times10^8\text{ m/s}}{1.75\times10^8\text{ m/s}} = 1.71$$

105. Monocle An antireflective coating with an index of refraction of 1.4 is applied to a monocle with an index of refraction of 1.52. If the thickness of the coating is 75 nm, what is/are the wavelength(s) of light for which complete destructive interference will occur? (Chapter 19)

Because $n_{film} > n_{air}$, there is a phase inversion on the first reflection. Because $n_{monocle} > n_{film}$, there is a phase inversion on the second reflection.

For destructive interference:

$$2t = \left(m + \frac{1}{2}\right)\frac{\lambda}{n_{film}}$$

$$\lambda = \frac{2tn_{\text{film}}}{m + \frac{1}{2}}$$

$$= \frac{(2)(75\ \text{nm})(1.4)}{m + \frac{1}{2}}$$

$$= \left(m + \frac{1}{2}\right)^{-1}(2.1\times10^{2}\ \text{nm})$$

For $m = 0$

$$= \left(\frac{1}{2}\right)^{-1}(2.1\times10^{2}\ \text{nm})$$

$$= 4.2\times10^{2}\ \text{nm}$$

For $m = 1$

$$= \left(\frac{3}{2}\right)^{-1}(2.1\times10^{2}\ \text{nm})$$

$$= 2.8\times10^{2}\ \text{nm}$$

This is an ultraviolet wavelength, so it is not light. All other values of m give wavelengths that are shorter than the light. So $\lambda = 4.2\times10^{2}$ nm is the only wavelength of light for which destructive interference occurs.

106. Two charges of 2.0×10^{-5} C and 8.0×10^{-6} C experience a force between them of 9.0 N. How far apart are the two charges? (Chapter 20)

$$F = K\frac{q_Aq_B}{d^2}, \text{ so } d = \sqrt{\frac{Kq_Aq_B}{F}}$$

$$= \sqrt{\frac{(9.0\times10^{9}\ \text{N·m}^2/\text{C}^2)(2.0\times10^{-5}\ \text{C})(8.0\times10^{-6}\ \text{C})}{9.0\ \text{N}}} = 0.40\ \text{m}$$

107. A field strength, E, is measured a distance, d, from a point charge, Q. What would happen to the magnitude of E in the following situations? (Chapter 21)

$$E = \frac{KQ}{d^2}$$

a. d is tripled

$\frac{E}{9}$

b. Q is tripled

3*E*

c. both d and Q are tripled

$\frac{E}{3}$

d. the test charge q' is tripled

***E*; by definition, field strength is force per unit test charge.**

e. all three, d, Q, and q', are tripled

$\frac{E}{3}$

108. The current flow in a 12-V circuit drops from 0.55 A to 0.44 A. Calculate the change in resistance. (Chapter 22)

$\mathbf{R_1 = V/I = 12\ V/0.55\ A = 21.8\ \Omega}$

$\mathbf{R_2 = V/I = 12\ V/0.44\ A = 27.3\ \Omega}$

$\mathbf{\Delta R = R_2 - R_1}$

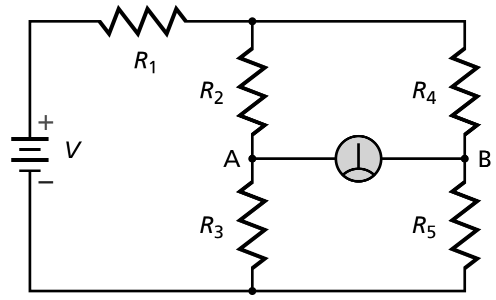
$$= \frac{12\text{ V}}{0.44\text{ A}} - \frac{12\text{ V}}{0.55\text{ A}}$$

$$= 5.5\ \Omega$$

Challenge Problem

page 628

When the galvanometer, a device used to measure very small currents or voltages, in this circuit measures zero, the circuit is said to be balanced.



1. Your lab partner states that the only way to balance this circuit is to make all the resistors equal. Will this balance the circuit? Is there more than one way to balance this circuit? Explain.

Yes; yes. You also can balance the circuit by adjusting the resistance values so that $R_7/R_3 = R_4/R_5$ remains equal.

2. Derive a general equation for a balanced circuit using the given labels. *Hint: Treat the circuit as a voltage divider.*

One definition of balance is that $V_{AB} = 0$. If this is so, then $V_{R3} = V_{R5}$. These voltage drops can be defined using Ohm's law:

$V_{R3} = I_1R_3$ **and** $V_{R5} = I_2R_5$

also, $I_1 = \dfrac{V - (I_1 + I_2)R_1}{R_2 + R_3}$

and $I_2 = \dfrac{V - (I_1 + I_2)R_1}{R_4 + R_5}$

substitute $V_{R3} = \dfrac{R_3V - (I_1 + I_2)R_1R_3}{R_2 + R_3}$

and $V_{R5} = \dfrac{R_5V - (I_1 + I_2)R_1R_5}{R_4 + R_5}$

$V_{R3} = V_{R5}$**. Removing R_3 from the left numerator and R_5 from the right numerator gives the following:**

$$\frac{V - (I_1 + I_2)R_1}{\left(\frac{R_2}{R_3} + 1\right)} = \frac{V - (I_1 + I_2)R_1}{\left(\frac{R_4}{R_5} + 1\right)}$$

$$\frac{1}{\left(\frac{R_2}{R_3} + 1\right)} = \frac{1}{\left(\frac{R_4}{R_5} + 1\right)}$$

$$\frac{R_3}{R_2} = \frac{R_5}{R_4}$$

3. Which of the resistors can be replaced with a variable resistor and then used to balance the circuit?

any resistor but R_1

4. Which of the resistors can be replaced with a variable resistor and then used as a sensitivity control? Why would this be necessary? How would it be used in practice?

R_1. A galvanometer is a sensitive instrument and can be damaged by too much current flow. If R_1 is adjustable, it is set for a high value before the circuit is energized. This limits the current flow through the galvanometer if the circuit happens to be way out of balance. As the balancing resistor is adjusted and as the meter reading approaches zero, the sensitivity then is increased by decreasing R_1.

CHAPTER 24 Magnetic Fields

Practice Problems

24.1 Magnets: Permanent and Temporary pages 643–651

page 647

1. If you hold a bar magnet in each hand and bring your hands close together, will the force be attractive or repulsive if the magnets are held in the following ways?

a. the two north poles are brought close together

repulsive

b. a north pole and a south pole are brought together

attractive

2. **Figure 24-7** shows five disk magnets floating above each other. The north pole of the top-most disk faces up. Which poles are on the top side of each of the other magnets?

■ **Figure 24-7**

south, north, south, north

3. A magnet attracts a nail, which, in turn, attracts many small tacks, as shown in Figure 24-3 on page 645. If the north pole of the permanent magnet is the left end, as shown, which end of the nail is the south pole?

the bottom (the point)

4. Why do magnetic compasses sometimes give false readings?

because Earth's magnetic field is distorted by objects made of iron, nickel, or cobalt in the vicinity of the compass, and by ore deposits of these same metals

page 650

5. A long, straight, current-carrying wire runs from north to south.

a. A compass needle placed above the wire points with its north pole toward the east. In what direction is the current flowing?

from south to north

b. If a compass is put underneath the wire, in which direction will the compass needle point?

west

6. How does the strength of a magnetic field, 1 cm from a current-carrying wire, compare with each of the following?

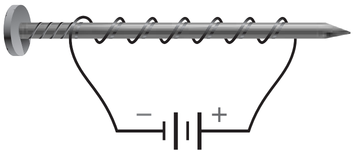
a. the strength of the field that is 2 cm from the wire

Because magnetic field strength varies inversely with the distance from the wire, the magnetic field at 1 cm will be twice as strong as the magnetic field at 2 cm.

b. the strength of the field that is 3 cm from the wire

Because magnetic field strength varies inversely with the distance from the wire, the magnetic field at 1 cm will be three times as strong as the magnetic field at 3 cm.

7. A student makes a magnet by winding wire around a nail and connecting it to a battery, as shown in **Figure 24-13.** Which end of the nail, the pointed end or the head, will be the north pole?



■ **Figure 24-13**

the pointed end

8. You have a spool of wire, a glass rod, an iron rod, and an aluminum rod. Which rod should you use to make an electromagnet to pick up steel objects? Explain.

Use the iron rod. Iron would be attracted to a permanent magnet and take on properties of a magnet, whereas aluminum or glass would not. This effect would support the magnetic field in the wire coil and thus make the strongest electromagnet.

9. The electromagnet in problem 8 works well, but you decide that you would like to make its strength adjustable by using a potentiometer as a variable resistor. Is this possible? Explain.

Yes. Connect the potentiometer in series with the power supply and the coil. Adjusting the potentiometer for more resistance will decrease the current flow and the strength of the field.

Section Review

24.1 Magnets: Permanent and Temporary pages 643–651

page 651

10. **Magnetic Fields** Is a magnetic field real, or is it just a means of scientific modeling?

Field lines are not real. The field is real.

11. **Magnetic Forces** Identify some magnetic forces around you. How could you demonstrate the effects of those forces?

Student answers may vary. Answers could include magnets on a refrigerator and Earth's magnetic field. The effects of these forces can be demonstrated by bringing another magnet, or a material that can be magnetized, nearby.

12. **Magnetic Fields** A current-carrying wire is passed through a card on which iron filings are sprinkled. The filings show the magnetic field around the wire. A second wire is close to and parallel to the first wire. There is an identical current in the second wire. If the two currents are in the same direction, how will the first magnetic field be affected? How will it be affected if the two currents are in opposite directions?

It would be approximately twice as large; it would be approximately zero.

13. **Direction of a Magnetic Field** Describe the right-hand rule used to determine the direction of a magnetic field around a straight, current-carrying wire.

If you grasp the wire with your right hand, with your thumb pointing in the direction of the conventional current, your fingers curl in the direction of the field.

14. **Electromagnets** A glass sheet is placed over an active electromagnet, and iron filings sprinkled on the sheet create a pattern on it. If this experiment is repeated with the polarity of the power supply reversed, what observable differences will result? Explain.

None. The filings would show the same field pattern but a compass would show the magnetic polarity reversal.

15. **Critical Thinking** Imagine a toy containing two parallel, horizontal metal rods, one above the other. The top rod is free to move up and down.

a. The top rod floats above the lower one. If the top rod's direction is reversed, however, it falls down onto the lower rod. Explain why the rods could behave in this way.

The metal rods could be magnets with their axes parallel. If the top

magnet is positioned so that its north and south poles are above the north and south poles of the bottom magnet, it will be repelled and float above. If the top magnet is turned end for end, it will be attracted to the bottom magnet.

b. Assume that the top rod was lost and replaced with another one. In this case, the top rod falls on top of the bottom rod no matter what its orientation is. What type of replacement rod must have been used?

If an ordinary iron bar is used on top, it will be attracted to the bottom magnet in any orientation.

Practice Problems

24.2 Forces Caused by Magnetic Fields pages 652–659

page 654

16. What is the name of the rule used to predict the direction of force on a current-carrying wire at right angles to a magnetic field? Identify what must be known to use this rule.

Third right-hand rule. The direction of the current and the direction of the field must be known.

17. A wire that is 0.50 m long and carrying a current of 8.0 A is at right angles to a 0.40-T magnetic field. How strong is the force that acts on the wire?

$$F = BIL = (0.40\ \text{N/A·m})(8.0\ \text{A})(0.50\ \text{m}) = 1.6\ \text{N}$$

18. A wire that is 75 cm long, carrying a current of 6.0 A, is at right angles to a uniform magnetic field. The magnitude of the force acting on the wire is 0.60 N. What is the strength of the magnetic field?

$$F = BIL$$

$$B = \frac{F}{IL} = \frac{0.60\ \text{N}}{(6.0\ \text{A})(0.75\ \text{m})} = 0.13\ \text{T}$$

19. A 40.0-cm-long copper wire carries a current of 6.0 A and weighs 0.35 N. A certain magnetic field is strong enough to balance the force of gravity on the wire. What is the strength of the magnetic field?

$F = BIL$, where F = weight of the wire

$$B = \frac{F}{IL} = \frac{0.35\ \text{N}}{(6.0\ \text{A})(0.400\ \text{m})} = 0.15\ \text{T}$$

20. How much current will be required to produce a force of 0.38 N on a 10.0 cm length of wire at right angles to a 0.49-T field?

$$F = BIL$$

$$I = \frac{F}{BL} = \frac{0.38\ \text{N}}{(0.49\ \text{T})(0.100\ \text{m})} = 7.8\ \text{A}$$

page 658

21. In what direction does the thumb point when using the third right-hand rule for an electron moving at right angles to a magnetic field?

opposite to the direction of the electron motion

22. An electron passes through a magnetic field at right angles to the field at a velocity of 4.0×10^{6} m/s. The strength of the magnetic field is 0.50 T. What is the magnitude of the force acting on the electron?

$$F = Bqv$$
$$= (0.50\ \text{T})(1.60\times10^{-19}\ \text{C})(4.0\times10^{6}\ \text{m/s})$$
$$= 3.2\times10^{-13}\ \text{N}$$

23. A stream of doubly ionized particles (missing two electrons, and thus, carrying a net charge of two elementary charges) moves at a velocity of 3.0×10^{4} m/s perpendicular to a magnetic field of 9.0×10^{-2} T. What is the magnitude of the force acting on each ion?

$$F = Bqv$$
$$= (9.0\times10^{-2}\ \text{T})(2)(1.60\times10^{-19}\ \text{C})(3.0\times10^{4}\ \text{m/s})$$
$$= 8.6\times10^{-16}\ \text{N}$$

24. Triply ionized particles in a beam carry a net positive charge of three elementary charge units. The beam enters a magnetic field of 4.0×10^{-2} T. The particles have a speed of 9.0×10^{6} m/s. What is the magnitude of the force acting on each particle?

$$F = Bqv$$
$$= (4.0\times10^{-2}\ \text{T})(3)(1.60\times10^{-19}\ \text{C})(9.0\times10^{6}\ \text{m/s})$$
$$= 1.7\times10^{-13}\ \text{N}$$

25. Doubly ionized helium atoms (alpha particles) are traveling at right angles to a magnetic field at a speed of 4.0×10^{4} m/s. The field strength is 5.0×10^{-2} T. What force acts on each particle?

$$F = Bqv$$
$$= (5.0\times10^{-2}\ \text{T})(2)(1.60\times10^{-19}\ \text{C})(4.0\times10^{4}\ \text{m/s})$$
$$= 6.4\times10^{-16}\ \text{N}$$

Section Review

24.2 Forces Caused by Magnetic Fields pages 652–659

page 659

26. Magnetic Forces Imagine that a current-carrying wire is perpendicular to Earth's magnetic field and runs east-west. If the current is east, in which direction is the force on the wire?

up, away from the surface of Earth

27. Deflection A beam of electrons in a cathode-ray tube approaches the deflecting magnets. The north pole is at the top of the tube; the south pole is on the bottom. If you are looking at the tube from the direction of the phosphor screen, in which direction are the electrons deflected?

to the left side of the screen

28. Galvanometers Compare the diagram of a galvanometer in Figure 24-18 on page 655 with the electric motor in Figure 24-20 on page 656. How is the galvanometer similar to an electric motor? How are they different?

Both the galvanometer and the electric motor use a loop of wire positioned between the poles of a permanent magnet. When a current passes through the loop, the magnetic field of the permanent magnet exerts a force on the loop. The loop in a galvanometer cannot rotate more than 180°. The loop in an electric motor rotates through many 360° turns. The motor's split-ring commutator allows the current in the loop to reverse as the loop becomes vertical in the magnetic field, enabling the loop to spin in the magnetic field. The galvanometer measures unknown currents; the electric motor has many uses.

29. Motors When the plane of the coil in a motor is perpendicular to the magnetic field, the forces do not exert a torque on the coil. Does this mean that the coil does not rotate? Explain.

Not necessarily; if the coil is already in rotation, then rotational inertia will carry it past the point of zero torque. It is the coil's acceleration that is zero, not the velocity.

30. Resistance A galvanometer requires 180 μA for full-scale deflection. What is the total resistance of the meter and the multiplier resistor for a 5.0-V full-scale deflection?

$$R = \frac{V}{I} = \frac{50\ \text{V}}{180\ \mu\text{A}} = 28\ \text{k}\Omega$$

31. Critical Thinking How do you know that the forces on parallel current-carrying wires are a result of magnetic attraction between wires, and not a result of electrostatics? *Hint: Consider what the charges are like when the force is attractive. Then consider what the forces are when three wires carry currents in the same direction.*

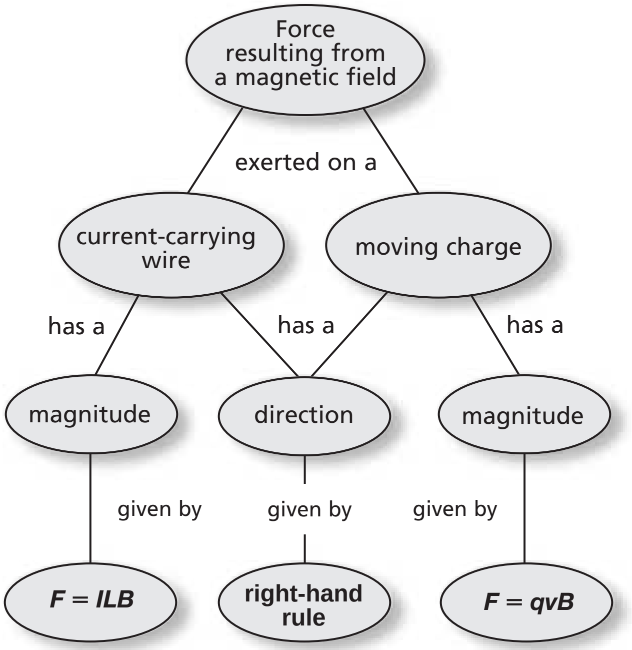
If the currents are in the same direction, the force is attractive. If it were due to electrostatic forces, the like charges would make the force repulsive. Three wires would all attract each other, which could never happen if the forces were due to electrostatic charges.

Chapter Assessment

Concept Mapping

page 664

32. Complete the following concept map using the following: *right-hand rule*, $F = qvB$, and $F = ILB$.



Mastering Concepts

page 664

33. State the rule for magnetic attraction and repulsion. (24.1)

Like poles repel one another; opposite poles attract.

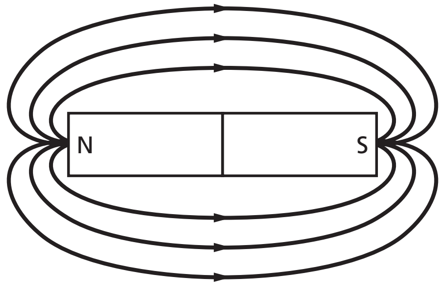
34. Describe how a temporary magnet differs from a permanent magnet. (24.1)

A temporary magnet is like a magnet only while under the influence of another magnet. A permanent magnet needs no outside influence.

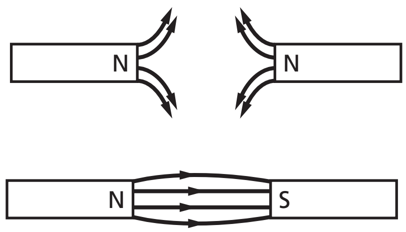
35. Name the three most important common magnetic elements. (24.1)

iron, cobalt, and nickel

36. Draw a small bar magnet and show the magnetic field lines as they appear around the magnet. Use arrows to show the direction of the field lines. (24.1)



37. Draw the magnetic field between two like magnetic poles and then between two unlike magnetic poles. Show the directions of the fields. (24.1)



38. If you broke a magnet in two, would you have isolated north and south poles? Explain. (24.1)

No, new poles would form on each of the broken ends.

39. Describe how to use the first right-hand rule to determine the direction of a magnetic field around a straight current-carrying wire. (24.1)

Grasp the wire with the right hand, keeping thumb pointing in the direction of the conventional current through the wire. Fingers will encircle the wire and point in the direction of the field.

40. If a current-carrying wire is bent into a loop, why is the magnetic field inside the loop stronger than the magnetic field outside? (24.1)

The magnetic field lines are concentrated inside the loop.

41. Describe how to use the second right-hand rule to determine the polarity of an electromagnet. (24.1)

Grasp the coil with the right hand, keeping the fingers encircling the coil in the direction of the conventional current flow through the loops. The thumb of the right hand will point toward the north pole of the electromagnet.

42. Each electron in a piece of iron is like a tiny magnet. The iron, however, may not be a magnet. Explain. (24.1)

The electrons are not all oriented and moving in the same direction; their magnetic fields have random directions.

43. Why will dropping or heating a magnet weaken it? (24.1)

The domains are jostled out of alignment.

44. Describe how to use the third right-hand rule to determine the direction of force on a current-carrying wire placed in a magnetic field. (24.2)

Point the fingers of your right hand in the direction of the magnetic field. Point your thumb in the direction of the conventional current in the wire. The palm of your hand then faces in the direction of the force on the wire.

45. A strong current suddenly is switched on in a wire. No force acts on the wire, however. Can you conclude that there is no magnetic field at the location of the wire? Explain. (24.2)

No, if a field is parallel to the wire, no force would result.

46. What kind of meter is created when a shunt is added to a galvanometer? (24.2)

an ammeter

Applying Concepts

pages 664–665

47. A small bar magnet is hidden in a fixed position inside a tennis ball. Describe an experiment that you could do to find the location of the north pole and the south pole of the magnet.

Use a compass. The north pole of the compass needle is attracted to the south pole of the magnet and vice versa.

48. A piece of metal is attracted to one pole of a large magnet. Describe how you could tell whether the metal is a temporary magnet or a permanent magnet.

Move it to the other pole. If the same end is attracted, it is a temporary magnet; if the same end is repelled and the other end is attracted, it is a permanent magnet.

49. Is the magnetic force that Earth exerts on a compass needle less than, equal to, or greater than the force that the compass needle exerts on Earth? Explain.

The forces are equal according to Newton's third law.

50. **Compass** Suppose you are lost in the woods but have a compass with you. Unfortunately, the red paint marking the north pole of the compass needle has worn off. You have a flashlight with a battery and a length of wire. How could you identify the north pole of the compass?

Connect the wire to the battery so that the current is away from you in one section. Hold the compass directly above and close to that section of the wire. By the right-hand rule, the end of the compass needle that points right is the north pole.

51. A magnet can attract a piece of iron that is not a permanent magnet. A charged rubber rod can attract an uncharged insulator. Describe the different microscopic processes producing these similar phenomena.

The magnet causes the domains in the iron to point in the same direction. The charged rod separates the positive and negative charges in the insulator.

52. A current-carrying wire runs across a laboratory bench. Describe at least two ways in which you could find the direction of the current.

Use a compass to find the direction of the magnetic field. Bring up a strong magnet and find the direction of the force on the wire, then use the right-hand rule.

53. In which direction, in relation to a magnetic field, would you run a current-carrying wire so that the force on it, resulting from the field, is minimized, or even made to be zero?

Run the wire parallel to the magnetic field.

54. Two wires carry equal currents and run parallel to each other.

a. If the two currents are in opposite directions, where will the magnetic field from the two wires be larger than the field from either wire alone?

The magnetic field will be larger anywhere between the two wires.

b. Where will the magnetic field from both be exactly twice as large as from one wire?

The magnetic field will be twice as large along a line directly between the wires that is equal in distance from each wire.

c. If the two currents are in the same direction, where will the magnetic field be exactly zero?

The magnetic field will be zero along a line directly between the wires that is equal in distance from each wire.

55. How is the range of a voltmeter changed when the resistor's resistance is increased?

The range of the voltmeter increases.

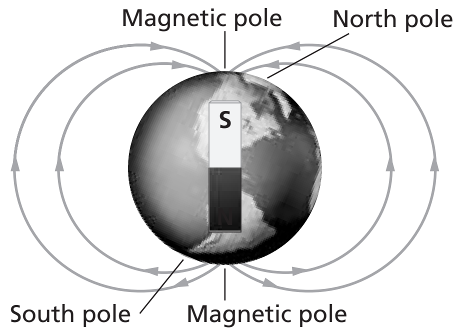
56. A magnetic field can exert a force on a charged particle. Can the field change the particle's kinetic energy? Explain.

No, the force is always perpendicular to the velocity. No work is done. The energy is not changed.

57. A beam of protons is moving from the back to the front of a room. It is deflected upward by a magnetic field. What is the direction of the field causing the deflection?

Facing the front of the room, the velocity is forward, the force is upward, and therefore, using the third right-hand rule, B is to the left.

58. Earth's magnetic field lines are shown in **Figure 24-23.** At what location, poles or equator, is the magnetic field strength greatest? Explain.



■ **Figure 24-23**

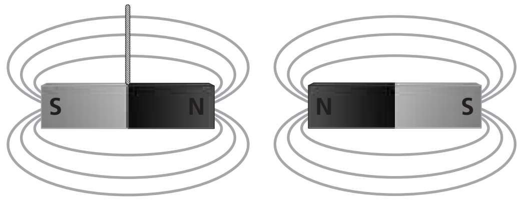
Earth's magnetic field strength is greatest at the poles. The field lines are closer together at the poles.

Mastering Problems

24.1 Magnets: Permanent and Temporary pages 665–666

Level 1

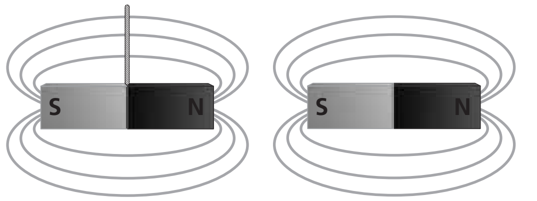
59. As the magnet below in **Figure 24-24** moves toward the suspended magnet, what will the magnet suspended by the string do?



■ **Figure 24-24**

Move to the left or begin to turn. Like poles repel.

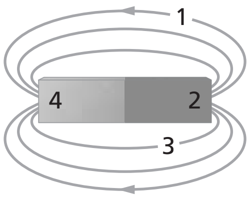
60. As the magnet in **Figure 24-25** moves toward the suspended magnet, what will the magnet that is suspended by the string do?



■ **Figure 24-25**

Move to the right. Unlike poles attract.

61. Refer to **Figure 24-26** to answer the following questions.



■ **Figure 24-26**

a. Where are the poles?

4 and 2, by definition

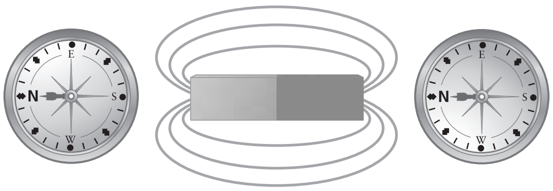
b. Where is the north pole?

2, by definition and field direction

c. Where is the south pole?

4, by definition and field direction

62. **Figure 24-27** shows the response of a compass in two different positions near a magnet. Where is the south pole of the magnet located?



■ **Figure 24-27**

At the right end, unlike poles attract.

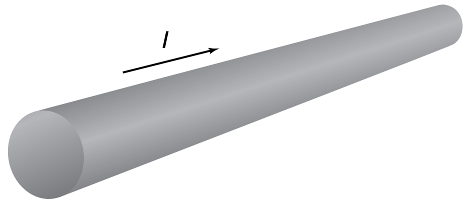
63. A wire that is 1.50 m long and carrying a current of 10.0 A is at right angles to a uniform magnetic field. The force acting on the wire is 0.60 N. What is the strength of the magnetic field?

$$\boldsymbol{F = ILB}$$

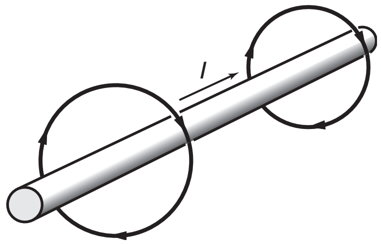
$$\boldsymbol{B = \frac{F}{IL} = \frac{0.60\ \text{N}}{(10.0\ \text{A})(1.50\ \text{m})} = 0.040\ \text{N/A·m}}$$

$$\boldsymbol{= 0.040\ \text{T}}$$

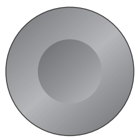
64. A conventional current flows through a wire, as shown in **Figure 24-28.** Copy the wire segment and sketch the magnetic field that the current generates.



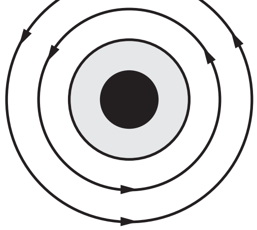
■ **Figure 24-28**



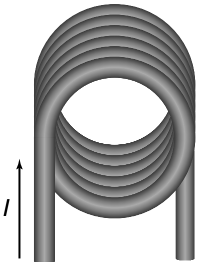
65. The current is coming straight out of the page in **Figure 24-29.** Copy the figure and sketch the magnetic field that the current generates.



■ **Figure 24-29**



66. **Figure 24-30** shows the end view of an electromagnet with current flowing through it.



■ **Figure 24-30**

a. What is the direction of the magnetic field inside the loops?

down into the page

b. What is the direction of the magnetic field outside the loops?

up (out of the page)

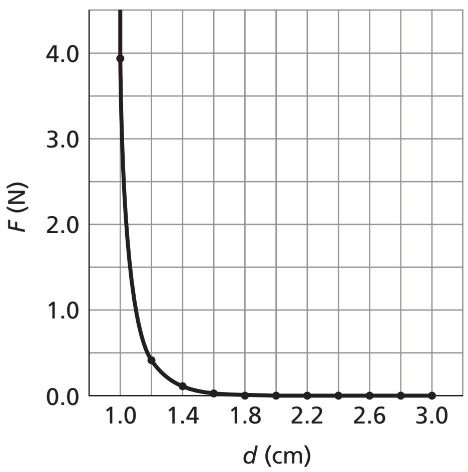
Level 2

67. **Ceramic Magnets** The repulsive force between two ceramic magnets was measured and found to depend on distance, as given in **Table 24-1.**

Table 24-1

Separation, *d* (cm)	Force, *F* (N)
1.0	3.93
1.2	0.40
1.4	0.13
1.6	0.057
1.8	0.030
2.0	0.018
2.2	0.011
2.4	0.0076
2.6	0.0053
2.8	0.0038
3.0	0.0028

a. Plot the force as a function of distance.



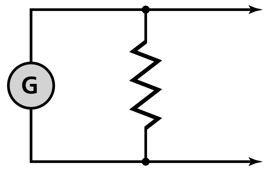
b. Does this force follow an inverse square law?

No.

24.2 Forces Caused by Magnetic Fields pages 666–667

Level 1

68. The arrangement shown in **Figure 24-31** is used to convert a galvanometer to what type of device?



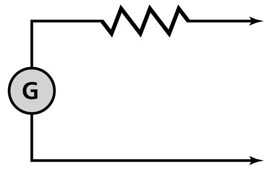
■ **Figure 24-31**

Ammeter, much of the current flows through the resistor and allows the measurement of higher currents.

69. What is the resistor shown in Figure 24-31 called?

Shunt; by definition shunt is another word for parallel.

70. The arrangement shown in **Figure 24-32** is used to convert a galvanometer to what type of device?



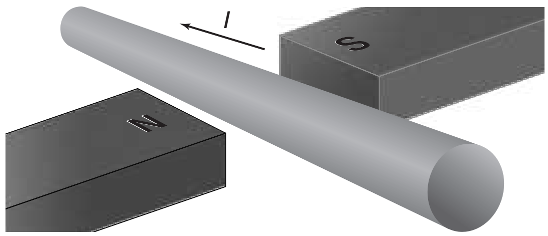
■ **Figure 24-32**

Voltmeter; the added resistance decreases the current for any given voltage.

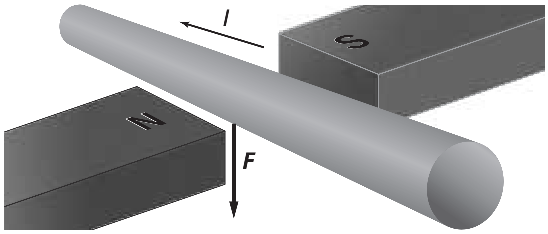
71. What is the resistor shown in Figure 24-32 called?

Multiplier; by definition since it multiplies the voltage range of the meter

72. A current-carrying wire is placed between the poles of a magnet, as shown in **Figure 24-33.** What is the direction of the force on the wire?



■ **Figure 24-33**



73. A wire that is 0.50 m long and carrying a current of 8.0 A is at right angles to a uniform magnetic field. The force on the wire is 0.40 N. What is the strength of the magnetic field?

$F = ILB$

$B = \frac{F}{IL} = \frac{0.40\text{ N}}{(8.0\text{ A})(0.50\text{ m})} = 0.10\text{ T}$

74. The current through a wire that is 0.80 m long is 5.0 A. The wire is perpendicular to a 0.60-T magnetic field. What is the magnitude of the force on the wire?

$F = ILB = (5.0\text{ A})(0.80\text{ m})(0.60\text{ N/A·m})$

$= 2.4\text{ N}$

75. A wire that is 25 cm long is at right angles to a 0.30-T uniform magnetic field. The current through the wire is 6.0 A. What is the magnitude of the force on the wire?

$F = ILB = (6.0\text{ A})(0.25\text{ m})(0.30\text{ N/A·m})$

$= 0.45\text{ N}$

76. A wire that is 35 cm long is parallel to a 0.53-T uniform magnetic field. The current through the wire is 4.5 A. What force acts on the wire?

If the wire is parallel to the field, no cutting is taking place, so no force is produced.

77. A wire that is 625 m long is perpendicular to a 0.40-T magnetic field. A 1.8-N force acts on the wire. What current is in the wire?

$F = ILB$

$I = \frac{F}{BL} = \frac{1.8\text{ N}}{(0.40\text{ T})(625\text{ m})}$

$= 0.0072\text{ A}$

$= 7.2\text{ mA}$

78. The force on a 0.80-m wire that is perpendicular to Earth's magnetic field is 0.12 N. What is the current in the wire? Use 5.0×10^{-5} T for Earth's magnetic field.

$F = ILB$

$I = \frac{F}{BL} = \frac{0.12\text{ N}}{(5.0\times10^{-5}\text{ T})(0.80\text{ m})}$

$= 3.0\times10^{3}\text{ A}$

$= 3.0\text{ kA}$

79. The force acting on a wire that is at right angles to a 0.80-T magnetic field is 3.6 N. The current in the wire is 7.5 A. How long is the wire?

$F = ILB$

$L = \frac{F}{BI} = \frac{3.6\text{ N}}{(0.80\text{ T})(7.5\text{ A})} = 0.60\text{ m}$

Level 2

80. A power line carries a 225-A current from east to west, parallel to the surface of Earth.

a. What is the magnitude of the force resulting from Earth's magnetic field acting on each meter of the wire? Use $B_{\text{Earth}} = 5.0\times10^{-5}$ T.

$F = ILB$

$\frac{F}{L} = IB = (225\text{ A})(5.0\times10^{-5}\text{ T})$

$= 0.011\text{ N/m}$

b. What is the direction of the force?

The force would be downward.

c. In your judgment, would this force be important in designing towers to hold this power line? Explain.

No; the force is much smaller than the weight of the wires.

81. Galvanometer A galvanometer deflects full-scale for a 50.0-μA current.

a. What must be the total resistance of the series resistor and the galvanometer to make a voltmeter with 10.0-V full-scale deflection?

$$V = IR$$

$$R = \frac{V}{I} = \frac{10.0 \text{ V}}{50.0\times10^{-6} \text{ A}} = 2.00\times10^{5}\ \Omega$$

$$= 2.00\times10^{2}\ \text{k}\Omega$$

b. If the galvanometer has a resistance of 1.0 kΩ, what should be the resistance of the series (multiplier) resistor?

Total resistance = 2.00×10^{2} kΩ, so the series resistor is 2.00×10^{2} kΩ − 1.0 kΩ = 199 kΩ.

82. The galvanometer in problem 81 is used to make an ammeter that deflects full-scale for 10 mA.

a. What is the potential difference across the galvanometer (1.0 kΩ resistance) when a current of 50 μA passes through it?

$$V = IR = (50\times10^{-6} \text{ A})(1.0\times10^{3}\ \Omega)$$

$$= 0.05 \text{ V}$$

b. What is the equivalent resistance of parallel resistors having the potential difference calculated in a circuit with a total current of 10 mA?

$$V = IR$$

$$R = \frac{V}{I} = \frac{5\times10^{-2} \text{ V}}{0.01 \text{ A}} = 5\ \Omega$$

c. What resistor should be placed parallel with the galvanometer to make the resistance calculated in part b?

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} \text{ so}$$

$$\frac{1}{R_1} = \frac{1}{R} - \frac{1}{R_2} = \frac{1}{5\ \Omega} - \frac{1}{1.0\times10^{3}\ \Omega}$$

so $R_1 = 5\ \Omega$

83. A beam of electrons moves at right angles to a magnetic field of 6.0×10^{-2} T. The electrons have a velocity of 2.5×10^{6} m/s. What is the magnitude of the force on each electron?

$$F = Bqv$$

$$= (6.0\times10^{-2} \text{ T})(1.6\times10^{-19} \text{ C})(2.5\times10^{6} \text{ m/s})$$

$$= 2.4\times10^{-14} \text{ N}$$

84. Subatomic Particle A muon (a particle with the same charge as an electron) is traveling at 4.21×10^{7} m/s at right angles to a magnetic field. The muon experiences a force of 5.00×10^{-12} N.

a. How strong is the magnetic field?

$$F = qvB$$

$$B = \frac{F}{qv}$$

$$= \frac{5.00\times10^{-12} \text{ N}}{(1.60\times10^{-19} \text{ C})(4.21\times10^{7} \text{ m/s})}$$

$$= 0.742 \text{ T}$$

b. What acceleration does the muon experience if its mass is 1.88×10^{-28} kg?

$$F = ma$$

$$a = \frac{F}{m} = \frac{5.00\times10^{-12} \text{ N}}{1.88\times10^{-28} \text{ kg}}$$

$$= 2.66\times10^{16} \text{ m/s}^2$$

85. A singly ionized particle experiences a force of 4.1×10^{-13} N when it travels at right angles through a 0.61-T magnetic field. What is the velocity of the particle?

$$F = qvB$$

$$v = \frac{F}{Bq} = \frac{4.1\times10^{-13} \text{ N}}{(0.61 \text{ T})(1.60\times10^{-19} \text{ C})}$$

$$= 4.2\times10^{6} \text{ m/s}$$

86. A room contains a strong, uniform magnetic field. A loop of fine wire in the room has current flowing through it. Assume that you rotate the loop until there is no tendency for it to rotate as a result of the field. What is the direction of the magnetic field relative to the plane of the coil?

The magnetic field is perpendicular to the plane of the coil. The right-hand rule would be used to find the direction of the field produced by the coil. The field in the room is in the same direction.

87. A force of 5.78×10^{-16} N acts on an unknown particle traveling at a 90° angle through a magnetic field. If the velocity of the particle is 5.65×10^{4} m/s and the field is 3.20×10^{-2} T, how many elementary charges does the particle carry?

$$F = qvB$$

$$q = \frac{F}{Bv} = \frac{5.78\times10^{-16}\ \text{N}}{(3.20\times10^{-2}\ \text{T})(5.65\times10^{4}\ \text{m/s})}$$

$$= 3.20\times10^{-19}\ \text{C}$$

$$\text{N} = (3.20\times10^{-19}\ \text{C})\left(\frac{1\ \text{charge}}{1.60\times10^{-19}\ \text{C}}\right)$$

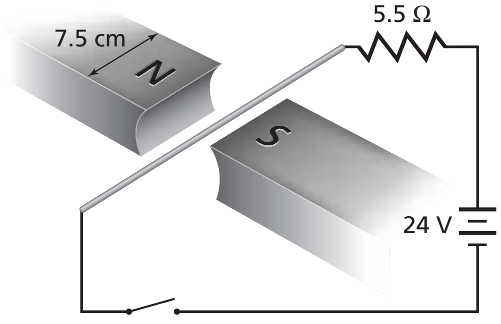
$$= 2\ \text{charges}$$

Mixed Review

pages 667–668

Level 2

88. A copper wire of insignificant resistance is placed in the center of an air gap between two magnetic poles, as shown in **Figure 24-34.** The field is confined to the gap and has a strength of 1.9 T.



■ **Figure 24-34**

a. Determine the force on the wire (direction and magnitude) when the switch is open.

0 N. With no current, there is no magnetic field produced by the wire and copper is not a magnetic material.

b. Determine the force on the wire (direction and magnitude) when the switch is closed.

Up, 0.62 N. The direction of the force is given by the third right-hand rule.

$$I = \frac{V}{R}$$

$$F = ILB = \frac{VLB}{R}$$

$$= \frac{(24\ \text{V})(0.075\ \text{m})(1.9\ \text{T})}{5.5\ \Omega}$$

$$= 0.62\ \text{N}$$

c. Determine the force on the wire (direction and magnitude) when the switch is closed and the battery is reversed.

Down, 0.62 N. The direction of the force is given by the third right-hand rule and the magnitude of the force is the same as in part b.

d. Determine the force on the wire (direction and magnitude) when the switch is closed and the wire is replaced with a different piece having a resistance of 5.5 Ω.

Up, 0.31 N. The direction of the force is given by the third right-hand rule.

$$I = \frac{V}{R}$$

$$F = ILB = \frac{VLB}{R}$$

$$= \frac{(24\ \text{V})(0.075\ \text{m})(1.9\ \text{T})}{5.5\ \Omega + 5.5\ \Omega}$$

$$= 0.31\ \text{N}$$

89. Two galvanometers are available. One has 50.0-μA full-scale sensitivity and the other has 500.0-μA full-scale sensitivity. Both have the same coil resistance of 855 Ω. Your challenge is to convert them to measure a current of 100.0 mA, full-scale.

a. Determine the shunt resistor for the 50.0-μA meter.

Find the voltage across the meter coil at full scale.

$$V = IR = (50.0\ \mu\text{A})(855\ \Omega) = 0.0428\ \text{V}$$

Calculate the shunt resistor.

$$R = \frac{V}{I} = \frac{0.0428\ \text{V}}{100.0\ \text{mA} - 50.0\ \mu\text{A}}$$

$$= 0.428\ \Omega$$

b. Determine the shunt resistor for the 500.0-μA meter.

Find the voltage across the meter coil at full scale.

$$V = IR = (500.0\ \mu\text{A})(855\ \Omega) = 0.428\ \text{V}$$

Calculate the shunt resistor.

$$R = \frac{V}{I} = \frac{0.428\ \text{V}}{100.0\ \text{mA} - 500.0\ \mu\text{A}}$$

$$= 4.30\ \Omega$$

c. Determine which of the two is better for actual use. Explain.

The 50.0-μA meter is better. Its much lower shunt resistance will do less to alter the total resistance of the circuit being measured. An ideal ammeter has a resistance of 0 Ω.

90. Subatomic Particle A beta particle (high-speed electron) is traveling at right angles to a 0.60-T magnetic field. It has a speed of 2.5×10^7 m/s. What size force acts on the particle?

$$F = Bqv$$

$$= (0.60\ \text{T})(1.6\times10^{-19}\ \text{C})(2.5\times10^7\ \text{m/s})$$

$$= 2.4\times10^{-12}\ \text{N}$$

91. The mass of an electron is 9.11×10^{-31} kg. What is the magnitude of the acceleration of the beta particle described in problem 90?

$$F = ma$$

$$a = \frac{F}{m} = \frac{2.4\times10^{-12}\ \text{N}}{9.11\times10^{-31}\ \text{kg}}$$

$$= 2.6\times10^{18}\ \text{m/s}^2$$

92. A magnetic field of 16 T acts in a direction due west. An electron is traveling due south at 8.1×10^5 m/s. What are the magnitude and the direction of the force acting on the electron?

$$F = Bqv$$

$$= (16\ \text{T})(1.6\times10^{-19}\ \text{C})(8.1\times10^5\ \text{m/s})$$

$= 2.1\times10^{-12}$ **N, upward (right-hand rule—remembering that electron flow is opposite to current flow)**

93. Loudspeaker The magnetic field in a loudspeaker is 0.15 T. The wire consists of 250 turns wound on a 2.5-cm-diameter cylindrical form. The resistance of the wire is 8.0 Ω. Find the force exerted on the wire when 15 V is placed across the wire.

$$I = \frac{V}{R}$$

$$L = (\text{\# of turns})(\text{circumference}) = n\pi d$$

$$F = BIL$$

$$F = \frac{BVn\pi d}{R}$$

$$= \frac{(0.15\ \text{T})(15\ \text{V})(250)(\pi)(0.025\ \text{m})}{8.0\ \Omega}$$

$$= 5.5\ \text{N}$$

94. A wire carrying 15 A of current has a length of 25 cm in a magnetic field of 0.85 T. The force on a current-carrying wire in a uniform magnetic field can be found using the equation $F = ILB \sin \theta$. Find the force on the wire when it makes the following angles with the magnetic field lines of

a. 90°

$$F = ILB \sin \theta$$

$$= (15\ \text{A})(0.25\ \text{m})(0.85\ \text{T})(\sin 90°)$$

$$= 3.2\ \text{N}$$

b. 45°

$$F = ILB \sin \theta$$

$$= (15\ \text{A})(0.25\ \text{m})(0.85\ \text{T})(\sin 45°)$$

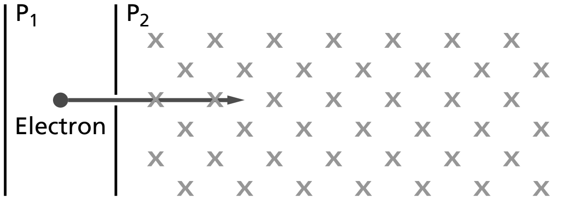
$$= 2.3\ \text{N}$$

c. 0°

$\sin 0° = 0$

so $F = 0$ N

95. An electron is accelerated from rest through a potential difference of 20,000 V, which exists between plates P_1 and P_2, shown in **Figure 24-35.** The electron then passes through a small opening into a magnetic field of uniform field strength, B. As indicated, the magnetic field is directed into the page.



■ **Figure 24-35**

a. State the direction of the electric field between the plates as either P_1 to P_2 or P_2 to P_1.

from P_2 to P_1

b. In terms of the information given, calculate the electron's speed at plate P_2.

$$KE = q\Delta V = (1.6\times10^{-19}\text{ C})(20{,}000\text{ J/C}) = 3.2\times10^{-15}\text{ J}$$

$$KE = \frac{1}{2}mv^2$$

$$v = \sqrt{\frac{2KE}{m}} = \sqrt{\frac{(2)(3.2\times10^{-15}\text{ J})}{9.11\times10^{-31}\text{ kg}}}$$

$$= 8\times10^{7}\text{ m/s}$$

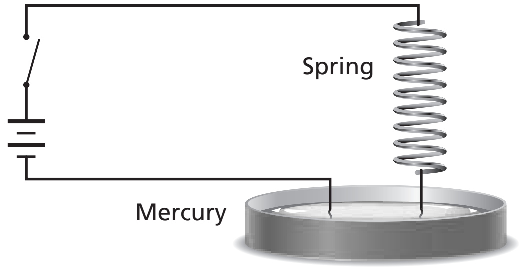
c. Describe the motion of the electron through the magnetic field.

clockwise

Thinking Critically

page 668

96. Apply Concepts A current is sent through a vertical spring, as shown in **Figure 24-36.** The end of the spring is in a cup filled with mercury. What will happen? Why?



■ **Figure 24-36**

When the current passes through the coil, the magnetic field increases and forces cause the spring to compress. The wire comes out of the mercury, the circuit opens, the magnetic field decreases, and the spring drops down. The spring will oscillate up and down.

97. Apply Concepts The magnetic field produced by a long, current-carrying wire is represented by $B = (2\times10^{-7}\text{ T·m/A})(I/d)$, where B is the field strength in teslas, I is the current in amps, and d is the distance from the wire in meters. Use this equation to estimate some magnetic fields that you encounter in everyday life.

a. The wiring in your home seldom carries more than 10 A. How does the magnetic field that is 0.5 m from such a wire compare to Earth's magnetic field?

$I = 10$ A, $d = 0.5$ m, so

$$B = \frac{(2\times10^{-7}\text{ T·m/A})I}{d}$$

$$= \frac{(2\times10^{-7}\text{ T·m/A})(10\text{ A})}{0.5\text{ m}}$$

$$= 4\times10^{-6}\text{ T}$$

Earth's field is 5×10^{-5} T, so Earth's field is about 12 times stronger than that of the wire.

b. High-voltage power transmission lines often carry 200 A at voltages as high as 765 kV. Estimate the magnetic field on the ground under such a line, assuming that it is about 20 m high. How does this field compare with a magnetic field in your home?

$I = 200$ A, $d = 20$ m, so

$$B = \frac{(2\times10^{-7}\text{ T·m/A})I}{d}$$

$$= \frac{(2\times10^{-7}\text{ T·m/A})(200\text{ A})}{20\text{ m}}$$

$$= 2\times10^{-6}\text{ T}$$

This is half as strong as the field in part a.

c. Some consumer groups have recommended that pregnant women not use electric blankets in case the magnetic fields cause health problems. Estimate the distance that a fetus might be from such a wire, clearly stating your assumptions. If such a blanket carries 1 A, find the magnetic field at the location of the fetus. Compare this with Earth's magnetic field.

Assume only one wire runs over "the fetus, and use the center of the fetus (where the vital organs are) as a reference point. At an early stage, the fetus might be 5 cm from the blanket. At later stages, the center of the fetus may be 10 cm away.

$I = 1$ A, $d = 0.05$ m, so

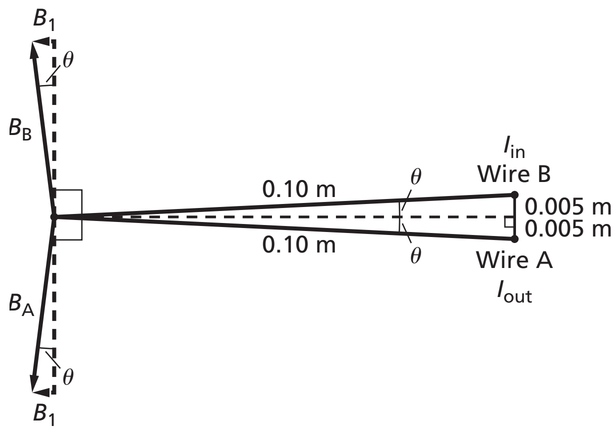
$$B = \frac{(2\times10^{-7}\text{ T·m/A})I}{d}$$

$$= \frac{(2\times10^{-7}\text{ T·m/A})(1\text{ A})}{0.05\text{ m}}$$

$= 4\times10^{-6}$ T

Earth's magnetic field of 5×10^{-5} T is about 12 times stronger.

98. Add Vectors In almost all cases described in problem 97, a second wire carries the same current in the opposite direction. Find the net magnetic field that is a distance of 0.10 m from each wire carrying 10 A. The wires are 0.01 m apart. Make a scale drawing of the situation. Calculate the magnitude of the field from each wire and use a right-hand rule to draw vectors showing the directions of the fields. Finally, find the vector sum of the two fields. State its magnitude and direction.



From each wire $I = 10$ A, $d = 0.10$ m, so

$$B = \frac{(2\times10^{-7}\ \text{T}\cdot\text{m/A})(10\ \text{A})}{0.10\ \text{m}} = 2\times10^{-5}\ \text{T}$$

From the diagram, only the components parallel to the line from the center of the wires contribute to the net field strength. The component from each wire is $B_1 = B \sin\theta$, where $\sin\theta = \frac{0.005\ \text{m}}{0.10\ \text{m}} = 0.05$, so $B_1 = (2\times10^{-5}\ \text{T})(0.05) = 1\times10^{-6}$ T. But, each wire contributes the same amount, so the total field is 2×10^{-6} T, about 1/25 Earth's field.

Writing In Physics

page 668

99. Research superconducting magnets and write a one-page summary of proposed future uses for such magnets. Be sure to describe any hurdles that stand in the way of the practical application of these magnets.

Student answers may vary. Superconducting magnets currently are used in magnetic resonance imaging (MRI), a medical technology. They are being tested for use in magnetically levitated high-speed trains, and it is hoped that superconducting magnets will help to make nuclear fusion energy practical. A drawback of superconducting magnets is that they require extremely low temperatures (near absolute zero). Scientists are trying to develop materials that are superconductive at higher temperatures.

Cumulative Review

page 668

100. How much work is required to move a charge of 6.40×10^{-3} C through a potential difference of 2500 V? (Chapter 21)

$W = qV = (6.40\times10^{-3}\ \text{C})(2500\ \text{V}) = 16$ J

101. The current flow in a 120-V circuit increases from 1.3 A to 2.3 A. Calculate the change in power. (Chapter 22)

$$P = IV$$
$$P_1 = I_1V,\ P_2 = I_2V$$
$$\Delta P = P_2 - P_1 = I_2V - I_1V$$
$$= V(I_2 - I_1)$$
$$= (120\ \text{V})(2.3\ \text{A} - 1.3\ \text{A})$$
$$= 120\ \text{W}$$

102. Determine the total resistance of three, 55-Ω resistors connected in parallel and then series-connected to two 55-Ω resistors connected in series. (Chapter 23)

$$\frac{1}{R_{parallel}} = \frac{1}{R} + \frac{1}{R} + \frac{1}{R} = \frac{1}{55\ \Omega} + \frac{1}{55\ \Omega} + \frac{1}{55\ \Omega} = \frac{3}{55\ \Omega}$$

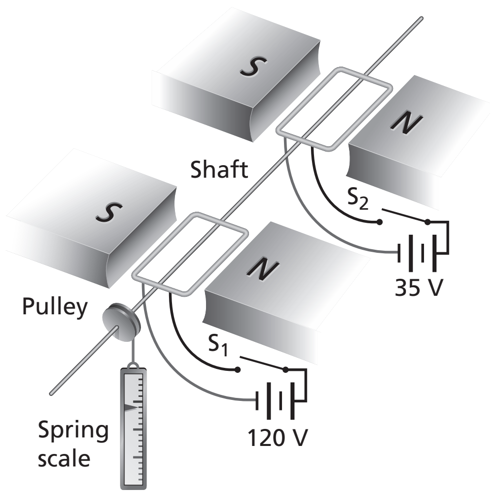
$$R_{parallel} = 18\ \Omega$$

$$R_{equiv} = R_{parallel} + R + R$$
$$= 18\ \Omega + 55\ \Omega + 55\ \Omega$$
$$= 128\ \Omega$$

Challenge Problem

page 656

The figure shows two identical motors with a common shaft. For simplicity, the commutators are not shown. Each armature coil consists of 48 turns of wire with rectangular dimensions of 17 cm wide by 35 cm deep. The armature resistance is 12 Ω. The red wire travels to the left (along half the width) and then back to the rear of the motor (along the depth). The magnetic field is 0.21 T. The diameter of the pulley is 7.2 cm. A rope fixed to the pulley and the floor prevents the motor shaft from turning.



1. Given $F = ILB$, derive an equation for the torque on the armature for the position shown.

Torque is defined as the product of the force and the lever arm. In the case of the motor armature position shown, the lever arm is equal to half of the width of the armature coil (the shaft is the center of rotation and is at the midpoint of the coil width). The length of the wire acted upon by the field is equal to the depth of the coil. This length is effectively increased by *n*, the number of turns in the coil. Finally, the torque is doubled because as one side is pushed up by the magnetic field, the other side is pushed down according to the third right-hand rule.

$\tau = 2nBI\text{(depth)(width/2)}$

Simplifying and replacing (depth)(width) with area, A, gives:

$\tau = nBIA$

The torque produced by the motor armature, in the position shown, is equal to the number of turns times the field strength times the armature current times the area of the armature coil.

2. With S_1 closed and S_2 open, determine the torque on the shaft and the force on the spring scale.

$$\tau = nBIA$$
$$= (48)(0.21\ \text{T})\left(\frac{120\ \text{V}}{12\ \Omega}\right)(0.35\ \text{m})(0.17\ \text{m})$$
$$= 6.0\ \text{N·m}$$

Because the shaft cannot turn, the system is in equilibrium and the force on the spring scale is found by considering half the pulley diameter:

$$F_{\text{spring scale}} = \frac{6.0\ \text{N·m}}{0.036\ \text{m}} = 170\ \text{N}$$

3. With both switches closed, determine the torque on the shaft and the force on the spring scale.

Both motors produce counterclockwise torque:

$$\tau_1 = (48)(0.21\ \text{T})\left(\frac{120\ \text{V}}{12\ \Omega}\right)(0.35\ \text{m})(0.17\ \text{m})$$
$$= 6.0\ \text{N·m}$$
$$\tau_2 = (48)(0.21\ \text{T})\left(\frac{35\ \text{V}}{12\ \Omega}\right)(0.35\ \text{m})(0.17\ \text{m})$$
$$= 1.7\ \text{N·m}$$

τ_{net} **= 7.7 N·m counterclockwise**

$$F_{\text{spring scale}} = \frac{7.7\ \text{N·m}}{0.036\ \text{m}} = 210\ \text{N}$$

4. What happens to torque if the armature is in a different position?

The torque is reduced when there is any rotation from the position shown because the lever arm is reduced. With 90° rotation, the force on the armature will be up and down (canceling) with the effective lever arm equal to zero. With the shown position as $\theta = 0°$:

$\tau = nBIA\cos\theta$

CHAPTER

25 Electromagnetic Induction

Practice Problems

25.1 Electric Current from Changing Magnetic Fields pages 671–678

page 675

1. A straight wire, 0.5 m long, is moved straight up at a speed of 20 m/s through a 0.4-T magnetic field pointed in the horizontal direction.

   a. What *EMF* is induced in the wire?

   $$EMF = BLv$$
   $$= (0.4\ \mathrm{T})(0.5\ \mathrm{m})(20\ \mathrm{m/s})$$
   $$= 4\ \mathrm{V}$$

   b. The wire is part of a circuit of total resistance of 6.0 Ω. What is the current in the circuit?

   $$I = \frac{EMF}{R} = \frac{4\ \mathrm{V}}{6.0\ \Omega} = 0.7\ \mathrm{A}$$

2. A straight wire, 25 m long, is mounted on an airplane flying at 125 m/s. The wire moves in a perpendicular direction through Earth's magnetic field ($B = 5.0\times10^{-5}$ T). What *EMF* is induced in the wire?

   $$EMF = BLv$$
   $$= (5.0\times10^{-5}\ \mathrm{T})(25\ \mathrm{m})(125\ \mathrm{m/s})$$
   $$= 0.16\ \mathrm{V}$$

3. A straight wire, 30.0 m long, moves at 2.0 m/s in a perpendicular direction through a 1.0-T magnetic field.

   a. What *EMF* is induced in the wire?

   $$EMF = BLv$$
   $$= (1.0\ \mathrm{T})(30.0\ \mathrm{m})(2.0\ \mathrm{m/s})$$
   $$= 6.0\times10^{1}\ \mathrm{V}$$

   b. The total resistance of the circuit of which the wire is a part is 15.0 Ω. What is the current?

   $$I = \frac{EMF}{R} = \frac{6.0\times10^{1}\ \mathrm{V}}{1.50\ \Omega} = 4.0\ \mathrm{A}$$

4. A permanent horseshoe magnet is mounted so that the magnetic field lines are vertical. If a student passes a straight wire between the poles and pulls it toward herself, the current flow through the wire is from right to left. Which is the north pole of the magnet?

   Using the right-hand rule, the north pole is at the bottom.

page 678

5. A generator develops a maximum voltage of 170 V.

   a. What is the effective voltage?

   $$V_{eff} = (0.707)V_{max} = (0.707)(170\ \mathrm{V})$$
   $$= 1.2\times10^{2}\ \mathrm{V}$$

   b. A 60-W lightbulb is placed across the generator with an I_{max} of 0.70 A. What is the effective current through the bulb?

   $$I_{eff} = (0.707)I_{max} = (0.707)(0.70\ \mathrm{A})$$
   $$= 0.49\ \mathrm{A}$$

   c. What is the resistance of the lightbulb when it is working?

   $$R = \frac{V_{eff}}{I_{eff}} = \frac{\frac{V_{max}}{\sqrt{2}}}{\frac{I_{max}}{\sqrt{2}}} = \frac{V_{max}}{I_{max}} = \frac{170\ \mathrm{V}}{0.70\ \mathrm{A}}$$
   $$= 2.4\times10^{2}\ \Omega$$

6. The RMS voltage of an AC household outlet is 117 V. What is the maximum voltage across a lamp connected to the outlet? If the RMS current through the lamp is 5.5 A, what is the maximum current in the lamp?

   $$V_{max} = \frac{V_{eff}}{0.707} = \frac{117\ \mathrm{V}}{0.707} = 165\ \mathrm{V}$$

   $$I_{max} = \frac{I_{eff}}{0.707} = \frac{5.5\ \mathrm{A}}{0.707} = 7.8\ \mathrm{A}$$

7. An AC generator delivers a peak voltage of 425 V.

a. What is the V_{eff} in a circuit placed across the generator?

$$V_{eff} = \frac{V_{max}}{\sqrt{2}} = \frac{425\ \text{V}}{\sqrt{2}} = 3.01\times10^{2}\ \text{V}$$

b. The resistance is $5.0\times10^{2}\ \Omega$. What is the effective current?

$$I_{eff} = \frac{V_{eff}}{R} = \frac{3.01\times10^{2}\ \text{V}}{5.0\times10^{2}\ \Omega} = 0.60\ \text{A}$$

8. If the average power dissipated by an electric light is 75 W, what is the peak power?

$$P = \frac{1}{2}P_{max}$$

$$P_{max} = (2)P = (2)(75\ \text{W}) = 1.5\times10^{2}\ \text{W}$$

Section Review

25.1 Electric Current from Changing Magnetic Fields pages 671–678

page 678

9. Generator Could you make a generator by mounting permanent magnets on a rotating shaft and keeping the coil stationary? Explain.

Yes, only relative motion between the coil and the magnetic field is important.

10. Bike Generator A bike generator lights the headlamp. What is the source of the energy for the bulb when the rider travels along a flat road?

the stored chemical energy of the bike rider

11. Microphone Consider the microphone shown in Figure 25-3. When the diaphragm is pushed in, what is the direction of the current in the coil?

clockwise from the left

12. Frequency What changes to the generator are required to increase the frequency?

increase the number of magnetic pole pairs

13. Output Voltage Explain why the output voltage of an electric generator increases when the magnetic field is made stronger. What else is affected by strengthening the magnetic field?

The magnitude of the induced voltage is directly related to the strength of the magnetic field. A greater voltage is induced in the conductor(s) if the field strength is increased. The current and the power in the generator circuit also were affected.

14. Generator Explain the fundamental operating principle of an electric generator.

Michael Faraday discovered that a voltage is induced in a length of electric wire moving in a magnetic field. The induced voltage may be increased by using a stronger magnetic field, increasing the velocity of the conductor, or increasing the effective length of the conductor.

15. Critical Thinking A student asks, "Why does AC dissipate any power? The energy going into the lamp when the current is positive is removed when the current is negative. The net is zero." Explain why this reasoning is wrong.

Power is the rate at which energy is transferred. Power is the product of *I* and *V*. When *I* is positive, so is *V* and therefore, *P* is positive. When *I* is negative, so is *V*; thus, *P* is positive again. Energy is always transferred in the lamp.

Practice Problems

25.2 Changing Magnetic Fields Induce *EMF* pages 679–685

page 684

For the following problems, effective currents and voltages are indicated.

16. A step-down transformer has 7500 turns on its primary coil and 125 turns on its secondary coil. The voltage across the primary circuit is 7.2 kV. What voltage is being applied across the secondary circuit? If the current in the secondary circuit is 36 A, what is the current in the primary circuit?

$$\frac{V_s}{V_p} = \frac{N_s}{N_p}$$

$$V_s = \frac{V_p N_s}{N_p} = \frac{(7.2\times10^3\ \text{V})(125)}{7500}$$

$$= 1.2\times10^2\ \text{V}$$

$$V_p I_p = V_s I_s$$

$$I_p = \frac{V_s I_s}{V_p} = \frac{(1.2\times10^2\ \text{V})(36\ \text{A})}{7.2\times10^3\ \text{V}} = 0.60\ \text{A}$$

17. A step-up transformer has 300 turns on its primary coil and 90,000 turns on its secondary coil. The *EMF* of the generator to which the primary circuit is attached is 60.0 V. What is the *EMF* in the secondary circuit? The current in the secondary circuit is 0.50 A. What current is in the primary circuit?

$$V_s = \frac{V_p N_s}{N_p} = \frac{(60.0\ \text{V})(90{,}000)}{300}$$

$$= 1.80\times10^4\ \text{V}$$

$$I_p = \frac{V_s I_s}{V_p} = \frac{(1.80\times10^4\ \text{V})(0.50\ \text{A})}{60.0\ \text{V}}$$

$$= 1.5\times10^2\ \text{A}$$

Section Review

25.2 Changing Magnetic Fields Induce *EMF* pages 679–685

page 685

18. Coiled Wire and Magnets You hang a coil of wire with its ends joined so that it can swing easily. If you now plunge a magnet into the coil, the coil will swing. Which way will it swing relative to the magnet and why?

Away from the magnet. The changing magnetic field induces a current in the coil, producing a magnetic field. This field opposes the field of the magnet, and thus, the force between coil and magnet is repulsive.

19. Motors If you unplugged a running vacuum cleaner from a wall outlet, you would be much more likely to see a spark than you would be if you unplugged a lighted lamp from the wall. Why?

The inductance of the motor creates a back-*EMF* that causes the spark. The bulb has very low self-inductance, so there is no back-*EMF*.

20. Transformers and Current Explain why a transformer may only be operated on alternating current.

In order to magnetically link the primary and secondary coils, a varying current must flow in the primary coil. This changing current sets up a magnetic field that builds, expanding outwards, and collapses as the current flow direction changes.

21. Transformers Frequently, transformer coils that have only a few turns are made of very thick (low-resistance) wire, while those with many turns are made of thin wire. Why?

More current flows through the coil with fewer turns, so the resistance must be kept low to prevent voltage drops and I^2R power loss and heating.

22. Step-Up Transformers Refer to the step-up transformer shown in Figure 25-13. Explain what will happen to the primary current if the secondary coil is short-circuited.

According to the transformer equations, the ratio of primary to secondary current is equal to the ratio of turns and doesn't change. Thus, if the secondary current increases, so does the primary.

23. Critical Thinking Would permanent magnets make good transformer cores? Explain.

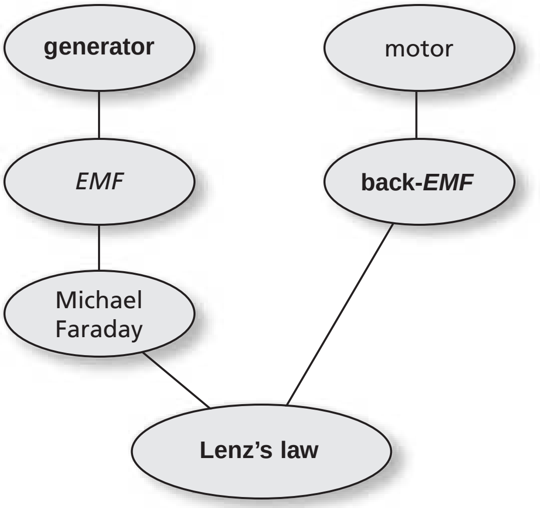
No, the induced voltage depends on a changing magnetic field through the core. Permanent magnets are "permanent" because they are made of materials that resist such changes in magnetic fields.

Chapter Assessment

Concept Mapping

page 690

24. Complete the following concept map using the following terms: *generator, back-EMF, Lenz's law.*



Mastering Concepts

page 690

25. What is the armature of an electric generator? (25.1)

The armature of an electric generator consists of a number of wire loops wound around an iron core and placed in a strong magnetic field. As it rotates in the magnetic field, the loops cut through magnetic field lines and an electric current is induced.

26. Why is iron used in an armature? (25.1)

Iron is used in an armature to increase the strength of the magnetic field.

For problems 27–29, refer to ***Figure 25-16.***

27. A single conductor moves through a magnetic field and generates a voltage. In what direction should the wire be moved, relative to the magnetic field to generate the minimum voltage? (25.1)

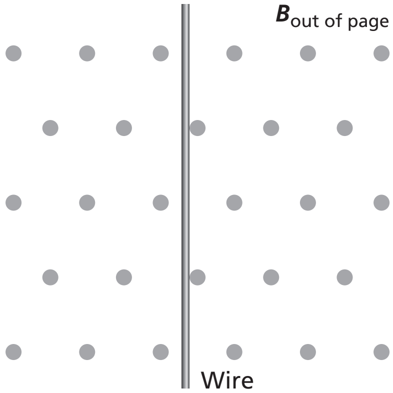
The minimum amount of voltage (0 V), is generated when the conductor is moving parallel to the magnetic lines of force.

28. What is the polarity of the voltage induced in the wire when it passes the south pole of the magnetic field? (25.1)

A conductor moving by a south magnetic pole will have a positive induced voltage.

29. What is the effect of increasing the net conductor length in an electric generator? (25.1)

Increasing the conductor length results in a net increase in induced voltage.



■ **Figure 25-16**

30. How were Oersted's and Faraday's results similar? How were they different? (25.1)

They are similar in that they each show a relationship between electricity and magnetism. They are different in that a steady electric current produces a magnetic field, but a change in magnetic field is needed to produce an electric current.

31. You have a coil of wire and a bar magnet. Describe how you could use them to generate an electric current. (25.1)

Either move the magnet into or out of the coil, or move the coil up and down over the end of the magnet.

32. What does *EMF* stand for? Why is the name inaccurate? (25.1)

Electromotive force; it is not a force but an electric potential (energy per unit of charge).

33. What is the difference between a generator and a motor? (25.1)

In a generator, mechanical energy turns an armature in a magnetic field. The induced voltage produces current, thus producing electric energy. In a motor, voltage is placed across an armature coil in a magnetic field. The voltage produces current in the coil and the armature turns, producing mechanical energy.

34. List the major parts of an AC generator. (25.1)

An AC generator consists of a permanent magnet, an armature, a set of brushes, and a slip ring.

35. Why is the effective value of an AC current less than its maximum value? (25.1)

In an alternating-current generator, as the armature turns, the generated power varies between some maximum value and zero. The average power is equal to one-half the maximum power. The effective current is the constant value of current that would cause the average power to be dissipated in the load, R.

$$P_{avg} = \frac{1}{2}P_{max} = \frac{1}{2}I_{max}{}^2R = I_{eff}{}^2R$$

$$I_{eff} = \frac{I_{max}}{\sqrt{2}} < I_{max}$$

36. Hydroelectricity Water trapped behind a dam turns turbines that rotate generators. List all the forms of energy that take part in the cycle that includes the stored water and the electricity produced. (25.1)

There is potential energy in the stored water, kinetic energy in the falling water and turning turbine, and electric energy in the generator. In addition, there are frictional losses in the turbine and generator resulting in thermal energy.

37. State Lenz's law. (25.2)

An induced current always acts in such a direction that its magnetic field opposes the change by which the current is induced.

38. What causes back-*EMF* in an electric motor? (25.2)

This is Lenz's law. Once the motor starts turning, it behaves as a generator and will generate current in opposition to the current being put into the motor.

39. Why is there no spark when you close a switch and put current through an inductor, but there is a spark when you open the switch? (25.2)

The spark is from the back-*EMF* that tries to keep the current flowing. The back-*EMF* is large because the current has dropped quickly to zero. When closing the switch, the current increase isn't so fast because of the resistance in the wires.

40. Why is the self-inductance of a coil a major factor when the coil is in an AC circuit but a minor factor when the coil is in a DC circuit? (25.2)

An alternating current is always changing in the magnitude and direction. Therefore, self-induction is a constant factor. A direct current eventually becomes steady, and thus, after a short time, there is no changing magnetic field.

41. Explain why the word *change* appears so often in this chapter. (25.2)

As Faraday discovered, only a changing magnetic field induces *EMF.*

42. Upon what does the ratio of the *EMF* in the primary circuit of a transformer to the *EMF* in the secondary circuit of the transformer depend? (25.2)

The ratio of number of turns of wire in the primary coil to the number of turns of wire in the secondary coil determines the *EMF* ratio.

Applying Concepts

pages 690–692

43. Use unit substitution to show that the units of *BLv* are volts.

The unit of *BLv* is (T)(m)(m/s).

T = N/A·m and A = C/s.

So, *BLv* = (N·s/C·m)(m)(m/s) = N·m/C

Because J = N·m and V = J/C, the unit of *BLv* is V (volts).

44. When a wire is moved through a magnetic field, does the resistance of the closed circuit affect current only, *EMF* only, both, or neither?

current only

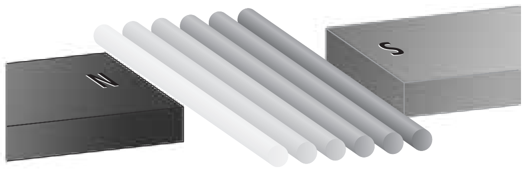
45. **Biking** As Logan slows his bike, what happens to the *EMF* produced by his bike's generator? Use the term *armature* in your explanation.

As Logan slows his bike, the rotation of the armature in the magnetic field of the generator slows, and the *EMF* is reduced.

46. The direction of AC voltage changes 120 times each second. Does this mean that a device connected to an AC voltage alternately delivers and accepts energy?

No; the signs of the current and voltage reverse at the same time, and, therefore, the product of the current and the voltage is always positive.

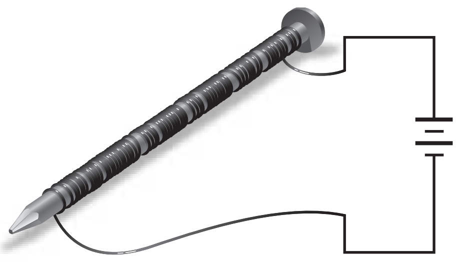
47. A wire is moved horizontally between the poles of a magnet, as shown in **Figure 25-17.** What is the direction of the induced current?



■ **Figure 25-17**

No current is induced because the direction of the velocity is parallel to the magnetic field.

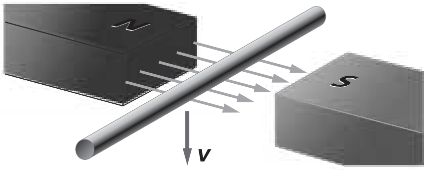
48. You make an electromagnet by winding wire around a large nail, as shown in **Figure 25-18.** If you connect the magnet to a battery, is the current larger just after you make the connection or several tenths of a second after the connection is made? Or, is it always the same? Explain.



■ **Figure 25-18**

It is larger several tenths of a second after the connection is made. The back-*EMF* opposes current just after the connection is made.

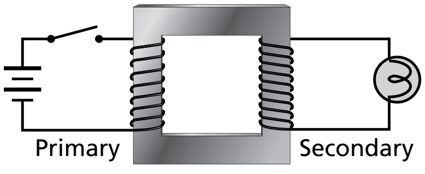
49. A segment of a wire loop is moving downward through the poles of a magnet, as shown in **Figure 25-19.** What is the direction of the induced current?



■ **Figure 25-19**

The current direction is out-of-page to the left along the path of the wire.

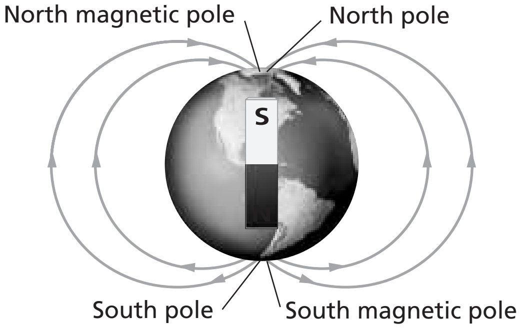
50. A transformer is connected to a battery through a switch. The secondary circuit contains a lightbulb, as shown in **Figure 25-20.** Will the lamp be lighted as long as the switch is closed, only at the moment the switch is closed, or only at the moment the switch is opened? Explain.



■ **Figure 25-20**

The bulb will light because there is a current in the secondary circuit. This will happen whenever the primary current changes, so the bulb will glow either when the switch is closed or when it is opened.

51. Earth's Magnetic Field The direction of Earth's magnetic field in the northern hemisphere is downward and to the north as shown in **Figure 25-21.** If an east-west wire moves from north to south, in which direction is the current?



■ **Figure 25-21**

The current is from west to east.

52. You move a length of copper wire down through a magnetic field, *B*, as shown in Figure 25-19.

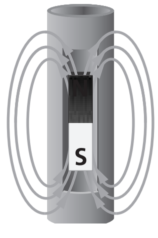
a. Will the induced current move to the right or left in the wire segment in the diagram?

The right-hand rule will show the current moving left.

b. As soon as the wire is moved in the field, a current appears in it. Thus, the wire segment is a current-carrying wire located in a magnetic field. A force must act on the wire. What will be the direction of the force acting on the wire as a result of the induced current?

The force will act in an upward direction.

53. A physics instructor drops a magnet through a copper pipe, as illustrated in **Figure 25-22.** The magnet falls very slowly, and the students in the class conclude that there must be some force opposing gravity.



■ **Figure 25-22**

a. What is the direction of the current induced in the pipe by the falling magnet if the south pole is toward the bottom?

Induced *EMF* is perpendicular to both the field and velocity, so the current must be circumferential. Field lines move in toward the south pole and out from the north pole. By the right-hand rule, current is clockwise near the south pole and counterclockwise near the north pole.

b. The induced current produces a magnetic field. What is the direction of the field?

Near the south pole, the field inside the pipe is down; near the north pole, it is up.

c. How does this field reduce the acceleration of the falling magnet?

Induced field exerts an upward force on both poles.

54. Generators Why is a generator more difficult to rotate when it is connected to a circuit and supplying current than it is when it is standing alone?

When the armature of a generator is rotated, a force that opposes the direction of rotation is produced as a result of induced current (Lenz's law). When standing alone, however, no current is generated and consequently no opposing force is produced.

55. Explain why the initial start-up current is so high in an electric motor. Also explain how Lenz's law applies at the instant $t > 0$.

If the armature (conductors) are not rotating, no lines of force are being cut, and no voltage is induced. Therefore, the back-*EMF* is zero. Since there is no current in the armature, no magnetic field is formed around the stationary conductor. It should be noted that this explanation only holds true at the instant of startup, at time just greater than 0. The instant the armature begins to rotate, it will be cutting the lines of force and will have an induced voltage. This voltage, the back-*EMF,* will have a

polarity such that it produces a magnetic field opposing the field that created it. This reduces the current in the motor. Therefore, the motion of the motor increases its apparent resistance.

56. Using Figure 25-10 in conjunction with Lenz's law, explain why all practical transformer cores incorporate a laminated core.

A laminated core is constructed from thin sheets of steel, separated by a very thin coating of varnish (insulation). Eddy currents are greatly reduced because of this insulation. Current in the core is caused by the changing magnetic flux within the core. The eddy currents exist due to the induced voltage within the magnetic core.

57. A practical transformer is constructed with a laminated core that is not a superconductor. Because the eddy currents cannot be completely eliminated, there is always a small core loss. This results, in part, in a net loss of power within the transformer. What fundamental law makes it impossible to bring this loss to zero?

Lenz's law

58. Explain the process of mutual induction within a transformer.

An AC current applied to the primary coil of a transformer, results in a changing current flow through the coil winding. This current, in turn, generates a magnetic flux, alternately building and collapsing as the direction of current changes. This strong magnetic field radiates outward in all directions from the primary coil. When the magnetic field reaches the stationary secondary coil on the other side of the core, a voltage is induced within that coil. The voltage or *EMF* induced depends upon the rate at which the magnetic field alternates (supply frequency), number of turns on the coil, and the strength of the magnetic flux. Since the magnetic flux is responsible for inducing a voltage in the secondary coil, we say that it is magnetically linked.

59. Shawn drops a magnet, north pole down, through a vertical copper pipe.

a. What is the direction of the induced current in the copper pipe as the bottom of the magnet passes?

clockwise around the pipe, as viewed from above

b. The induced current produces a magnetic field. What is the direction of the induced magnetic field?

down the pipe, at the location of the south pole of the magnet (or opposite the magnet's field)

Mastering Problems

25.1 Electric Current from Changing Magnetic Fields

pages 692–693

Level 1

60. A wire, 20.0-m long, moves at 4.0 m/s perpendicularly through a magnetic field. An *EMF* of 40 V is induced in the wire. What is the strength of the magnetic field?

$EMF = BLv$

$B = \frac{EMF}{Lv} = \frac{40\ \text{V}}{(20.0\ \text{m})(4.0\ \text{m/s})}$

$= 0.5\ \text{T}$

61. **Airplanes** An airplane traveling at 9.50×10^{2} km/h passes over a region where Earth's magnetic field is 4.5×10^{-5} T and is nearly vertical. What voltage is induced between the plane's wing tips, which are 75 m apart?

$EMF = BLv$

$= (4.5\times10^{-5}\ \text{T})(75\ \text{m})(9.50\times10^{2}\ \text{km/h})(1000\ \text{m/km})(1\ \text{h}/3600\ \text{s})$

$= 0.89\ \text{V}$

62. A straight wire, 0.75-m long, moves upward through a horizontal 0.30-T magnetic field, as shown in **Figure 25-23,** at a speed of 16 m/s.

a. What *EMF* is induced in the wire?

$EMF = BLv$

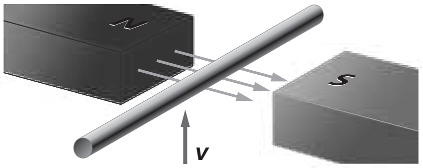
$= (0.30\ \text{T})(0.75\ \text{m})(16\ \text{m/s})$

$= 3.6\ \text{V}$

b. The wire is part of a circuit with a total resistance of 11 Ω. What is the current?

$EMF = IR$

$I = \frac{EMF}{R} = \frac{3.6\ \text{V}}{11\ \Omega} = 0.33\ \text{A}$



■ **Figure 25-23**

63. At what speed would a 0.20-m length of wire have to move across a 2.5-T magnetic field to induce an *EMF* of 10 V?

$EMF = BLv$

$v = \frac{EMF}{BL} = \frac{10\ \text{V}}{(2.5\ \text{T})(0.20\ \text{m})}$

$= 20\ \text{m/s}$

64. An AC generator develops a maximum *EMF* of 565 V. What effective *EMF* does the generator deliver to an external circuit?

$V_{eff} = \frac{V_{max}}{\sqrt{2}} = \frac{565\ \text{V}}{\sqrt{2}} = 4.00\times10^2\ \text{V}$

65. An AC generator develops a maximum voltage of 150 V. It delivers a maximum current of 30.0 A to an external circuit.

a. What is the effective voltage of the generator?

$V_{eff} = (0.707)V_{max} = (0.707)(150\ \text{V})$

$= 110\ \text{V}$

b. What effective current does the generator deliver to the external circuit?

$I_{eff} = (0.707)I_{max} = (0.707)(30.0\ \text{V})$

$= 21.2\ \text{A}$

c. What is the effective power dissipated in the circuit?

$P_{eff} = I_{eff}V_{eff} = \left(\frac{I_{max}}{\sqrt{2}}\right)\left(\frac{V_{max}}{\sqrt{2}}\right)$

$= \frac{1}{2}I_{max}V_{max} = \left(\frac{1}{2}\right)(150\ \text{V})(30.0\ \text{A})$

$= 2.3\ \text{kW}$

66. Electric Stove An electric stove is connected to an AC source with an effective voltage of 240 V.

a. Find the maximum voltage across one of the stove's elements when it is operating.

$V_{eff} = (0.707)V_{max}$

$V_{max} = \frac{V_{eff}}{0.707} = \frac{240\ \text{V}}{0.707} = 340\ \text{V}$

b. The resistance of the operating element is 11 Ω. What is the effective current?

$V_{eff} = I_{eff}R$

$I_{eff} = \frac{V_{eff}}{R} = \frac{240\ \text{V}}{11\ \Omega} = 22\ \text{A}$

67. You wish to generate an *EMF* of 4.5 V by moving a wire at 4.0 m/s through a 0.050-T magnetic field. How long must the wire be, and what should be the angle between the field and direction of motion to use the shortest wire?

$EMF = BLv$

$L = \frac{EMF}{Bv} = \frac{4.5\ \text{V}}{(0.050\ \text{T})(4.0\ \text{m/s})}$

$= 23\ \text{m}$

This is the shortest length of wire assuming that the wire and the direction of motion are each perpendicular to the field.

Level 2

68. A 40.0-cm wire is moved perpendicularly through a magnetic field of 0.32 T with a velocity of 1.3 m/s. If this wire is connected into a circuit of 10.0-Ω resistance, what is the current?

$EMF = BLv$

$= (0.32\ \text{T})(0.400\ \text{m})(1.3\ \text{m/s})$

$= 0.17\ \text{V}$

$I = \frac{EMF}{R} = \frac{0.17\ \text{V}}{10.0\ \Omega} = 17\ \text{mA}$

69. You connect both ends of a copper wire with a total resistance of 0.10 Ω to the terminals of a galvanometer. The galvanometer has a resistance of 875 Ω. You then move a 10.0-cm segment of the wire upward at 1.0 m/s through a 2.0×10^{-2}-T magnetic field. What current will the galvanometer indicate?

$EMF = BLv$

$= (2.0\times10^{-2}\text{ T})(0.100\text{ m})(1.0\text{ m/s})$

$= 2.0\times10^{-3}\text{ V}$

$I = \frac{V}{R} = \frac{2.0\times10^{-3}\text{ V}}{875\ \Omega} = 2.3\times10^{-6}\text{ A}$

$= 2.3\ \mu\text{A}$

70. The direction of a 0.045-T magnetic field is 60.0° above the horizontal. A wire, 2.5-m long, moves horizontally at 2.4 m/s.

a. What is the vertical component of the magnetic field?

The vertical component of magnetic field is

$B \sin 60.0° = (0.045\text{ T})(\sin 60.0°)$

$= 0.039\text{ T}$

b. What *EMF* is induced in the wire?

$EMF = BLv$

$= (0.039\text{ T})(2.5\text{ m})(2.4\text{ m/s})$

$= 0.23\text{ V}$

71. Dams A generator at a dam can supply 375 MW (375×10^6 W) of electrical power. Assume that the turbine and generator are 85 percent efficient.

a. Find the rate at which falling water must supply energy to the turbine.

$\text{eff} = \frac{P_{out}}{P_{in}} \times 100$

$P_{in} = P_{out} \times \frac{100}{\text{eff}}$

$= 375\text{ MW}\left(\frac{100}{85}\right)$

$= 440\text{ MW input}$

b. The energy of the water comes from a change in potential energy, $PE = mgh$. What is the change in PE needed each second?

440 MW = 440 MJ/s

$= 4.4\times10^8$ **J each second**

c. If the water falls 22 m, what is the mass of the water that must pass through the turbine each second to supply this power?

$PE = mgh$

$m = \frac{PE}{gh} = \frac{4.4\times10^8\text{ J}}{(9.80\text{ m/s}^2)(22\text{ m})}$

$= 2.0\times10^6\text{ kg}$

72. A conductor rotating in a magnetic field has a length of 20 cm. If the magnetic-flux density is 4.0 T, determine the induced voltage when the conductor is moving perpendicular to the line of force. Assume that the conductor travels at a constant velocity of 1 m/s.

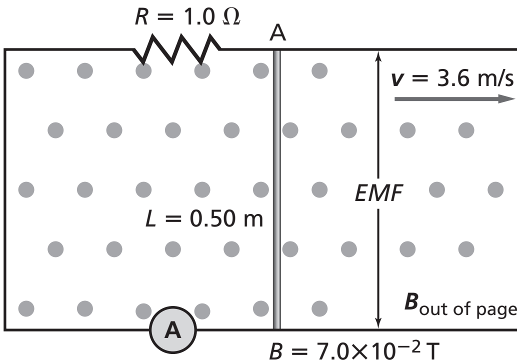
When the conductor is moving perpendicular to the line of force

$E_{ind} = BLv$

$= (4.0\text{ T})(0.20\text{ m})(1\text{ m/s})$

$= 0.8\text{ V}$

73. Refer to Example Problem 1 and **Figure 25-24** to determine the following.



■ **Figure 25-24**

a. induced voltage in the conductor

$EMF_{ind} = BLv$

$= (7.0\times10^{-2}\text{ T})(0.50\text{ m})(3.6\text{ m/s})$

$= 0.13\text{ V}$

b. current (I)

$I = \frac{EMF_{ind}}{R} = \frac{0.13\text{ V}}{1.0\ \Omega} = 0.13\text{ A}$

c. direction of flux rotation around the conductor

Flux rotates clockwise around the conductor when viewed from above.

d. polarity of point A relative to point B

Point A is negative relative to point B.

25.2 Changing Magnetic Fields Induce EMF

page 693

Level 1

74. The primary coil of a transformer has 150 turns. It is connected to a 120-V source. Calculate the number of turns on the secondary coil needed to supply the following voltages.

a. 625 V

$$\frac{V_s}{V_p} = \frac{N_s}{N_p}$$

$$N_s = \left(\frac{V_s}{V_p}\right)N_p = \left(\frac{625\text{ V}}{120\text{ V}}\right)(150)$$

$$= 781\text{ turns, which rounds to 780}$$

b. 35 V

$$N_s = \left(\frac{V_s}{V_p}\right)N_p = \left(\frac{35\text{ V}}{120\text{ V}}\right)(150)$$

$$= 44\text{ turns}$$

c. 6.0 V

$$N_s = \left(\frac{V_s}{V_p}\right)N_p = \left(\frac{6.0\text{ V}}{120\text{ V}}\right)(150)$$

$$= 7.5\text{ turns}$$

75. A step-up transformer has 80 turns on its primary coil and 1200 turns on its secondary coil. The primary circuit is supplied with an alternating current at 120 V.

a. What voltage is being applied across the secondary circuit?

$$\frac{V_p}{V_s} = \frac{N_p}{N_s}$$

$$V_s = \frac{V_pN_s}{N_p} = \frac{(120\text{ V})(1200)}{80} = 1.8\text{ kV}$$

b. The current in the secondary circuit is 2.0 A. What current is in the primary circuit?

$$V_pI_p = V_sI_s$$

$$I_p = \frac{V_sI_s}{V_p} = \frac{(1.8\times10^3\text{ V})(2.0\text{ A})}{120\text{ V}}$$

$$= 3.0\times10^1\text{ A}$$

c. What are the power input and output of the transformer?

$$V_pI_p = (120\text{ V})(30.0\text{ A}) = 3.6\text{ kW}$$

$$V_sI_s = (1800\text{ V})(2.0\text{ A}) = 3.6\text{ kW}$$

76. Laptop Computers The power supply in a laptop computer requires an effective voltage of 9.0 V from a 120-V line.

a. If the primary coil has 475 turns, how many does the secondary coil have?

$$\frac{V_s}{V_p} = \frac{N_s}{N_p}$$

$$N_s = \frac{V_sN_p}{V_p} = \frac{(9.0\text{ V})(475)}{120\text{ V}}$$

$$= 36\text{ turns}$$

b. A 125-mA current is in the computer. What current is in the primary circuit?

$$V_pI_p = V_sI_s$$

$$I_p = \frac{V_sI_s}{V_p} = \frac{(9.0\text{ V})(125\text{ mA})}{7200\text{ V}}$$

$$= 9.4\text{ mA}$$

Level 2

77. Hair Dryers A hair dryer manufactured for use in the United States uses 10 A at 120 V. It is used with a transformer in England, where the line voltage is 240 V.

a. What should be the ratio of the turns of the transformer?

$$\frac{V_p}{V_s} = \frac{N_p}{N_s} = \frac{240\text{ V}}{120\text{ V}} = \frac{2.0}{1.0}$$

or 2 to 1

b. What current will the hair dryer now draw?

$$V_pI_p = V_sI_s$$

$$I_p = \frac{V_sI_s}{V_p} = \frac{(120\text{ V})(10\text{ A})}{240\text{ V}} = 5\text{ A}$$

78. A 150-W transformer has an input voltage of 9.0 V and an output current of 5.0 A.

a. Is this a step-up or step-down transformer?

$$P_{out} = V_sI_s$$

$$V_s = \frac{P_{out}}{I_s} = \frac{150\text{ W}}{5.0\text{ A}} = 3.0\times10^1\text{ V}$$

step-up transformer

b. What is the ratio of V_{output} to V_{input}?

$P = V_s I_s$

$$V_s = \frac{P}{I_s} = \frac{150\ W}{5.0\ A} = 3.0\times10^1\ V$$

$$\frac{V_{output}}{V_{input}} = \frac{3.0\times10^1\ V}{9.0\ V} = \frac{1.0\times10^1}{3.0}$$

or 10 to 3

79. Scott connects a transformer to a 24-V source and measures 8.0 V at the secondary circuit. If the primary and secondary circuits were reversed, what would the new output voltage be?

The turns ratio is

$$\frac{N_s}{N_p} = \frac{V_s}{V_p} = \frac{8.0\ V}{24\ V} = \frac{1.0}{3.0}$$

Reversed, it would be $\frac{3.0}{1.0}$.

Thus, the voltage would now be found by

$$\frac{N_s}{N_p} = \frac{V_s}{V_p}$$

$$V_s = \left(\frac{N_s}{N_p}\right)V_p = (3.0)(24\ V) = 72\ V$$

Mixed Review

pages 693–694

Level 1

80. A step-up transformer's primary coil has 500 turns. Its secondary coil has 15,000 turns. The primary circuit is connected to an AC generator having an *EMF* of 120 V.

a. Calculate the *EMF* of the secondary circuit.

$$\frac{V_p}{V_s} = \frac{N_p}{N_s}$$

$$V_s = \frac{V_p N_s}{N_p} = \frac{(120\ V)(15{,}000)}{500}$$

$$= 3.6\times10^3\ V$$

b. Find the current in the primary circuit if the current in the secondary circuit is 3.0 A.

$V_p I_p = V_s I_s$

$$I_p = \frac{V_s I_s}{V_p} = \frac{(3600\ V)(3.0\ A)}{120\ V} = 9.0\times10^1\ A$$

c. What power is drawn by the primary circuit? What power is supplied by the secondary circuit?

$$V_p I_p = (120\ V)(9.0\times10^1\ A)$$
$$= 1.1\times10^4\ W$$

$$V_s I_s = (3600\ V)(3.0\ A) = 1.1\times10^4\ W$$

81. With what speed must a 0.20-m-long wire cut across a magnetic field for which *B* is 2.5 T if it is to have an *EMF* of 10 V induced in it?

$EMF = BLv$

$$v = \frac{EMF}{BL} = \frac{10\ V}{(2.5\ T)(0.20\ m)}$$

$$= 20\ m/s$$

82. At what speed must a wire conductor 50-cm long be moved at right angles to a magnetic field of induction 0.20 T to induce an *EMF* of 1.0 V in it?

$EMF = BLv$

$$v = \frac{EMF}{BL} = \frac{1.0\ V}{(0.20\ T)(0.5\ m)}$$

$$= 1\times10^1\ m/s$$

83. A house lighting circuit is rated at 120-V effective voltage. What is the peak voltage that can be expected in this circuit?

$V_{eff} = (0.707)V_{max}$

$$V_{max} = \frac{V_{eff}}{0.707} = \frac{120\ V}{0.707} = 170\ V$$

84. **Toaster** A toaster draws 2.5 A of alternating current. What is the peak current through this toaster?

$I_{eff} = (0.707)I_{max}$

$$I_{max} = \frac{I_{eff}}{0.707} = \frac{2.5\ A}{0.707} = 3.5\ A$$

85. The insulation of a capacitor will break down if the instantaneous voltage exceeds 575 V. What is the largest effective alternating voltage that may be applied to the capacitor?

$$V_{eff} = \frac{V_{max}}{\sqrt{2}} = \frac{575}{\sqrt{2}} = 407\ V$$

86. **Circuit Breaker** A magnetic circuit breaker will open its circuit if the instantaneous current reaches 21.25 A. What is the largest effective current the circuit will carry?

$$I_{eff} = \frac{I_{max}}{\sqrt{2}} = \frac{21.25\text{ A}}{\sqrt{2}} = 15.03\text{ A}$$

87. The electricity received at an electrical substation has a potential difference of 240,000 V. What should the ratio of the turns of the step-down transformer be to have an output of 440 V?

$$\frac{N_s}{N_p} = \frac{V_s}{V_p} = \frac{440\text{ V}}{240{,}000\text{ V}} = \frac{1}{545}$$

primary : secondary = 545 : 1

88. An alternating-current electric generator supplies a 45-kW industrial electric heater. If the system voltage is 660 V_{rms}, what is the peak current supplied?

$$I_{rms} = \frac{45\text{ kW}}{660\text{ V}} = 68\text{ A}$$

Therefore, $I_{peak} = \frac{68\text{ A}}{0.707} = 96\text{ A}$

89. A certain step-down transformer has 100 turns on the primary coil and 10 turns on the secondary coil. If a 2.0-kW resistive load is connected to the transformer, what is the effective primary current that flows? Assume that the secondary voltage is 60.0 V_{pk}.

$$V_{s,\ eff} = \frac{V_{s,\ peak}}{\sqrt{2}} = \frac{60.0\text{ V}}{\sqrt{2}} = 42.4\text{ V}$$

$$I_{s,\ eff} = \frac{P}{V_{s,\ eff}} = \frac{2.0\times10^3\text{ W}}{42.4\text{ V}} = 47\text{ A}$$

$$I_{p,\ eff} = \left(\frac{N_s}{N_p}\right)I_{s,\ eff} = \left(\frac{10}{100}\right)\left(47\text{ A}\right) = 4.7\text{ A}$$

90. A transformer rated at 100 kVA has an efficiency of 98 percent.

a. If the connected load consumes 98 kW of power, what is the input power to the transformer?

$$P_{out} = 98\text{ kW}$$

$$P_{in} = \frac{98\text{ kW}}{0.98} = 1.0\times10^2\text{ kW}$$

b. What is the maximum primary current with the transformer consuming its rated reactive power? Assume that $V_P = 600$ V.

$$I = \frac{100\text{ kVA}}{600\text{ V}} = 200\text{ A}$$

Level 2

91. A wire, 0.40-m long, cuts perpendicularly across a magnetic field for which *B* is 2.0 T at a velocity of 8.0 m/s.

a. What *EMF* is induced in the wire?

$$EMF = BLv$$
$$= (2.0\text{ T})(0.40\text{ m})(8.0\text{ m/s})$$
$$= 6.4\text{ V}$$

b. If the wire is in a circuit with a resistance of 6.4 Ω, what is the size of the current in the wire?

$$EMF = IR$$

$$I = \frac{EMF}{R} = \frac{6.4\text{ V}}{6.4\ \Omega} = 1.0\text{ A}$$

92. A coil of wire, which has a total length of 7.50 m, is moved perpendicularly to Earth's magnetic field at 5.50 m/s. What is the size of the current in the wire if the total resistance of the wire is 5.0×10^{-2} mΩ? Assume Earth's magnetic field is 5×10^{-5} T.

$EMF = BLv$ and $V = IR$, but $EMF = V$, so $IR = BLv$, and

$$I = \frac{BLv}{R} = \frac{(5.0\times10^{-5}\text{ T})(7.50\text{ m})(5.50\text{ m/s})}{5.0\times10^{-2}\text{ m}\Omega}$$

$$= 4.1\times10^{-2}\text{ A} = 41\text{ mA}$$

93. The peak value of the alternating voltage applied to a 144-Ω resistor is 1.00×10^2 V. What power must the resistor be able to handle?

$P = IV$ and $V = IR$, so $I = \frac{V}{R}$ therefore,

$$P_{max} = \left(\frac{V}{R}\right)V = \frac{V^2}{R} = \frac{(1.00\times10^2\text{ V})^2}{144\ \Omega}$$

$$= 69.4\text{ W}$$

The average power is $P_{max}/2$ so the resistor must dissipate 34.7 W.

94. **Television** The CRT in a television uses a step-up transformer to change 120 V to 48,000 V. The secondary side of the transformer has 20,000 turns and an output of 1.0 mA.

a. How many turns does the primary side have?

$$\frac{V_s}{V_p} = \frac{N_s}{N_p}$$

$$N_p = \frac{N_s V_p}{V_s} = \frac{(20{,}000)(120\text{ V})}{48\,000\text{ V}}$$

$$= 50\text{ turns}$$

b. What is the input current?

$$V_p I_p = V_s I_s$$

$$I_p = \frac{V_s I_s}{V_p} = \frac{(48{,}000\text{ V})(1.0\times10^{-3}\text{ A})}{120\text{ V}}$$

$$= 0.40\text{ A}$$

Thinking Critically

page 694

95. Apply Concepts Suppose that an "anti-Lenz's law" existed that meant a force was exerted to increase the change in a magnetic field. Thus, when more energy was demanded, the force needed to turn the generator would be reduced. What conservation law would be violated by this new "law"? Explain.

It would violate the law of conversation of energy. More energy would come out than went in. A generator would create energy, not just change it from one form to another.

96. Analyze Real transformers are not 100 percent efficient. Write an expression for transformer efficiency in percent using power. A step-down transformer that has an efficiency of 92.5 percent is used to obtain 28.0 V from a 125-V household voltage. The current in the secondary circuit is 25.0 A. What is the current in the primary circuit?

Efficiency

$$e = \frac{P_s}{P_p} \times 100$$

Secondary power:

$$P_s = V_s I_s = (28.0\text{ V})(25.0\text{ A})$$

$$= 7.00\times10^2\text{ W}$$

Primary power:

$$P_p = \frac{(100)P_s}{e} = \frac{(100)(7.00\times10^2\text{ W})}{92.5} = 757\text{ W}$$

Primary current:

$$I_p = \frac{P_p}{V_p} = \frac{757\text{ W}}{125\text{ V}} = 6.05\text{ A}$$

97. Analyze and Conclude A transformer that supplies eight homes has an efficiency of 95 percent. All eight homes have operating electric ovens that each draw 35 A from 240-V lines. How much power is supplied to the ovens in the eight homes? How much power is dissipated as heat in the transformer?

Secondary power:

$$P_s = (\#\text{ of homes})V_s I_s$$

$$= (8)(240\text{ V})(35\text{ A}) = 67\text{ kW}$$

67 kW is supplied to the ovens in the eight homes.

Primary power:

$$P_p = \frac{(100)P_s}{e} = \frac{(100)(67\text{ W})}{95} = 71\text{ kW}$$

The difference between these two is the power dissipated as heat, 4 kW.

Writing in Physics

page 694

98. Common tools, such as an electric drill, are typically constructed using a universal motor. Using your local library, and other sources, explain how this type of motor may operate on either AC or DC current.

A series DC Motor uses both an armature and series coil. When operated on alternating current, the polarity on both fields changes simultaneously. Therefore, the polarity of the magnetic field remains unchanged, and hence the direction of rotation is constant.

Cumulative Review

page 694

99. Light is emitted by a distant star at a frequency of 4.56×10^{14} Hz. If the star is moving toward Earth at a speed of 2750 km/s, what frequency light will be detected by observers on Earth? (Chapter 16)

$$f_{obs} = f\left(1 \pm \frac{v}{c}\right)$$

Because they are moving toward each other

$$f_{obs} = f\left(1 + \frac{v}{c}\right)$$

$$= (4.56\times10^{14}\ \text{Hz})\left(1 + \frac{2.75\times10^{6}\ \text{m/s}}{3.00\times10^{8}\ \text{m/s}}\right)$$

$$= 4.60\times10^{4}\ \text{Hz}$$

100. A distant galaxy emits light at a frequency of 7.29×10^{14} Hz. Observers on Earth receive the light at a frequency of 6.14×10^{14} Hz. How fast is the galaxy moving, and in what direction? (Chapter 16)

The galaxy is moving away from Earth because the observed frequency is lower than the emitted frequency. To find the speed:

$$f_{obs} = f\left(1 + \frac{v}{c}\right)$$

Because the observed light has a lower frequency, the galaxy must be moving away from Earth. So, use the negative form of the equation above

$$f_{obs} = f\left(1 - \frac{v}{c}\right)$$

$$\frac{f_{obs}}{f} = 1 - \frac{v}{c}$$

$$\frac{v}{c} = 1 - \frac{f_{obs}}{f}$$

$$v = c\left(1 - \frac{f_{obs}}{f}\right)$$

$$= (3.00\times10^{8}\ \text{m/s})\left(1 - \frac{6.14\times10^{14}\ \text{Hz}}{7.29\times10^{14}\ \text{Hz}}\right)$$

$$= 4.73\times10^{7}\ \text{m/s}$$

101. How much charge is on a 22-μF capacitor with 48 V applied to it? (Chapter 21)

$$C = \frac{q}{\Delta V}$$

$$q = C\Delta V$$

$$= (22\times10^{-6}\ \text{F})(48\ \text{V})$$

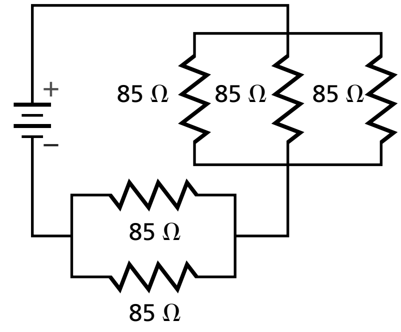
$$= 1.1\times10^{-3}\ \text{C}$$

102. Find the voltage across a 22-Ω, 5.0-W resistor operating at half of its rating. (Chapter 22)

$$P = V^2/R$$

$$V = \sqrt{PR} = \sqrt{\left(\frac{5.0\ \text{W}}{2}\right)(22\ \Omega)} = 7.4\ \text{V}$$

103. Determine the total resistance of three, 85-Ω resistors connected in parallel and then series-connected to two 85-Ω resistors connected in parallel, as shown in **Figure 25-25.** (Chapter 23)



■ **Figure 25-25**

$$\frac{1}{R_{3\ \text{in parallel}}} = \frac{1}{85\ \Omega} + \frac{1}{85\ \Omega} + \frac{1}{85\ \Omega}$$

$$R_{3\ \text{in parallel}} = 28.3\ \Omega$$

$$\frac{1}{R_{2\ \text{in parallel}}} = \frac{1}{85\ \Omega} + \frac{1}{85\ \Omega}$$

$$R_{2\ \text{in parallel}} = 42.5\ \Omega$$

$$R = R_{3\ \text{in parallel}} + R_{2\ \text{in parallel}}$$

$$= 28.3\ \Omega + 42.5\ \Omega$$

$$= 71\ \Omega$$

104. An electron with a velocity of 2.1×10^{6} m/s is at right angles to a 0.81-T magnetic field. What is the force on the electron produced by the magnetic field? What is the electron's acceleration? The mass of an electron is 9.11×10^{-31} kg. (Chapter 24)

$$F = Bqv$$

$$= (0.81\ \text{T})(1.60\times10^{-19}\ \text{C})(2.1\times10^{6}\ \text{m/s})$$

$$= 2.7\times10^{-13}\ \text{N}$$

$$F = ma$$

$$a = \frac{F}{m} = \frac{2.7\times10^{-13}\ \text{N}}{9.11\times10^{-31}\ \text{kg}}$$

$$= 3.0\times10^{17}\ \text{m/s}^2$$

Challenge Problem

page 685

A distribution transformer (T_1) has its primary coil connected to a 3.0-kV AC source. The secondary coil is connected to the primary coil of a second transformer (T_2) by copper conductors. Finally, the secondary coil of transformer T_2 connects to a load that uses 10.0 kW of power. Transformer T_1 has a turn ratio of 5:1, and T_2 has a load voltage of 120 V. The transformer efficiencies are 100.0 percent and 97.0 percent, respectively.

1. Calculate the load current.

   $$I_L = \frac{P_L}{V_L} = \frac{10.0\text{ kW}}{120\text{ V}} = 83\text{ A}$$

2. How much power is being dissipated by transformer T_2?

   $$P_2 = \frac{P_L}{0.970} = \frac{10.0\text{ kW}}{0.970} = 10.3\text{ kW}$$

   P_2 is power input to transformer T_2. Of the 10.3 kW, 0.3 kW is dissipated by T_2; the other 10.0 kW is dissipated in the load.

3. What is the secondary current of transformer T_1?

   $$V_{s1} = \left(\frac{1}{5}\right)(3.0\times10^3\text{ V})$$
   $$= 6.0\times10^2\text{ V}$$
   $$I_{s1} = \frac{P_2}{V_{s1}} = \frac{10.3\times10^3\text{ W}}{6.0\times10^2\text{ V}} = 17\text{ A}$$

4. How much current is the AC source supplying to T_1?

   $$I_{p1} = \left(\frac{1}{5}\right)I_{s1} = \left(\frac{1}{5}\right)(17\text{ A}) = 3.4\text{ A}$$

CHAPTER

26 Electromagnetism

Practice Problems

26.1 Interactions of Electric and Magnetic Fields and Matter pages 697–704

page 700

Assume that all charged particles move perpendicular to a uniform magnetic field.

1. A proton moves at a speed of 7.5×10^{3} m/s as it passes through a magnetic field of 0.60 T. Find the radius of the circular path. Note that the charge carried by the proton is equal to that of the electron, but is positive.

$$Bqv = \frac{mv^2}{r}$$

$$r = \frac{mv}{Bq}$$

$$= \frac{(1.67\times10^{-27}\ \text{kg})(7.5\times10^{3}\ \text{m/s})}{(0.60\ \text{T})(1.60\times10^{-19}\ \text{C})}$$

$$= 1.3\times10^{-4}\ \text{m}$$

2. Electrons move through a magnetic field of 6.0×10^{-2} T balanced by an electric field of 3.0×10^{3} N/C. What is the speed of the electrons?

$$Bqv = Eq$$

$$v = \frac{E}{B} = \frac{3.0\times10^{3}\ \text{N/C}}{6.0\times10^{-2}\ \text{T}}$$

$$= 5.0\times10^{4}\ \text{m/s}$$

3. Calculate the radius of the circular path that the electrons in problem 2 follow in the absence of the electric field.

$$Bqv = \frac{mv^2}{r}$$

$$r = \frac{mv}{Bq}$$

$$= \frac{(9.11\times10^{-31}\ \text{kg})(5.0\times10^{4}\ \text{m/s})}{(6.0\times10^{-2}\ \text{T})(1.60\times10^{-19}\ \text{C})} = 4.7\times10^{-6}\ \text{m}$$

4. Protons passing without deflection through a magnetic field of 0.60 T are balanced by an electric field of 4.5×10^{3} N/C. What is the speed of the moving protons?

$$Bqv = Eq$$

$$v = \frac{E}{B} = \frac{4.5\times10^{3}\ \text{N/C}}{0.60\ \text{T}}$$

$$= 7.5\times10^{3}\ \text{m/s}$$

page 703

5. A beam of singly ionized (1+) oxygen atoms is sent through a mass spectrometer. The values are $B = 7.2\times10^{-2}$ T, $q = 1.60\times10^{-19}$ C, $r = 0.085$ m, and $V = 110$ V. Find the mass of an oxygen atom.

$$m = \frac{B^2r^2q}{2V} = \frac{(7.2\times10^{-2}\ \text{T})^2(0.085\ \text{m})^2(1.60\times10^{-19}\ \text{C})}{(2)(110\ \text{V})} = 2.7\times10^{-26}\ \text{kg}$$

6. A mass spectrometer analyzes and gives data for a beam of doubly ionized (2+) argon atoms. The values are $q = 2(1.60\times10^{-19}$ C$)$, $B = 5.0\times10^{-2}$ T, $r = 0.106$ m, and $V = 66.0$ V. Find the mass of an argon atom.

$$m = \frac{B^2r^2q}{2V} = \frac{(5.0\times10^{-2}\ \text{T})^2(0.106\ \text{m})^2(2)(1.60\times10^{-19}\ \text{C})}{(2)(66.0\ \text{V})} = 6.8\times10^{-26}\ \text{kg}$$

7. A stream of singly ionized (1+) lithium atoms is not deflected as it passes through a magnetic field of 1.5×10^{-3} T that is perpendicular to an electric field of 6.0×10^{2} N/C. What is the speed of the lithium atoms as they pass through the two fields?

$$Bqv = Eq$$

$$v = \frac{E}{B} = \frac{6.0\times10^{2}\ \text{N/C}}{1.5\times10^{-3}\ \text{T}}$$

$$= 4.0\times10^{5}\ \text{m/s}$$

8. In Example Problem 2, the mass of a neon isotope is determined. Another neon isotope is found to have a mass of 22 proton masses. How far apart on the photographic film would these two isotopes land?

Use the charge-to-mass ratio to find the ratio of the radii of the two isotopes.

$$\frac{q}{m} = \frac{2V}{B^2r^2}$$

Thus, $r = \frac{1}{B}\sqrt{\frac{2Vm}{q}}$ **and,** $\frac{r_{22}}{r_{20}} = \frac{\frac{1}{B}\sqrt{\frac{2Vm_{22}}{q}}}{\frac{1}{B}\sqrt{\frac{2Vm_{20}}{q}}} = \sqrt{\frac{m_{22}}{m_{20}}}$

The radius of the isotope with a mass of 22 proton masses, then, is

$$r_{22} = r_{20}\sqrt{\frac{m_{22}}{m_{20}}}$$

$$= r_{20}\sqrt{\frac{22m_p}{20m_p}}$$

$$= \sqrt{\frac{22}{20}}r_{20}$$

$$= \sqrt{\frac{22}{20}}(0.053\ \text{m})$$

$$= 0.056\ \text{m}$$

The difference in the radii is $r_{22} - r_{20} = 0.056\ \text{m} - 0.053\ \text{m} = 0.003\ \text{m} = 3\ \text{mm}$

Section Review

26.1 Interactions of Electric and Magnetic Fields and Matter pages 697–704

page 704

9. Cathode-Ray Tube Describe how a cathode-ray tube forms an electron beam.

Electrons are emitted by the cathode, accelerated by a potential difference, and passed through slits to form a beam.

10. Magnetic Field The radius of the circular path of an ion in a mass spectrometer is given by $r = (1/B)\sqrt{2Vm/q}$. Use this equation to explain how a mass spectrometer is able to separate ions of different masses.

Assuming all of the ions have the same charge, the only variable that is not constant in the equation is the ion mass, *m.* As *m* increases, the radius of the ion's path also increases. This results in separate paths for each unique mass.

11. Magnetic Field A modern mass spectrometer can analyze molecules having masses of hundreds of proton masses. If the singly charged ions of these molecules are produced using the same accelerating voltage, how would the mass spectrometer's magnetic field have to be changed for the ions to hit the film?

Since $r = (1/B)\sqrt{2Vm/q}$, as *m* increases, so too must *B*. If *m* is raised by a factor of about 10, *B* would have to increase by a factor of about 3 because to keep *r* constant, *B* must increase as $\sqrt{m}$.

12. Path Radius A proton moves at a speed of 4.2×10^4 m/s as it passes through a magnetic field of 1.20 T. Find the radius of the circular path.

$$\frac{q}{m} = \frac{v}{Br}$$

$$r = \frac{vm}{qB} = \frac{(4.2\times10^4\ \text{m/s})(1.67\times10^{-27}\ \text{kg})}{(1.60\times10^{-19}\ \text{C})(1.20\ \text{T})} = 3.7\times10^{-4}\ \text{m}$$

13. Mass A beam of doubly ionized (2+) oxygen atoms is accelerated by a potential difference of 232 V. The oxygen then enters a magnetic field of 75 mT and follows a curved path with a radius of 8.3 cm. What is the mass of the oxygen atom?

$$\frac{q}{m} = \frac{2V}{B^2r^2}$$

$$m = \frac{qB^2r^2}{2V} = \frac{(2)(1.60\times10^{-19}\ \text{C})(75\times10^{-3}\ \text{T})^2(8.3\times10^{-2}\ \text{m})^2}{(2)(232\ \text{V})}$$

$$= 2.7\times10^{-26}\ \text{kg}$$

14. **Critical Thinking** Regardless of the energy of the electrons used to produce ions, J. J. Thomson never could remove more than one electron from a hydrogen atom. What could he have concluded about the positive charge of a hydrogen atom?

It must be only a single elementary charge.

Practice Problems

26.2 Electric and Magnetic Fields in Space pages 705–713

page 706

15. What is the speed in air of an electromagnetic wave having a frequency of 3.2×10^{19} Hz?

All electromagnetic waves travel through air or a vacuum at *c*, 3.00×10^{8} m/s.

16. What is the wavelength of green light having a frequency of 5.70×10^{14} Hz?

$$\lambda = \frac{c}{f} = \frac{3.00\times10^{8}\text{ m/s}}{5.70\times10^{14}\text{ Hz}} = 5.26\times10^{-7}\text{ m}$$

17. An electromagnetic wave has a frequency of 8.2×10^{14} Hz. What is the wavelength of the wave?

$$\lambda = \frac{c}{f} = \frac{3.00\times10^{8}\text{ m/s}}{8.2\times10^{14}\text{ Hz}} = 3.7\times10^{-7}\text{ m}$$

18. What is the frequency of an electromagnetic wave having a wavelength of 2.2×10^{-2} m?

$$\lambda = \frac{c}{f}$$

$$f = \frac{c}{\lambda} = \frac{3.00\times10^{8}\text{ m/s}}{2.2\times10^{-2}\text{ m}} = 1.4\times10^{10}\text{ Hz}$$

page 707

19. What is the speed of an electromagnetic wave traveling through the air? Use $c = 299{,}792{,}458$ m/s in your calculation.

$$v = \frac{c}{\sqrt{K}} = \frac{299{,}792{,}458\text{ m/s}}{\sqrt{1.00054}}$$

$$= 2.99712\times10^{8}\text{ m/s}$$

20. For light traveling through water, the dielectric constant is 1.77. What is the speed of light traveling through water?

$$v = \frac{c}{\sqrt{K}} = \frac{3.00\times10^{8}\text{ m/s}}{\sqrt{1.77}}$$

$$= 2.25\times10^{8}\text{ m/s}$$

21. The speed of light traveling through a material is 2.43×10^{8} m/s. What is the dielectric constant of the material?

$$v = \frac{c}{\sqrt{K}}$$

$$K = \left(\frac{c}{v}\right)^2 = \left(\frac{3.00\times10^{8}\text{ m/s}}{2.43\times10^{8}\text{ m/s}}\right)^2 = 1.52$$

Section Review

26.2 Electric and Magnetic Fields in Space pages 705–713

page 713

22. **Wave Propagation** Explain how electromagnetic waves are able to propagate through space.

The changing electric field induces a changing magnetic field, and the changing magnetic field induces a changing electric field. The waves propagate as these two fields regenerate each other.

23. **Electromagnetic Waves** What are some of the primary characteristics of electromagnetic waves? Do electromagnetic waves behave differently from the way that other waves, such as sound waves, behave? Explain.

Electromagnetic waves can be described by frequency and wavelength. They behave similarly to other waves in that they reflect, refract, diffract, interfere, and can be Doppler shifted. The difference between the electromagnetic waves and other waves, such as sound waves, is that electromagnetic waves can travel through a vacuum and can be polarized.

24. Frequency An electromagnetic wave is found to have a wavelength of 1.5×10^{-5} m. What is the frequency of the wave?

$$\lambda = \frac{c}{f}$$

$$f = \frac{c}{\lambda} = \frac{3.00\times10^{8}\ \text{m/s}}{1.5\times10^{-5}\ \text{m}} = 2.0\times10^{13}\ \text{Hz}$$

25. TV Signals Television antennas normally have metal rod elements that are oriented horizontally. From this information, what can you deduce about the directions of the electric fields in television signals?

They also must be horizontal.

26. Parabolic Receivers Why is it important for a parabolic dish's receiving antenna to be properly aligned with the transmitter?

Parabolic dish antennas are only able to receive signals within a very narrow range of angles. It is, therefore, necessary to carefully align the dish receiver with the transmitting antennas to maximize the received signal strength.

27. Antenna Design Television channels 2 through 6 have frequencies just below the FM radio band, while channels 7 through 13 have much higher frequencies. Which signals would require a longer antenna: those of channel 7 or those of channel 6? Provide a reason for your answer.

The signals of channel 6 would require a longer antenna. Lower-frequency waves would have longer wavelengths.

28. Dielectric Constant The speed of light traveling through an unknown material is 1.98×10^{8} m/s. Given that the speed of light in a vacuum is 3.00×10^{8} m/s, what is the dielectric constant of the unknown material?

$$v = \frac{c}{\sqrt{K}}$$

$$K = \left(\frac{c}{v}\right)^2 = \left(\frac{3.00\times10^{8}\ \text{m/s}}{1.98\times10^{8}\ \text{m/s}}\right)^2 = 2.30$$

29. Critical Thinking Most of the UV radiation from the Sun is blocked by the ozone layer in Earth's atmosphere. In recent years, scientists have discovered that the ozone layer over both Antarctica and the Arctic Ocean is thinning. Use what you have learned about electromagnetic waves and energy to explain why some scientists are very concerned about the thinning ozone layer.

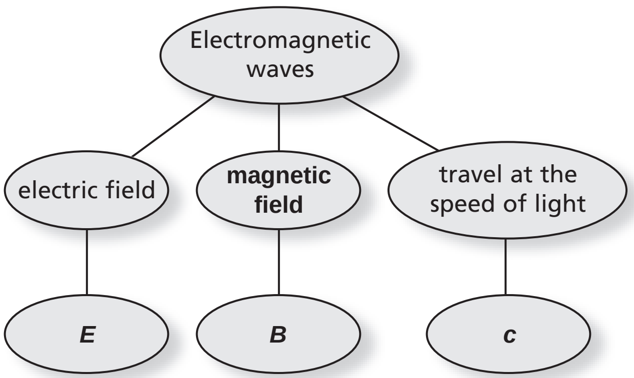
If the entire ozone layer is thinning, the amount of UV radiation from the Sun that is blocked by the ozone layer will decrease, allowing more UV rays to reach the surface of Earth. The wavelengths of UV waves are short enough, and their energies are high enough, to damage skin molecules. Thus, the resulting increase in UV rays to which humans would be exposed could increase the prevalence of skin cancer.

Chapter Assessment

Concept Mapping

page 718

30. Complete the following concept map using the following term and symbols: *E, c, magnetic field.*



Mastering Concepts

page 718

31. What are the mass and charge of an electron? (26.1)

The mass of an electron is 9.11×10^{-31} kg.
Its charge is -1.60×10^{-19} C.

32. What are isotopes? (26.1)

Isotopes are atoms of the same element that have different masses.

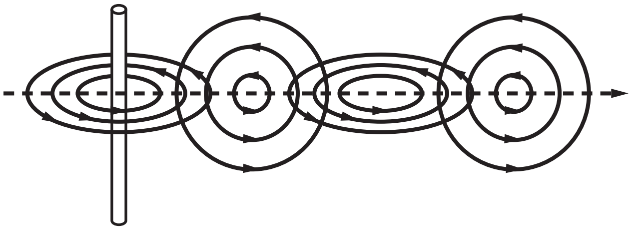
33. The direction of an induced magnetic field is always at what angle to the changing electric field? (26.2)

An induced magnetic field is always at right angles to the changing electric field.

34. Why must an AC generator be used to propagate electromagnetic waves? If a DC generator were used, when would it create electromagnetic waves? (26.2)

An AC generator supplies the changing electric field, which in turn generates a changing magnetic field. A DC generator would only generate a changing electric field when turned on or off.

35. A vertical antenna wire transmits radio waves. Sketch the antenna and the electric and magnetic fields that it creates. (26.2)



36. What happens to a quartz crystal when a voltage is applied across it? (26.2)

Quartz crystals bend or deform when voltage is placed across them. The quartz crystal then will vibrate at a set frequency.

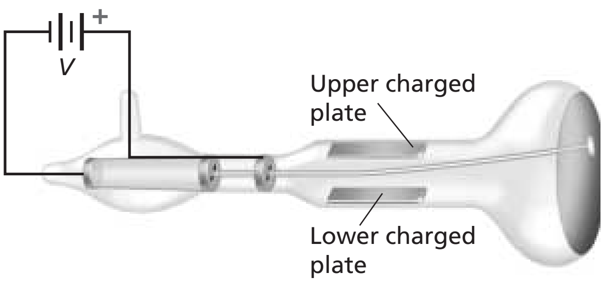
37. How does an antenna's receiving circuit select electromagnetic radio waves of a certain frequency and reject all others? (26.2)

By adjusting the capacitance of the antenna circuit, the oscillation frequency of the circuit equals the frequency of the desired radio waves. Resonance occurs, causing the electrons in the circuit to oscillate at that frequency.

Applying Concepts

page 718

38. The electrons in a Thomson tube travel from left to right, as shown in **Figure 26-14.** Which deflection plate should be charged positively to bend the electron beam upward?



■ **Figure 26-14**

The top plate should be charged positively.

39. The Thomson tube in question 38 uses a magnetic field to deflect the electron beam. What would the direction of the magnetic field need to be to bend the beam downward?

The magnetic field would be directed into the plane of the paper.

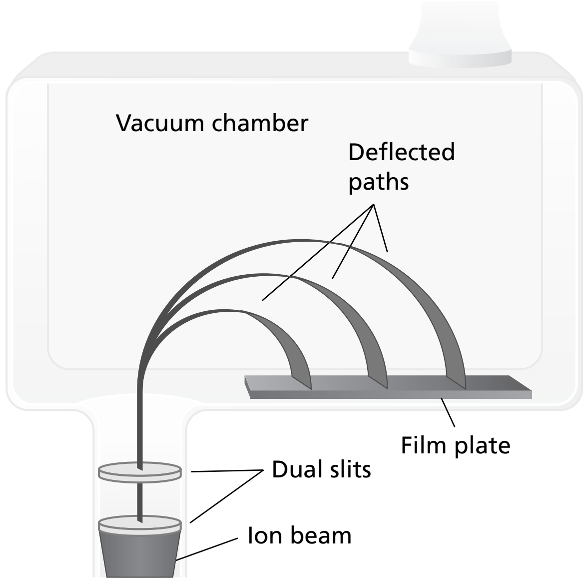
40. Show that the units of E/B are the same as the units for velocity.

$$\frac{E}{B} = \frac{\frac{N}{C}}{\frac{N}{A\cdot m}} = \frac{A\cdot m}{C}$$

Because 1 A is 1 C/s, this becomes

$$\frac{E}{B} = \frac{C\cdot m}{s\cdot C} = \frac{m}{s}$$

41. The vacuum chamber of a mass spectrometer is shown in **Figure 26-15.** If a sample of ionized neon is being tested in the mass spectrometer, in what direction must the magnetic field be directed to bend the ions into a clockwise semicircle?



■ Figure 26-15

The magnetic field is found by the right-hand rule and would be directed out from and perpendicular to the plane of the paper.

42. If the sign of the charge on the particles in question 41 is changed from positive to negative, do the directions of either or both of the fields have to be changed to keep the particles undeflected? Explain.

You can either change both fields or neither field, but you cannot change only one field.

43. For each of the following properties, identify whether radio waves, light waves, or X rays have the largest value.

a. wavelength

Radio waves have the longest wavelengths.

b. frequency

X rays have the highest frequencies.

c. velocity

All travel at the same velocity, which is the speed of light.

44. TV Waves The frequency of television waves broadcast on channel 2 is about 58 MHz. The waves broadcast on channel 7 are about 180 MHz. Which channel requires a longer antenna?

Channel 2 waves have a lower frequency and a longer wavelength, so channel 2 requires a longer antenna. The length of an antenna is directly proportional to wavelength.

45. Suppose the eyes of an alien being are sensitive to microwaves. Would you expect such a being to have larger or smaller eyes than yours? Why?

The eyes would be much larger, because the wavelength of microwave radiation is much larger than that of visible light.

Mastering Problems

26.1 Interactions of Electric and Magnetic Fields and Matter

page 719

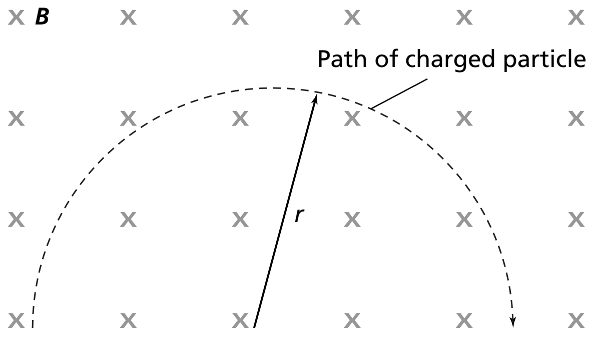
Level 1

46. Electrons moving at 3.6×10^4 m/s pass through an electric field with an intensity of 5.8×10^3 N/C. How large a magnetic field must the electrons also experience for their path to be undeflected?

$$v = \frac{E}{B}$$

$$B = \frac{E}{v} = \frac{5.8\times10^3\ \text{N/C}}{3.6\times10^4\ \text{m/s}} = 0.16\ \text{T}$$

47. A proton moves across a 0.36-T magnetic field, as shown in **Figure 26-16.** If the proton moves in a circular path with a radius of 0.20 m, what is the speed of the proton?



■ Figure 26-16

$$\frac{q}{m} = \frac{2v}{Br}$$

$$v = \frac{Brq}{m} = \frac{(0.36\ \text{T})(0.20\ \text{m})(1.60\times10^{-19}\ \text{C})}{1.67\times10^{-27}\ \text{kg}}$$

$$= 6.9\times10^6\ \text{m/s}$$

48. A proton enters a 6.0×10^{-2}-T magnetic field with a speed of 5.4×10^{4} m/s. What is the radius of the circular path it follows?

$$r = \frac{mv}{Bq} = \frac{(1.67\times10^{-27}\text{ kg})(5.4\times10^{4}\text{ m/s})}{(6.0\times10^{-2}\text{ T})(1.60\times10^{-19}\text{ C})} = 9.4\times10^{-3}\text{ m}$$

49. An electron is accelerated by a 4.5-kV potential difference. How strong a magnetic field must be experienced by the electron if its path is a circle of radius 5.0 cm?

$$B = \frac{1}{r}\sqrt{\frac{2Vm}{q}} = \frac{1}{0.050\text{ m}}\sqrt{\frac{(2)(4.5\times10^{3}\text{ V})(9.11\times10^{-31}\text{ kg})}{1.60\times10^{-19}\text{ C}}}$$

$$= 4.5\times10^{-3}\text{ T}$$

50. A mass spectrometer yields the following data for a beam of doubly ionized (2+) sodium atoms: $B = 8.0\times10^{-2}$ T, $q = 2(1.60\times10^{-19}$ C), $r = 0.077$ m, and $V = 156$ V. Calculate the mass of a sodium atom.

$$\frac{q}{m} = \frac{2V}{B^2r^2}$$

$$m = \frac{qB^2r^2}{2V} = \frac{(2)(1.60\times10^{-19}\text{ C})(8.0\times10^{-2}\text{ T})^2(0.077\text{ m})^2}{(2)(156\text{ V})} = 3.9\times10^{-26}\text{ kg}$$

Level 2

51. An alpha particle has a mass of approximately 6.6×10^{-27} kg and has a charge of 2+. Such a particle is observed to move through a 2.0-T magnetic field along a path of radius 0.15 m.

a. What speed does the particle have?

$$\frac{q}{m} = \frac{v}{Br}$$

$$v = \frac{Bqr}{m} = \frac{(2.0\text{ T})(2)(1.60\times10^{-19}\text{ C})(0.15\text{ m})}{6.6\times10^{-27}\text{ kg}}$$

$$= 1.5\times10^{7}\text{ m/s}$$

b. What is its kinetic energy?

$$KE = \frac{1}{2}mv^2 = \frac{1}{2}m\left(\frac{Bqr}{m}\right)^2 = \frac{q^2B^2r^2}{2m} = \frac{(2)(1.60\times10^{-19}\text{ C})(2.0\text{ T})^2(0.15\text{ m})^2}{(2)(6.6\times10^{-27}\text{ kg})}$$

$$= 7.0\times10^{-13}\text{ J}$$

c. What potential difference would be required to give it this kinetic energy?

$$KE = qV$$

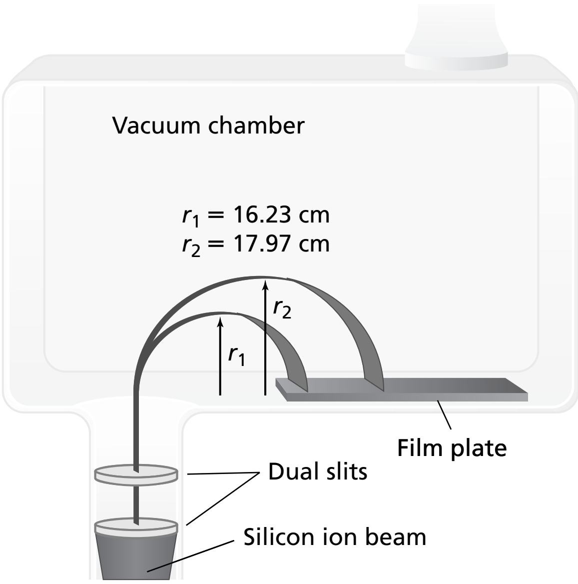
$$V = \frac{KE}{q} = \frac{7.0\times10^{-13}\text{ J}}{(2)(1.60\times10^{-19}\text{ C})} = 2.2\times10^{6}\text{ V}$$

52. A mass spectrometer analyzes carbon-containing molecules with a mass of 175×10^{3} proton masses. What percent differentiation is needed to produce a sample of molecules in which only carbon isotopes of mass 12, and none of mass 13, are present?

The difference between carbon-12 and carbon-13 is one proton mass. To distinguish between these, a percent differentiation of one proton mass out of 175×10^3 is needed, or

$$\frac{1}{175{,}000}\times 100 = \frac{1}{1750}\text{ percent.}$$

53. **Silicon Isotopes** In a mass spectrometer, ionized silicon atoms have curvatures, as shown in **Figure 26-17.** If the smaller radius corresponds to a mass of 28 proton masses, what is the mass of the other silicon isotope?



■ **Figure 26-17**

$$\frac{q}{m} = \frac{2V}{B^2r^2}$$

so m is proportional to r^2

$$\frac{m_2}{m_1} = \frac{{r_2}^2}{{r_1}^2}$$

$$m_2 = m_1\left(\frac{r_2}{r_1}\right)^2$$

$$= (28\ m_p)\left(\frac{17.97\text{ cm}}{16.23\text{ cm}}\right)^2 = 34m_p$$

$$m_2 = 34m_p = (34)(1.67\times10^{-27}\text{ kg})$$

$$= 5.7\times10^{-26}\text{ kg}$$

26.2 Electric and Magnetic Fields in Space page 719

Level 1

54. **Radio Waves** The radio waves reflected by a parabolic dish are 2.0 cm long. How long should the antenna be that detects the waves?

The antenna is $\frac{\lambda}{2}$, or 1.0 cm long.

55. **TV** A television signal is transmitted on a carrier frequency of 66 MHz. If the wires on a receiving antenna are placed $\frac{1}{4}\lambda$ apart, determine the physical distance between the receiving antenna wires.

$$\frac{1}{4}\lambda = \left(\frac{1}{4}\right)\frac{c}{f}$$

$$= \frac{3.00\times10^8\text{ m/s}}{(4)(66\times10^6\text{ Hz})}$$

$$= 1.1\text{ m}$$

56. **Bar-Code Scanner** A bar-code scanner uses a laser light source with a wavelength of about 650 nm. Determine the frequency of the laser light source.

$$f = \frac{c}{\lambda} = \frac{3.00\times10^8\text{ m/s}}{650\times10^{-9}\text{ m}} = 4.6\times10^{14}\text{ Hz}$$

57. What is the optimum length of a receiving antenna that is to receive a 101.3-MHz radio signal?

Optimum antenna length is

$$\frac{1}{2}\lambda = \left(\frac{1}{2}\right)\frac{c}{f}$$

$$= \frac{3.00\times10^8\text{ m/s}}{(2)(101.3\times10^6\text{ Hz})}$$

$$= 1.48\text{ m}$$

Level 2

58. An EM wave with a frequency of 100-MHz is transmitted through a coaxial cable having a dielectric constant of 2.30. What is the velocity of the wave's propagation?

$$v = \frac{c}{\sqrt{K}} = \frac{3.00\times10^8\text{ m/s}}{\sqrt{2.30}} = 1.98\times10^8\text{ m/s}$$