

Chapter 1: Electric and Magnetic Fields

Practice, page 314

- 1. The path of lightning is determined by pockets of ionized air molecules in the atmosphere. Since the air pockets are not evenly spaced and are randomly distributed, the path of the lightning strike is not a straight line. Instead, lightning strikes are jagged, following the pockets of ionized air molecules.
- 2. a. If the air has a high moisture content, it will release more energy as water vapour condenses into droplets. The added energy has the effect of heating up the parcel of air, which causes it to rise even higher.
 - **b.** A rising column of water vapour rushes past a column of descending water droplets. Since water molecules in the droplets hold onto their electrons more tightly than water molecules in the vapour, the water droplets become negatively charged by collecting electrons from some of the water molecules. As the droplets fall, the bottom of the cloud becomes negatively charged and the top of the cloud becomes positively charged.
- 3. a. Since the ebonite rod gained electrons, it is said to be negatively charged.

b.
$$q_{\rm rod} = 1.4 \times 10^{10}$$
 electrons $\times \frac{1.00 \text{ C}}{6.25 \times 10^{18} \text{ electrons}}$
= $2.2 \times 10^{-9} \text{ C}$

The ebonite rod would have a charge of -2.2×10^{-9} C. Note that the charge on the rod is negative since the rod gained electrons.

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4. a. q = 15 C $V = 1.50 \times 10^8 \text{ V}$ $\Delta E_p = ?$ $V = \frac{\Delta E_p}{q}$ $(1.50 \times 10^8 \text{ J/C})(15 \text{ C})$ $= 2.3 \times 10^9 \text{ J}$

The lightning strike delivered 2.3×10^9 J of energy.

b. The value of the electrical energy delivered by the lightning strike in question 4.a. is nearly 80% of the value of the total electrical energy used by a typical Alberta home in one month. Although these energy values are very similar, a key difference is that the energy in a lightning strike is delivered in a fraction of a second, while the electrical energy used by the house is used over one full month.

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5. a. Trees and ridges project into the air and are likely locations for lightning strikes. In an open field, a hiker could be the highest point and, therefore, a potential target for a lightning strike.

- **b.** The hikers are illustrated in an area of low ground and are shown sitting down to avoid making themselves part of the shortest path for the lightning. Additional precautions include sitting on their packs and keeping metal gear away from their bodies. These precautions help reduce the possibility of a hiker becoming part of the conducting path.
- 6. When a compass is used to determine direction, the only influence on the magnetic compass needle should be Earth's magnetic field. Objects containing iron, cobalt, and nickel could influence the compass needle in a way that causes it to give an inaccurate reading.
- 7. The peak of a mountain is farther from the centre of Earth than the base of the mountain, so the gravitational field lines are slightly farther apart at the peak than at the base. The low concentration of gravitational field lines at the peak indicates that the gravitational field is weaker at this location.

Type of Field	General Description of Sources for This Field	General Description of Test Bodies for This Field	Two Examples of a Source for This Field
electric	Source objects are either positively or negatively charged.	Test bodies are small charged objects.	 the negative charge on the bottom of a thundercloud the metal grid on a bug zapper
magnetic	Source objects are either magnets or electric currents.	Test bodies are small magnets, such as compass needles.	 a current-carrying coil in a speaker a fridge magnet
gravitational	Source objects have mass.	Test bodies are small objects with mass.	• Earth • the Sun

1.1 Questions, pages 326 and 327

Knowledge

- 1. a. An object has a negative charge if it has more electrons than protons. This is usually created by the object gaining excess electrons from some other object.
 - **b.** An object has a positive charge if it has fewer electrons than protons. This is usually created by the object losing electrons to some other object.
 - c. A coulomb is an SI unit for charge, where one coulomb is equivalent to the transfer of 6.25×10^{18} electrons.
 - d. Electric potential difference is the change in potential energy per unit of charge.
 - e. Voltage is another term for electric potential difference.
 - **f.** A volt is a unit for voltage, where 1 V = 1 J/C.
 - **g.** An electric field is a property of the space around a source charge that enables the source charge to exert forces on other charges that enter this region.

8.

- **h.** A magnetic field is a property of the space around a magnet or an electric current that enables the magnet or electric current to exert forces on other magnets, such as compass needles, that enter this region.
- **i.** A gravitational field is a property of the space around a source mass that enables the source mass to exert forces on other masses that enter this region.
- **j.** A test body is an observable object that can experience a force due to the presence of a field. The nature of the test body is matched to the type of field that it is able to detect—small masses are the test bodies for gravitational fields, small charges are the test bodies for electric fields, and tiny magnets (like compass needles) are the test bodies for magnetic fields.
- **k.** Field lines are a pattern of lines that describe the direction of a field by the way they point and the strength of a field by their density.
- 2. Electric, magnetic, and gravitational fields have the following characteristics in common:
 - A source object is able to exert a force on a test object without any physical contact.
 - The field can be described in terms of field lines.
 - The fields are invisible.

Electric, magnetic, and gravitational fields have the following differing characteristics:

- The sources and test objects for each field differ. Electric, magnetic, and gravitational fields involve interactions between objects that have charge, magnetic poles, and mass, respectively.
- The field lines for each type of field form different types of patterns.
- Electric field lines can point toward or away from a source, depending upon the nature of the source charge.
- Magnetic field lines form loops that are directed from the north pole to the south pole.
- Gravitational field lines always point toward the source.
- **3.** Fields are completely invisible. They can only be observed indirectly through their effects on matter. The particular characteristics of the matter that allow a field to be observed define the characteristics of the test body for that field. Test bodies for electric, magnetic, and gravitational fields have charge, magnetic poles, and mass, respectively.

Applying Concepts



electric field

5. a. Since the child lost some of the electrons from her body to the plastic material of the playground slide, she became positively charged, while the slide became negatively charged.



c. The voltage developed as a child goes down a slide is a large value—over 20 000 V. This means that 20 000 J of energy are stored for every coulomb of charge that is transferred between the child and the slide. The fact that not many coulombs of charge are transferred means that the total energy is relatively small—large enough to give an unpleasant shock, but not large enough to be life-threatening.

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- **9.** A positively charged particle would tend to attract electrons that are held by molecules. In some cases, the electrons could be removed from a covalent bond between two atoms within the molecule, causing the chemical bond to break and the structure of the molecule to change.
- **10.** As you learned in Unit A, the DNA molecule consists of two strands of nucleotides. The strands are said to be complementary because the phosphate base in a nucleotide on one strand will only bond with a certain base from a nucleotide on the other strand. Complementary base pairings for DNA are adenine with thymine and cytosine with guanine.

If a fast-moving charged particle damages an adenine base on one strand of DNA, there is only one way for the cell to repair this damage because the thymine base on the other strand will only bond with a replacement adenine base. However, if an ionized particle breaks both strands, the blueprint for an accurate repair has been destroyed. If the cell randomly adds the same number of bases that were destroyed by the ionized particle, the result could be a point mutation. If the cell attempts a repair by simply rejoining the broken strands without substituting for the destroyed bases, the result is a more serious frameshift mutation. As you learned in Unit A, mutations such as these can cause the death of the cell or can lead to diseases such as cancer.

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11. If the exponent was forgotten and the value for distance was not squared, the denominator of the fraction would have too small a value. This means that the value for gravitational field strength would be much too large.

Practice, page 334

12. Location II

$$r = 2.00 \times 10^{7} \,\mathrm{m}$$

$$g = \frac{Gm}{r^{2}}$$

$$m = 5.98 \times 10^{24} \,\mathrm{kg}$$

$$g = ?$$

$$= \frac{(6.67 \times 10^{-11} \,\mathrm{N} \cdot \mathrm{m}^{2}/\mathrm{kg}^{2})(5.98 \times 10^{24} \,\mathrm{kg})}{(2.00 \times 10^{7} \,\mathrm{m})^{2}}$$

$$= 0.997 \,\mathrm{N/kg}$$

The gravitational field strength of Earth at location II is 0.997 N/kg.

Location III

$$r = 1.00 \times 10^{8} \text{ m}$$

$$g = \frac{Gm}{r^{2}}$$

$$m = 5.98 \times 10^{24} \text{ kg}$$

$$g = ?$$

$$= \frac{(6.67 \times 10^{-11} \text{ N} \cdot \text{m}^{2}/\text{kg}^{2})(5.98 \times 10^{24} \text{ kg})}{(1.00 \times 10^{8} \text{ m})^{2}}$$

$$= 0.0399 \text{ N/kg}$$

The gravitational field strength of Earth at location III is 0.0399 N/kg.

Location IV

$$r = 2.00 \times 10^{8} \text{ m}$$

$$g = \frac{Gm}{r^{2}}$$

$$m = 5.98 \times 10^{24} \text{ kg}$$

$$g = ?$$

$$= \frac{(6.67 \times 10^{-11} \text{ N} \cdot \text{m}^{2}/\text{kg}^{2})(5.98 \times 10^{24} \text{ kg})}{(2.00 \times 10^{8} \text{ m})^{2}}$$

$$= 0.009 \text{ 97 N/kg}$$

The gravitational field strength of Earth at location IV is 0.009 97 N/kg.

Location V

$$r = 3.457 \times 10^{8} \text{ m}$$

$$g = \frac{Gm}{r^{2}}$$

$$g = ?$$

$$g = \frac{(6.67 \times 10^{-11} \text{ N} \cdot \text{m}^{2}/\text{kg}^{2})(5.98 \times 10^{24} \text{ kg})}{(3.457 \times 10^{8} \text{ m})^{2}}$$

$$= 0.003 \text{ 34 N/kg}$$

The gravitational field strength of Earth at location V is 0.003 34 N/kg.

13. Location V

$$r = 3.83 \times 10^{7} \text{ m}$$

$$g = \frac{Gm}{r^{2}}$$

$$g = ?$$

$$g = \frac{(6.67 \times 10^{-11} \text{ N} \cdot \text{m}^{2}/\text{kg}^{2})(7.35 \times 10^{22} \text{ kg})}{(3.83 \times 10^{7} \text{ m})^{2}}$$

$$= 0.003 \text{ 34 N/kg}$$

The gravitational field strength of the Moon at location V is 0.003 34 N/kg.

Location VI

$$r = 1.84 \times 10^{6} \text{ m}$$

$$g = \frac{Gm}{r^{2}}$$

$$m = 7.35 \times 10^{22} \text{ kg}$$

$$g = ?$$

$$= \frac{(6.67 \times 10^{-11} \text{ N} \cdot \text{m}^{2}/\text{kg}^{2})(7.35 \times 10^{22} \text{ kg})}{(1.84 \times 10^{6} \text{ m})^{2}}$$

$$= 1.45 \text{ N/kg}$$

The gravitational field strength of the Moon at location VI is 1.45 N/kg.



- **d.** The gravitational field strength of the Moon is 0.003 34 N/kg, directed toward the Moon. The gravitational field strength of Earth is 0.003 34 N/kg, directed toward Earth. The strengths of these two gravitational fields are the same, but they act in opposite directions.
- e. If a space vehicle comes to rest and turns off its engines at location V, both the Moon and Earth would exert the same gravitational force on it because the strength of the gravitational field from each object is the same. However, because the gravitational fields act in opposite directions, the forces would also act in opposite directions and would cancel out.
- 15. a. If the distance from Earth doubles, the value of the denominator in the gravitational field strength equation is increased by a factor of 4. This is due to the fact that the value of *r* is doubled and then squared, so the overall effect is r^2 is 4 times larger. Since the denominator is 4 times larger, the gravitational field strength is only $\frac{1}{4}$ of its previous value.
 - **b.** If the distance from Earth increases by a factor of 10, the value of the denominator in the gravitational field strength equation is increased by a factor of 100. This is due to the fact that the value of *r* is made 10 times larger and then squared, so the overall effect is r^2 is 100 times larger. Since the denominator is 100 times larger, the gravitational field strength is only $\frac{1}{100}$ of its previous value.

Practice, page 338

16. a.
$$q = +0.0200 \text{ C}$$

 $r_{\text{midpoint}} = 10.0 \text{ m}$
 $|\vec{E}| = ?$
 $= \frac{(8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2)(0.0200 \text{ C})}{(10.0 \text{ m})^2}$
 $= 1.80 \times 10^6 \text{ N/C}$

The strength of the electric field at the midpoint due to the sphere on the left is 1.80×10^6 N/C.

- **b.** The direction of the electric field at the midpoint due to the sphere on the left is to the right because this is the way that a positive test charge would be forced.
- c. Since the values for source charge and distance are the same, the electric field strength will have the same value for the sphere on the right as for the sphere on the left: 7.2×10^6 N/C. However, the direction of the electric field is to the left, since this is the way that a positive test charge would be forced by the source charge on the right.
- **d.** The electric field of the source charge on the left is 1.80×10^6 N/C, right. The electric field of the source charge on the right is 1.80×10^6 N/C, left. Since these two vectors are equal but opposite, the electric fields cancel.

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17. a. The diagram showing the electric fields around the balloons should look similar to the one given.



b. Calculate the electric field strength due to one balloon at the midpoint.

$$r = 22 \operatorname{cm} \times \frac{1 \operatorname{m}}{100 \operatorname{cm}} \qquad |\vec{E}| = \frac{kq}{r^2}$$

= 0.22 m
$$q = -5.0 \operatorname{nC} \qquad = \frac{(8.99 \times 10^9 \operatorname{N} \cdot \operatorname{m}^2/\operatorname{C}^2)(5.0 \times 10^{-9} \operatorname{C})}{(0.22 \operatorname{m})^2}$$

= 929 N/C
$$|\vec{E}| = ?$$

The strength of the electric field at the midpoint due to one balloon is 929 N/C.

Determine the direction of the electric field vectors.

- For the balloon on the left, the electric field due to this source charge will point to the left, since this is the way a positive test body would be forced.
- For the balloon on the right, the electric field due to this source charge will point to the right, since this is the way a positive test body would be forced.

Combine the results from the calculation and analysis to state the final answer.



Since the electric field of one balloon is equal in magnitude but opposite in direction to the electric field of the other balloon, the electric field vectors cancel. The result is the net electric field is zero.

Practice, page 343

18. Magnetic fields can be produced by electric currents and by permanent magnets. In the case of a coil with an electric current passing through the loops of wire, it is moving charges that form the electric current; so, ultimately, moving charges are the source of the magnetic field.

In the case of a permanent magnet, the spinning motion and orbital motion of electrons within the atoms of the magnetic material form the moving charges. If the motion of the electrons can be organized so that the magnetic fields are aligned, it is as if each electron contributes to the total magnetic field of a bar magnet in the same way that each loop of wire contributes to the total magnetic field of a coil. This is why the resulting magnetic field of a bar magnet is identical to that formed by a current-carrying coil.

19. Refer to the "Labelling the Magnetic Field Around a Current-Carrying Coil—Labelled" handout.

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- **20.** The major challenge in NASA's plans is providing energy for the charged positive spheres and the current-carrying coils that will be positioned above the base. Vast amounts of electrical energy would need to be generated on a continuous basis.
- **21.** Earth's inhabitants are protected from the harmful effects of charged particles from the solar wind and cosmic radiation by Earth's magnetic field and the shielding effects of the atmosphere.

1.2 Questions, pages 346 to 348

Knowledge

1. a. Mars

$$m = 6.42 \times 10^{23} \text{ kg} \qquad g = \frac{Gm}{r^2}$$

$$r = 3.40 \times 10^3 \text{ km} \times \frac{1000 \text{ m}}{1 \text{ km}} \qquad = \frac{(6.67 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2)(6.42 \times 10^{23} \text{ kg})}{(3.40 \times 10^6 \text{ m})^2}$$

$$= 3.40 \times 10^6 \text{ m} \qquad = 3.704 \text{ } 273 \text{ } 356 \text{ N/kg}$$

$$= 3.70 \text{ N/kg}$$

The gravitational field strength on the surface of Mars is 3.70 N/kg.

Io

$$m = 8.94 \times 10^{22} \text{ kg} \qquad g = \frac{Gm}{r^2}$$

$$r = 1.82 \times 10^3 \text{ km} \times \frac{1000 \text{ m}}{1 \text{ km}} = \frac{(6.67 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2)(8.94 \times 10^{22} \text{ kg})}{(1.82 \times 10^6 \text{ m})^2}$$

$$= 1.800 \text{ 199 } 251 \text{ N/kg}$$

$$= 1.80 \text{ N/kg}$$

The gravitational field strength on the surface of Io is 1.80 N/kg.



c. Mars

<i>g</i> = 3.704 273 356 N/kg	$F_{\rm g} = mg$
m = 100 kg	=(100 kg)(3.704 273 356 N/kg)
$F_{\rm g} = ?$	= 370 N

The force of gravity on this astronaut would be 370 N on the surface of Mars.

Io

<i>g</i> = 1.800 199 251 N/kg	$F_{\rm g} = mg$
m = 100 kg	=(100 kg)(1.800 199 251 N/kg)
$F_{\rm g} = ?$	=180 N

The force of gravity on this astronaut would be 180 N on the surface of Io.

d. The mass and radius values for Mars result in a larger gravitational field strength on the surface of Mars than on the surface of Io. Since the gravitational field strength is larger, the gravitational field lines are drawn closer together and the force on a 100-kg astronaut is greater on Mars than it would be on Io.

2. a. van de Graaff Generator

$$q = 3.5 \ \mu C \qquad |\vec{E}| = \frac{kq}{r^2} = 3.5 \times 10^{-6} C \qquad = \frac{(8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2)(3.5 \times 10^{-6} \text{ C})}{(0.18 \text{ m})^2} = 0.18 \text{ m} \qquad = 971141.9753 \text{ N/C} |\vec{E}| = ?$$

The strength of the electric field on the surface of the van de Graaff generator is 9.7×10^5 N/C.

Balloon

$$q = -4.7 \text{ nC} \qquad |\vec{E}| = \frac{kq}{r^2} = -4.7 \times 10^{-9} \text{ C} \qquad = \frac{(8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2)(4.7 \times 10^{-9} \text{ C})}{(0.17 \text{ m})^2} = 0.17 \text{ m} \qquad = 1462.041522 \text{ N/C} = 1.5 \times 10^3 \text{ N/C}$$

The strength of the electric field on the surface of the balloon is 1.5×10^3 N/C.

b. van de Graaff Generator

Balloon





c. van de Graaff Generator

$$\begin{aligned} \left| \vec{E} \right| &= 971\,141.9753 \text{ N/C} & F_{e} &= \left| \vec{E} \right| q \\ q &= -3.5 \times 10^{-12} \text{ C} &= (971\,141.9753 \text{ N/C}) (3.5 \times 10^{-12} \text{ C}) \\ F_{e} &= ? &= 3.4 \times 10^{-6} \text{ N} \end{aligned}$$

The magnitude of the electric force on the dust speck is 3.4×10^{-6} N. Since the dust speck is negative and the van de Graaff globe is positive, the force on the dust speck will be towards the van de Graaff globe.

 $\vec{F}_{e} = 3.4 \times 10^{-6}$ N, toward the van de Graaff generator

Balloon

$$\begin{aligned} \left| \vec{E} \right| &= 1462.041\ 522\ \text{N/C} & F_e &= \left| \vec{E} \right| q \\ q &= -3.5 \times 10^{-12} \text{C} &= (1462.041\ 522\ \text{N/C}) (3.5 \times 10^{-12}\ \text{C}) \\ F_e &= ? &= 5.1 \times 10^{-9}\ \text{N} \end{aligned}$$

The magnitude of the electric force on the dust speck is 5.1×10^{-9} N. Since the dust speck is negative and the surface of the balloon is negative, the force on the dust speck will be away from the surface of the balloon.

 $\vec{F_e} = 5.1 \times 10^{-9}$ N, away from the balloon



Applying Concepts

- **4. a.** Gravitational fields always point toward the source object. So, at the location of *ACE*, the direction of the gravitational field of the Sun is toward the Sun.
 - **b.** Gravitational fields always point toward the source object. So, at the location of *ACE*, the direction of the gravitational field of Earth is toward Earth.
 - **c.** The gravitational field vectors are pulling *ACE* in opposite directions. Although the gravitational field of the Sun is larger, the gravitational field of Earth is able to reduce the effects of this field by cancelling out a portion of the Sun's gravitational field.

- **5. a.** The positively charged component acts as a positive source object for an electric field. Since a positively charged test object that comes close to this source would be repelled, the direction of the electric field lines is away from the positively charged component.
 - **b.** Since opposite charges attract, the negatively charged electrons on nearby components would be attracted to the positively charged source.
 - **c.** No, the answers to questions 5.a. and 5.b. do not contradict one another. The answer to question 5.a. describes the direction of the force on a positively charged test body. Electric fields are always described in terms of positively charged test bodies. The answer to question 5.b. describes the direction of the force on a negatively charged electron. It makes sense that the directions in questions 5.a. and 5.b. should be opposite because the test bodies have opposite charges.
- 6. The information from the *ACE* website would be very useful to the tour operators because it would enable them to monitor changes in the solar wind. The solar wind is the phenomenon that powers the northern lights. Sudden increases in solar-wind activity could indicate that the "space weather" is more likely to produce northern lights, making the conditions ideal for a night of observing them.

Practice, page 350

- 22. When a large speaker is generating sound waves, the movement of the speaker cone may be invisible to your eyes; yet, if you gently place your fingertips on the outside edge of the speaker cone, you can feel the vibrations.
- **23. a.** A microphone converts the mechanical energy of sound waves into the energy of an electrical signal. A headphone transforms the energy in an electrical signal into the mechanical energy of sound waves.
 - **b.** Your sense of hearing involves the same basic process as a microphone—the mechanical energy of vibrations is converted into an electrical signal. However, in the case of hearing, the electrical signal is transmitted biochemically through nerve cells instead of through wires.

Practice, page 357

24.	$q = 1.12 \times 10^4 \text{ C}$	$I = \frac{q}{t}$
	$t = 30 \text{ min} \times \frac{60 \text{ s}}{1 \text{ min}}$	$=\frac{1.12\times10^{4} \text{ C}}{1.8\times10^{3} \text{ s}}$
	$=1.8 \times 10^{3} s$	=6.2 C/s
	I = ?	=6.2 A

The quantity of energy that passes through the wire segment as the motor is running is 6.2 A.

25. An adequate supply of electrical energy would allow for the possibility of large refrigeration units in centralized food-storage facilities. The refrigeration units could be used to store food that might otherwise spoil if it were stored at higher temperatures. Having less food lost due to spoilage would be an important first step in making more food available to the local population.

Practice, page 360

26. Motor 1

The armature of this motor has a south pole at the top of the coil and a north pole at the bottom of the coil. The south pole will drop to the left because it is attracted to the north pole of the fixed magnets. The north pole will rise to the right because it is attracted to the south pole of the fixed magnets. The rotation that results from the interaction of the magnetic poles would appear to be counterclockwise when viewed from the front of the armature's shaft.

Motor 2

The armature of this motor has a north pole at the top of the coil and a south pole at the bottom of the coil. The north pole will drop to the left because it is attracted to the south pole of the fixed magnets. The south pole will rise to the right because it is attracted to the north pole of the fixed magnets. The rotation that results from the interaction of the magnetic poles would appear to be counterclockwise when viewed from the front of the armature's shaft.

Motor 3

The armature of this motor has a south pole at the top of the coil and a north pole at the bottom of the coil. The south pole will drop to the right because it is attracted to the north pole of the fixed magnets. The north pole will rise to the left because it is attracted to the south pole of the fixed magnets. The rotation that results from the interaction of the magnetic poles would appear to be clockwise when viewed from the front of the armature's shaft.

- 27. This device takes an input of electrical energy and converts it into the mechanical energy of the rotating shaft. Since the shaft is connected to the blades of a fan, the energy of the shaft is transferred to the kinetic energy of the moving fan blades. The turning fan blades then do work on the surrounding air, creating the kinetic energy of moving air, otherwise known as a breeze.
- 28. The inside surface of one magnet should be a north pole, and the inside surface of the other magnet should be a south pole.
- **29. a.** The piece of the motor identified in step 5 is called the armature.
 - **b.** The three separated contacts on the end of the axle are called the commutators.
 - c. The iron coil intensifies the magnetic field of each coil in much the same way a nail can intensify the magnetic field produced by the coil of a simple electromagnet.
 - d. Three coils would have several advantages. One advantage is that at least one coil would always be in a position to experience a large magnetic force due to the interaction with the fixed magnets on the metal casing. In the simple student-built motor, the single coil was in a position to experience a large force only during a small portion of a full rotation.

Another advantage of three coils is that the motor would be less likely to get stuck in one position. Recall your work from the "Building an Electric Motor." Since this motor had one coil, it sometimes got stuck in one position because the coil happened to align with the two fixed magnets. The three-coil system makes this kind of alignment impossible, so the motor can't get stuck in one position.

- **30. a.** The metal contacts are called brushes.
 - **b.** The brushes are made from thin material that is light and spring-like so contact can be maintained with the commutator while applying light pressure to allow the armature to rotate easily.

1.3 Questions, pages 364 and 365

Knowledge

1. Device 1 is a generator because the input is mechanical energy (supplied by the falling paper clips) and the output is electrical energy, as measured by a voltmeter. Since this generator has slip rings, it will act as a source of alternating current and is, therefore, an AC generator.

Device 2 is a DC motor because the input is electrical energy (supplied by an electrochemical cell) and the output is mechanical energy in the form of rising paper clips.

Device 3 is a generator because the input is mechanical energy (supplied by the falling paper clips) and the output is electrical energy, as measured by a voltmeter. Since this generator has a split-ring commutator, it will act as a source of direct current and is, therefore, a DC generator.

g. voltage source

f. split-ring commutator

h. split-ring commutator

e. slip rings

- **2. a.** rotating coil
 - **b.** brush
 - **c.** voltmeter
 - **d.** permanent magnet

Applying Concepts



- 4. The north pole of the armature will be attracted to the south pole on the inside surface of the magnet on the left. This means that the armature will rotate counterclockwise when viewed from the front.
- 5. The motor will continue to turn in the same direction because when the part of the armature that is currently on top is rotated to the lower left, the split in the commutator will align with the brushes. Even though the current will continue to flow through the armature at this point, the inertia of the spinning armature will carry it past until the current is re-established. When the current is re-established, it will switch directions because the brushes are touching different segments of the commutator, causing the part of the armature that used to be a north pole to become a south pole. The south pole will be repelled by the inside surface of the magnet on the right, so the armature will continue to rotate in the same direction. When the part of the armature that was originally on the top reaches the bottom, the cycle repeats since a north pole will once again be formed at the top of the armature.

6. The device shown is an AC generator, so the output is an alternating current.



7. If the number of armature rotations per minute is increased, the output of the generator has a higher frequency and the voltage peaks are higher.



Practice, page 369

- 31. The following answers describe the errors in the circuits shown on the handout "Multimeter Troubleshooting."
 - **a.** There are two errors with this attempt to measure current:
 - The meter is not connected in series with the device.
 - The top input lead of the meter is not set to measure current.
 - **b.** The meter is not connected in series with the device to measure current. The "1" on the display indicates that the current entering the meter is beyond the 20-mA scale that was selected on the dial of the meter. The usual outcome of this kind of error is that a fuse is blown in the meter.
 - **c.** Although the meter is correctly connected, the display reads "0.00" because the fuse in the meter has blown. The circumstance described in question 31.b. is the usual event that causes this sort of problem.
 - d. There are two errors with this attempt to measure voltage:
 - The meter is not connected in parallel with the device.
 - The top input lead of the meter is not set to measure voltage.
 - e. The positive lead of the meter is connected to the negative side of the circuit, while the negative lead of the meter is connected to the positive side of the circuit. This problem can be corrected by reversing the output leads of the power supply or by reversing the input leads of the meter.

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- **32. a.** Since the light bulb is connected directly to the household circuitry, the current passing through the bulb is AC.
 - b. V = 120 V I = 0.25 A R = ? $R = \frac{V}{I}$ $= \frac{120 \text{ V}}{0.25 \text{ A}}$ $= 4.8 \times 10^2 \Omega$

The resistance through the bulb is $4.8 \times 10^2 \Omega$.

33. a. The light bulb is operated by the batteries of the flashlight, so the current passing through the bulb is DC.

b.	V = 6.0 V	V = IR
	$R = 8.0 \ \Omega$	$I = \frac{V}{R}$
	= 8.0 V/A	6.0 V
	I = ?	$=\frac{1}{8.0 \text{ V/A}}$
	1 – .	= 0.75 A

The current through the bulb is 0.75 A.

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34.	$V_1 = 3.6 \text{ V}$	For voltage sources in series,
	$V_2 = 3.6 \text{ V}$	$V_{\text{total}} = V_1 + V_2 + V_3 + V_4$
	$V_{3} = 3.6 \text{ V}$	= 3.6 V + 3.6 V + 3.6 V + 3.6 V $= 14.4 V$
	$V_4 = 3.6 \text{ V}$	
	$V_{\rm total} = ?$	

The total voltage of the four cells connected in series is 14.4 V.

35. $V_{4-\text{cell combo}} = 14.4 \text{ V}$ $V_{4-\text{cell combo}} = 14.4 \text{ V}$ $V_{4-\text{cell combo}} = 14.4 \text{ V}$ $V_{\text{total}} = ?$ For voltage sources in parallel, $V_{\text{total}} = V_{4-\text{cell combo}} = V_{4-\text{cell combo}}$ = 14.4 V

The total voltage for the two four-cell combinations is 14.4 V.

36. a. $V_1 = 6.0 \text{ V}$ $V_2 = 6.0 \text{ V}$ $V_{\text{total}} = ?$ **36.** a. $V_1 = 6.0 \text{ V}$ $V_{\text{total}} = V_1 + V_2$ = 6.0 V + 6.0 V= 12.0 V

The total voltage available to this circuit is 12.0 V.

b.
$$R_1 = 20 \Omega$$
 For resistors in series,
 $R_2 = 40 \Omega$ $R_{\text{total}} = R_1 + R_2$
 $R_{\text{total}} = ?$ $= 20 \Omega + 40 \Omega$
 $= 60 \Omega$

The total resistance available to this circuit is 60 Ω .

c. $R_{\text{total}} = 60 \ \Omega$ V = IR $V_{\text{total}} = 12.0 \ \text{V}$ $I_{\text{total}} = ?$ $I_{\text{total}} = \frac{V_{\text{total}}}{R_{\text{total}}}$ $I_{\text{total}} = \frac{12.0 \ \text{V}}{60 \ \Omega}$ $= 0.20 \ \text{A}$

The total current flowing through the circuit is 0.20 A. Since the bulbs are connected in series, the current flowing through each bulb is the same as the total current, 0.20 A.

d.	$R_1 = 20 \ \Omega$	V = IR	$R_2 = 40 \ \Omega$	V = IR
	I = 0.20 A	$V_1 = IR_1$	I = 0.20 A	$V_2 = IR_2$
	V = 9	$=(0.20 \text{ A})(20 \Omega)$	V = 9	$=(0.20 \text{ A})(40 \Omega)$
	$V_1 = 2$	= 4.0 V	$V_2 = ?$	= 8.0 V

The voltage across resistor 1 is 4.0 V.

The voltage across resistor 2 is 8.0 V.

- e. If one bulb burns out, the current is interrupted for the whole circuit. Since no current is available for the other bulb, it will not be lit either.
- **37. a.** $V_1 = 6.0 \text{ V}$ $V_2 = 6.0 \text{ V}$ $V_{\text{total}} = ?$ $V_1 = V_2$ $V_1 = V_2$ $V_2 = 6.0 \text{ V}$ $V_2 = 6.0 \text{ V}$

Since the voltage sources are equal and connected in parallel, the total voltage is equal to the voltage across one source.

b. $R_1 = 20 \ \Omega$

For resistors in parallel,

$$R_{2} = 40 \ \Omega$$

$$R_{1} = \frac{1}{R_{1}} + \frac{1}{R_{2}}$$

$$R_{total} = ?$$

$$\frac{1}{R_{total}} = \left(\frac{1}{20 \ \Omega}\right) + \left(\frac{1}{40 \ \Omega}\right)$$

$$\frac{1}{R_{total}} = \left(0.050 \frac{1}{\Omega}\right) + \left(0.025 \frac{1}{\Omega}\right)$$

$$\frac{1}{R_{total}} = 0.075 \frac{1}{\Omega}$$

$$R_{total} = 13.\overline{3} \ \Omega$$

$$= 13 \ \Omega$$

The total resistance of the two bulbs is 13 Ω .

c. $V_{\text{total}} = 6.0 \text{ V}$ $R_{\text{total}} = 13.\overline{3} \Omega$ $I_{\text{total}} = ?$ V = IR $V_{\text{total}} = I_{\text{total}} R_{\text{total}}$ $I_{\text{total}} = \frac{V_{\text{total}}}{R_{\text{total}}}$ $= \frac{6.0 \text{ V}}{13.3 \text{ V/A}}$ = 0.45 A

The total current flowing through the whole circuit is 0.45 A.

d. Determine the current flowing through A_3 .

The current running through A_3 is the total current flowing through the whole circuit, which is 0.45 A.

Determine the current flowing through A_1 .

step 1: Since the resistors are connected in parallel, the voltage across R_1 is the same as the total voltage. Therefore, $V_1 = 6.0$ V.

step 2: Now, solve for I_1 , the current flowing through R_1 .

$V_1 = 6.0 \text{ V}$	V = IR
$R_1 = 20 \ \Omega$	$V_1 = I_1 R_1$
$I_1 = ?$	$I_1 = \frac{V_1}{R_1}$
	$=\frac{6.0 \text{ V}}{20 \text{ V/A}}$
	= 0.30 A

The current flowing through R_1 is 0.30 A.

step 3: Determine the current flowing through A_1 .

Since A_1 and R_1 are connected in series, the current flowing through A_1 is identical to the current flowing through R_1 . Therefore, the current flowing through A_1 is 0.30 A.

Determine the current flowing through A_2 .

step 1: Since the resistors are connected in parallel, the voltage across R_2 is the same as the total voltage. Therefore, $R_2 = 6.0$ V.

step 2: Now, solve for I_2 , the current flowing through R_2 .

$V_2 = 6.0 \text{ V}$	V = IR
$R_2 = 40 \ \Omega$	$V_{2} = I_{2}R_{2}$
$I_2 = ?$	$I_2 = \frac{V_2}{R_2}$
	$=\frac{6.0 \text{ V}}{40 \text{ V/A}}$
	= 0.15 A

The current flowing through R_2 is 0.15 A.

step 3: Determine the current flowing through A_2 .

Since A_2 and R_2 are connected in series, the current through A_2 = current through R_2 = 0.15 A.

- e. After flowing through ammeter 1, the current must divide. One part flows through ammeter 1; the other part flows through ammeter 2.
- **f.** If one of the bulbs burns out, the other light bulb is still able to emit light because there is more than one path for the current in a parallel circuit.

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38. a.	Blender		Toaster	
	$R = 60 \ \Omega$	V = IR	$R = 12 \Omega$	V = IR
	<i>V</i> =120 V	$I = \frac{V}{R}$	V = 120 V	$I = \frac{V}{R}$
	I = ?	$=\frac{120 \text{ V}}{60 \Omega}$ $= 2.0 \text{ A}$	<i>I</i> = ?	$=\frac{120 \text{ V}}{12 \Omega}$ $=10 \text{ A}$

The current flowing through the blender is 2.0 A.

The current flowing through the toaster is 10 A.

Kettle

$$R = 10 \ \Omega \qquad V = IR$$

$$V = 120 \ V \qquad I = \frac{V}{R}$$

$$I = ? \qquad = \frac{120 \ V}{10 \ \Omega}$$

$$= 12 \ A$$

The current flowing through the kettle is 12 A.

- **b.** The total current required by all three devices would be 24 A.
- c. $R_1 = 60 \ \Omega$ $R_2 = 12 \ \Omega$ $R_3 = 10 \ \Omega$ $R_{\text{total}} = 2$ $R_{\text{total}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$ $\frac{1}{R_{\text{total}}} = \frac{1}{60 \ \Omega} + \frac{1}{12 \ \Omega} + \frac{1}{10 \ \Omega}$ $\frac{1}{R_{\text{total}}} = 0.20 \frac{1}{\Omega}$ $R_{\text{total}} = 5.0 \ \Omega$

The total resistance of all the devices is 5.0 Ω .

d. V = 120 V $R_{\text{total}} = 5.0 \Omega$ $I_{\text{total}} = ?$ $V = I_{\text{total}}$ $I_{\text{total}} = \frac{V}{R_{\text{total}}}$ $= \frac{120 \text{ V}}{5.0 \Omega}$ = 24 A

The total current required by all the devices is 24 A. This value is consistent with the answer to question 38.b.

- e. If all three devices are switched on at the same time, the total current flowing through the circuit would be 24 A. The maximum safe current for household circuits like this is 15 A. When the current exceeds this value, the circuit breaker trips, shutting down the whole circuit.
- **f.** Each device that is switched on provides another new path for current to flow. Since more current is able to flow, the total current has increased and the effective total resistance of the whole circuit has been decreased. This is not a contradiction because even though a new device brings its own resistance to the circuit, the fact that a new path has been added acts to lower the total resistance.

1.4 Questions, page 384

Knowledge

- 1. All electric circuits require a source of voltage, connecting wires, and at least one device that converts electrical energy into other forms of energy.
- 2. The expression V = IR relates the variables for voltage, current, and resistance.
- 3. a. If the voltage is doubled, the value of the current is doubled.
 - **b.** If the resistance is doubled, the value of the current is halved.
- **4. a.** When voltage sources are connected in series, the total voltage is doubled, providing more energy to the circuit.
 - **b.** When voltage sources are connected in parallel, the total voltage is unchanged, but now two sources can share the burden of supplying energy to the circuit. This means that if the voltage sources are batteries, they will last twice as long. It also means that if one source fails, the other can still provide energy to the circuit.
- 5. a. When electrical devices are connected in series, the total energy drawn from the source of voltage is reduced.
 - **b.** When electrical devices are connected in parallel, each device is able to be switched off and on independently of the other devices in the circuit.
- 6. Answers may vary. One possibility is shown here.

Series Circuit	Parallel Circuit
The same current flows through each component connected in series. $I_{\text{total}} = I_1 = I_2 = I_3 = \dots$	The total current flowing into a number of components connected in parallel is equal to the sum of the current flowing through each of the components.
	$I_{\text{total}} = I_1 + I_2 + I_3 + \dots$
The total voltage across a number of components connected in series is equal to the sum of the voltage values across the individual components.	The same voltage exists across each component connected in parallel.
$V_{\text{total}} = V_1 + V_2 + V_3 + \dots$	$V_{\text{total}} = V_1 = V_2 = V_3 = \dots$
The total resistance of a number of components connected in series is equal to the sum of the resistance values of the individual components.	The total resistance of a number of components connected in parallel is given by the following equation:
$R_{\text{total}} = R_1 + R_2 + R_3 + \dots$	$\frac{1}{R_{\text{total}}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots$

Applying Concepts

7. $R = 100 \ \Omega$ V = IR $V = 9.00 \ V$ $I = \frac{V}{R}$ I = ? $= \frac{9.00 \ V}{100 \ V/A}$ $= 9.00 \times 10^{-2} \ A$

The current that flows through the resistor is 9.00×10^{-2} A.

8. $R = 50.0 \ \Omega$ V = IR $V = 45.0 \ V$ $I = \frac{V}{R}$ I = ? $= \frac{45.0 \ V}{50.0 \ V/A}$ $= 0.900 \ A$

The current that flows through the component is 0.900 A.

9. a.
$$V_1 = 12.0 \text{ V}$$
 For a series connection,

 $V_2 = 12.0 \text{ V}$
 $V_{\text{total}} = V_1 + V_2$
 $V_{\text{total}} = ?$
 $= 12.0 \text{ V} + 12.0 \text{ V}$
 $= 24.0 \text{ V}$

The total voltage for the batteries connected in series is 24.0 V.

b.
$$V_1 = 12.0 \text{ V}$$
 For a parallel connection,
 $V_2 = 12.0 \text{ V}$ $V_{\text{total}} = V_1 = V_2 = 12.0 \text{ V}$
 $V_{\text{total}} = ?$

The total voltage for the batteries connected in parallel is 12.0 V.

10. a. $R_1 = 50.0 \ \Omega$	For a series connection,
$R_2 = 50.0 \ \Omega$	$R_{\text{total}} = R_1 + R_2$
- D _ 2	$= 50.0 \ \Omega + 50.0 \ \Omega$
$\kappa_{\text{total}} = 2$	$=100.0 \ \Omega$

The total resistance for the two resistors connected in series is 100.0 Ω .



The total resistance for the resistors connected in parallel is 25.0 Ω .



b. i. $R_1 = 50.0 \Omega$ $R_2 = 80.0 \Omega$ $R_{\text{total}} = ?$ For resistors in series, $R_{\text{total}} = R_1 + R_2$ $= 50.0 \Omega + 80.0 \Omega$ $= 130.0 \Omega$

The total resistance of the circuit is 130.0 Ω .

ii. $R_{total} = 130.0 \Omega$ V = IR V = 18.0 V $I_{total} = ?$ $I_{total} = \frac{V}{R_{total}}$ $I_{total} = \frac{18.0 V}{130 V/A}$ $= 0.138 \ 461 \ 538 \ 5 \ A$ $= 0.138 \ A$

The total current flowing through each resistor is 0.138 A.

The voltage across R_1 is 6.92 V.

$$R_{2} = 80.0 \Omega \qquad V = IR$$

$$I = 0.138 \ 461 \ 538 \ 5 \ A \qquad V_{2} = IR_{2}$$

$$= (0.138 \ 461 \ 538 \ 5 \ A)(80.0 \ \Omega)$$

$$= 11.1 \ V$$

The voltage across R_2 is 11.1 V.

iv. If resistor R_1 burned out, the whole circuit would stop functioning. If there is only one path for current and that path is broken, the current stops flowing.



i.
$$R_1 = 500 \ \Omega$$

 $R_2 = 1000 \ \Omega$
 $R_{total} = ?$
For resistors in parallel,
 $\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2}$
 $\frac{1}{R_{total}} = \frac{1}{500 \ \Omega} + \frac{1}{1000 \ \Omega}$
 $\frac{1}{R_{total}} = \left(0.002 \frac{1}{\Omega}\right) + \left(0.001 \frac{1}{\Omega}\right)$
 $\frac{1}{R_{total}} = 0.003 \frac{1}{\Omega}$
 $R_{total} = 333.\overline{3} \ \Omega$
 $= 333 \ \Omega$

The total resistance of the circuit is 333 Ω .

ii. $V_1 = 1.50 \text{ V}$ For voltage sources in parallel, $V_2 = 1.50 \text{ V}$ $V_{\text{total}} = V_1 = V_2 = 1.50 \text{ V}$ $V_{\text{total}} = ?$

The total voltage of the cells is 1.50 V.

b. i

iii.
$$R_{total} = 333.3 \Omega$$

 $V = IR$
 $V_{total} = 1.50 V$
 $I_{total} = ?$
 $I_{total} = ?$
 $V = IR$
 $V_{total} = I_{total}R_{total}$
 $I_{total} = \frac{V_{total}}{R_{total}}$
 $= \frac{1.50 V}{333.3 V/A}$
 $= 4.50 \times 10^{-3} A \text{ or } 4.50 \text{ mA}$

The total current flowing through the circuit is 4.50×10^{-3} A or 4.50 mA.

- iv. All the components are connected in parallel, so the voltage values should all be equal. Therefore, the voltage across R_1 is 1.50 V and the voltage across R_2 is 1.50 V.
- v. If the 500- Ω resistor burned out, current would still be able to flow through the 1000- Ω resistor.
- **13.** When devices are connected in parallel, the voltage values across the devices are the same. Since a voltmeter is used to measure a voltage across a device, it makes sense that the voltmeter is connected in parallel so that the test leads of the meter will be at the same voltage as the device when they make contact.

When devices are connected in series, the current flowing through each device is the same. Since an ammeter is used to measure current through a device, it makes sense that the ammeter is connected in series so that the same current will flow through the ammeter as the other devices.

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39. a. First Model of Refrigerator

$$P = 700 \text{ W} \qquad P = \frac{E}{t}$$

$$t = 6.0 \text{ h} \times \frac{60 \text{ min}}{1 \text{ h}} \times \frac{60 \text{ s}}{1 \text{ min}} \qquad = (700 \text{ J/s})(21 \text{ 600 s})$$

$$= 21 \text{ 600 s} \qquad = 1.5 \times 10^7 \text{ J}$$

The energy used by the first model is 1.5×10^7 J.

Second Model of Refrigerator

$$P = 500 \text{ W} \qquad P = \frac{E}{t}$$

= 500 J/s
$$t = 6.0 \text{ h} \times \frac{60 \text{ min}}{1 \text{ h}} \times \frac{60 \text{ s}}{1 \text{ min}} \qquad = (500 \text{ J/s})(21\ 600 \text{ s})$$

= 21 600 s
$$E = ?$$

The energy used by the second model is 1.1×10^7 J.

b. The manufacturer of the 500-W model is able to claim that the model is "an environmentally friendly alternative" because this refrigerator will use less energy over its lifetime of use than the 700-W model. This means that this model will have less impact in terms of negative environmental consequences due to generating electricity.

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40.
$$R = 4.0 \ \Omega$$

 $I = 2.00 \ A$
 $P = I^2 R$
 $= (2.00 \ A)^2 (4.0 \ \Omega)$
 $= 16 \ W$

The power consumed by the speaker is 16 W. This confirms that the one-step approach results in the same answer as the two-step approach.

41. step 1: Calculate the voltage across the wires of the speaker.

$R = 4.0 \ \Omega$	V = IR
<i>I</i> = 4.50 A <i>V</i> = ?	$=(4.50 \text{ A})(4.0 \Omega)$
	=18 V

The voltage across the wires of the speaker is 18 V.

step 2: Calculate the power consumed by the speaker.

V = 18 V	P = IV
I = 4.50 A	=(4.50 A)(18 V)
P = ?	= 81 W

The power consumed by the speaker is 81 W. This confirms that the two-step approach results in the same answer as the one-step approach.



b.
$$R_1 = 8.0 \ \Omega$$

 $R_2 = 8.0 \ \Omega$
 $R_{total} = ?$
 $\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2}$
 $\frac{1}{R_{total}} = \frac{1}{8.0 \ \Omega} + \frac{1}{8.0 \ \Omega}$
 $\frac{1}{R_{total}} = \left(0.125 \frac{1}{\Omega}\right) + \left(0.125 \frac{1}{\Omega}\right)$
 $\frac{1}{R_{total}} = 0.250 \frac{1}{\Omega}$
 $R_{total} = 4.0 \ \Omega$

The total resistance of the two speakers is 4.0 Ω .

c.
$$R_{\text{total}} = 4.0 \ \Omega$$
 $P_{\text{max}} = I_{\text{max}}^2 R$
 $I_{\text{max}} = 5.0 \ \text{A}$ $= (5.0 \ \text{A})^2 (4.0 \ \Omega)$
 $P_{\text{max}} = ?$ $= 1.0 \times 10^2 \ \text{W}$

The maximum power consumed by the speakers is 1.0×10^2 W.

d. Method 1: Using P = IV $P = 1.0 \times 10^2 \text{ W}$ P = IV $V = \frac{P}{I}$ I = 5.0 A V = ? $=\frac{1.0 \times 10^2 \text{ W}}{5.0 \text{ A}}$ = 20 V

$$R_{total} = 4.0 \ \Omega$$
 $V = IR$
 $I = 5.0 \ A$ $= (5.0 \ A)(4.0 \ V/A)$
 $V = ?$

Method 2: Using V = IR

 $R_{\rm total} = 4.0 \ \Omega$

The voltage supplied to this circuit is 20 V.

The voltage supplied to this circuit is 20 V.



The total resistance of the two speakers in this circuit is 16.0 Ω .

c.	$R_{\text{total}} = 16.0 \ \Omega$	V = IR
	V = 20.0 V	$I = \frac{V}{R}$
	I = ?	$=\frac{20.0 \text{ V}}{16.0 \text{ V/A}}$
		=1.25 A

The total current drawn by the speakers in this circuit is 1.25 A.

d. I = 1.25 A V = 20.0 V P = ? P = IV = (1.25 A)(20.0 V)= 25.0 W

The power consumed by the two speakers in this circuit is 25.0 W.

- 44. a. If the goal was to produce the most sound energy from the 20-V input signal, the best arrangement would be to have the speakers connected in parallel. The parallel circuit has a power rating of 1.0×10^2 W, which means this arrangement of the speakers will use 1.0×10^2 J of electrical energy every second. The series circuit has a power rating of only 25 W, so it would use 25 J of electrical energy every second.
 - **b.** The disadvantages relate to the fact that the parallel arrangement draws quite a large amount of current from the sound system. It would be important to know whether other components can handle such a large current. In some cases, circuitry in other components (like amplifiers) can be damaged if a large amount of current runs through them. The large current also means that if the car's engine is shut off and the stereo is running directly from the car's battery, the parallel arrangement would drain the battery sooner than the series circuit.

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- **45.** The answers to this question will vary depending upon the particular appliances that happen to be in your home. The following list represents some of the most common devices.
 - devices with electronic displays and soft-touch keypads, such as microwave ovens, coffee makers, stoves, and dishwashers
 - devices with remote controls, such as VCRs, DVD players, TVs, stereo receivers, CD players, and garage door openers
 - devices that use AC adapters, such as small handheld vacuum cleaners, cordless phones, computer routers, computer modems, and some computer speaker systems

46. a.
$$P = 87 \text{ W} \times \frac{1 \text{ kW}}{1000 \text{ W}}$$

 $= 0.087 \text{ kW}$
 $t = 365 \text{ d} \times \frac{24 \text{ h}}{1 \text{ d}}$
 $= 8.76 \times 10^3 \text{ h}$
 $E = ?$
 $P = \frac{E}{t}$
 $E = Pt$
 $= (0.087 \text{ kW})(8.76 \times 10^3 \text{ h})$
 $= 762.12 \text{ kW} \cdot \text{h}$
 $= 7.6 \times 10^2 \text{ kW} \cdot \text{h}$

The total energy used by all the devices that use stand-by power is 7.6×10^2 kW•h.

b.	units of energy = $762.12 \text{ kW} \cdot \text{h}$	$cost of energy = units of energy \times cost per unit of energy$
	cost per unit of energy = $9.3 \text{¢/kW} \cdot \text{h}$	= $(762.12 \text{ kW} \cdot \text{h})(\$0.093/\text{kW} \cdot \text{h})$
	= \$0.093/kW•h	= \$70.88
	cost of energy = ?	= \$71

The cost of maintaining stand-by power for this household is about \$71.

c. The previous calculations show that although the amount of stand-by power used by one device may seem trivial, the cumulative effect of many of these devices can be significant for a household. If this line of thinking is taken farther by multiplying by all the households in Alberta, then by all those in Canada, and finally by all those in developed countries, the result is a huge amount of electrical energy that must be generated to supply all these devices with stand-by power.

The generation of electricity has an impact on the environment. In many places, including Alberta, electricity is generated by burning fossil fuels, which adds carbon dioxide and other emissions to the atmosphere. If the electricity is generated by hydroelectric generators or by huge wind turbines, there are still environmental consequences because these facilities must be situated, built, and maintained at some place in the environment.

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47. a. CO₂(g) Emitted

units of energy = 1.05×10^4 kW•h mass emitted = units of energy × emission rate emission rate = $1.0 \times 10^3 \frac{\text{g}}{\text{kW} \cdot \text{h}} \times \frac{1 \text{ kg}}{1000 \text{ g}}$ = 1.0 kg/kW•h

mass emitted = ?

This family accounts for 1.1×10^4 kg, or 11.0 t, of CO₂(g) emissions due to their electricity use.

SO_r(g) Emitted

units of energy = 1.05×10^4 kW•h emission rate = $1.9 \frac{g}{kW•h} \times \frac{1 \text{ kg}}{1000 \text{ g}}$ = 0.0019 kg/kW•h mass emitted = ?

This family accounts for 20 kg of $SO_y(g)$ emissions due to their use of electricity.

NO_v(g) Emitted

units of energy =
$$1.05 \times 10^4$$
 kW•h mass emi
emission rate = $1.4 \frac{g}{kW•h} \times \frac{1 \text{ kg}}{1000 \text{ g}}$
= 0.0014 kg/kW•h

hass emitted = units of energy × emission rate = $(1.05 \times 10^4 \text{ kW} \cdot \text{h})(0.0014 \text{ kg/kW} \cdot \text{h})$ = 15 kg

mass emitted = ?

This family accounts for 15 kg of $NO_{y}(g)$ emissions due to their use of electricity.

Particulate Matter Emitted

units of energy = 1.05×10^4 kW•h

mass emitted = units of energy
$$\times$$
 emission rate

=1.5 kg

emission rate = 0.14
$$\frac{g}{kW \cdot h} \times \frac{1 \text{ kg}}{1000 \text{ g}}$$

= 1.4 × 10⁻⁴ kg/kW · h

= $(1.05 \times 10^4 \text{ kW} \cdot \text{h})(1.4 \times 10^{-4} \text{ kg/kW} \cdot \text{h})$

This family accounts for 1.5 kg of particulate matter emissions due to their use of electricity.

b. units of energy =
$$1.05 \times 10^4$$
 kW•h cost = units of energy \times cost of energy
cost of energy = 8.8¢/kW•h = $(1.05 \times 10^4$ kW•h)($(0.088/\text{kW•h})$
= $(0.088/\text{kW•h})$ = $(0.088/\text{kW•h})$

This family's annual cost of electrical energy is \$924.

48. a.
$$P = 85 \text{ W} \times \frac{1 \text{ kW}}{1000 \text{ W}}$$

 $= 0.085 \text{ kW}$
 $t = 365 \text{ d} \times \frac{24 \text{ h}}{1 \text{ d}}$
 $= 8.76 \times 10^3 \text{ h}$
 $E = 2$
 $P = \frac{E}{t}$
 $E = Pt$
 $= (0.085 \text{ kW})(8.76 \times 10^3 \text{ h})$
 $= 744.6 \text{ kW} \cdot \text{h}$
 $= 7.5 \times 10^2 \text{ kW} \cdot \text{h}$

Every year, this family consumes 7.5×10^2 kW•h of electrical energy to maintain stand-by power for the devices in their home.

b. total electrical energy = 1.05×10^4 kW•h

energy for stand-by power = $744.6 \text{ kW} \cdot \text{h}$

percentage used for stand-by power = ?

percentage used for stand-by power = $\frac{\text{energy for stand-by power}}{\text{total energy}} \times 100\%$ = $\frac{744.6 \text{ kW} \cdot \text{h}}{1.05 \times 10^4 \text{ kW} \cdot \text{h}} \times 100\%$ = 7.1%

Approximately 7.1% of this family's annual electricity use can be traced to the consumption of stand-by power.

Since the mass of the emissions are all dependent upon the amount of electrical energy used, if 7.1% of this energy is attributed to stand-by power, then stand-by power accounts for 7.1% of emissions.

49. There are a number of strategies this family could consider to reduce their environmental emissions.

One strategy is to reduce careless consumption by turning off devices that are not being used. This strategy would include turning off lights, televisions, and radios that are not being used. Another strategy is to choose more energy-efficient models when devices need to be replaced. Examples would include replacing conventional light bulbs with the compact fluorescent type and replacing older appliances with models that use less energy. A final strategy is to avoid using devices that operate with excessive amounts of stand-by power. Although it may be difficult to find a microwave oven that does not have a digital clock and a soft-touch keypad, it is important to let manufacturers and retailers know that consumers place a high value on energy efficiency. Many manufacturers have responded to these demands by producing product lines that address these concerns.

Practice, page 402

50. a. This device is a step-down transformer because the voltage is being reduced from 4.00 kV in the primary coil to 240 V on the secondary coil.

b.
$$V_{\rm p} = 4.00 \text{ kV} \times \frac{1000 \text{ V}}{1 \text{ kV}}$$

 $= 4.00 \times 10^3 \text{ V}$
 $V_{\rm s} = 240 \text{ V}$
 $N_{\rm s} = 180$
 $N_{\rm p} = ?$
 $\frac{N_{\rm p}}{N_{\rm s}} = \frac{V_{\rm p}}{V_{\rm s}}$
 $N_{\rm p} = \frac{V_{\rm p}N_{\rm s}}{V_{\rm s}}$
 $= \frac{(4.00 \times 10^3 \text{ V})(180)}{240 \text{ V}}$
 $= 3.00 \times 10^3$

There are 3.00×10^3 turns of wire on the primary coil of this transformer.

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c.
$$V_{\rm p} = 4.00 \times 10^{3} \,\mathrm{V}$$

 $V_{\rm s} = 240 \,\mathrm{V}$
 $I_{\rm s} = 100 \,\mathrm{A}$
 $I_{\rm p} = ?$
 $I_{\rm p} = \frac{I_{\rm s} V_{\rm s}}{V_{\rm p}}$
 $I_{\rm p} = \frac{(100 \,\mathrm{A})(240 \,\mathrm{V})}{4.00 \times 10^{3} \,\mathrm{V}}$
 $= 6.00 \,\mathrm{A}$

The current supplied to the transformer is 6.00 A.

51. a. This device is a step-up transformer because the voltage is being increased from 20.0 kV to 230 kV.

b. The utility company boosts the 20.0-kV voltage from the generator to even higher values to reduce losses due to the heating of the cables during transmission. Since the equation that describes the power consumed by heating losses within the transmission cables is $P = I^2 R$, the value of the current has a huge impact on power losses because current is squared in the equation. However, in order to transmit the electrical energy, a combination of current and voltage is still required, as described by the equation P = IV. Since the current value must be minimized, the voltage value is maximized. This arrangement allows the transmission of large amounts of power with minimal losses due to heating effects.

c.
$$V_{s} = 230 \text{ kV} \times \frac{1000 \text{ V}}{1 \text{ kV}}$$

 $= 2.30 \times 10^{5} \text{ V}$
 $P_{s} = 1.2 \text{ MW} \times \frac{1 \times 10^{6} \text{ W}}{1 \text{ MW}}$
 $= 1.2 \times 10^{6} \text{ W}$
 $I_{s} = ?$
 $P = IV$
 $P_{s} = I_{s}V_{s}$
 $I_{s} = \frac{P_{s}}{V_{s}}$
 $= \frac{1.2 \times 10^{6} \text{ W}}{2.30 \times 10^{5} \text{ V}} \text{ W} = \text{V-A}$
 $= 5.217 \text{ 391 304 A}$
 $= 5.2 \text{ A}$

The current flowing through the transmission cables is 5.2 A.

d.
$$V_{\rm p} = 20.0 \text{ kV} \times \frac{1000 \text{ V}}{1 \text{ kV}}$$

 $= 2.00 \times 10^4 \text{ V}$
 $V_{\rm s} = 2.30 \times 10^5 \text{ V}$
 $I_{\rm s} = 5.217 \text{ 391 304 A}$
 $I_{\rm p} = ?$
 $\frac{V_{\rm p}}{V_{\rm s}} = \frac{I_{\rm s}}{I_{\rm p}}$
 $I_{\rm p} = \frac{V_{\rm s}I_{\rm s}}{V_{\rm p}}$
 $= \frac{(2.30 \times 10^5 \text{ V})(5.217 \text{ 391 304 A})}{2.00 \times 10^4 \text{ V}}$
 $= 60 \text{ A}$

The generator is supplying 60 A of current to the transformer at the generating station.

e. In an ideal transformer, the power rating of the secondary coil and the primary coil are equal. Therefore,

$$P_{\rm p} = P_{\rm s}$$
$$= 1.2 \text{ MW}$$
$$= 1.2 \times 10^{6} \text{ W}$$

The power equation can now be used to determine the current flowing in the primary coil.

$$P_{p} = 1.2 \times 10^{6} \text{ W} \qquad P = IV$$

$$P_{p} = I_{p}V_{p}$$

$$P_{p} = I_{p}V_{p}$$

$$P_{p} = I_{p}V_{p}$$

$$I_{p} = \frac{P_{p}}{V_{p}}$$

$$I_{p} = 2.00 \times 10^{4} \text{ V} \qquad I_{p} = \frac{1.2 \times 10^{6} \text{ W}}{2.00 \times 10^{4} \text{ V}} \quad W = V \cdot A$$

$$= 60 \text{ A}$$

The current flowing through the primary coil is 60 A.

1.5 Questions, page 403

Knowledge

- 1. It is misleading to call a bill from a utility company a "power bill" because the bill is charging the customer for the electrical energy used, not for the rate of using energy, which is power.
- 2. In a step-up transformer, the input voltage on the primary coil must be increased to a larger value on the secondary coil. In order for this to happen, the secondary coil must have more turns of wire.

Applying Concepts

3. There is no physical connection between the circuit of the primary coil and the circuit of the secondary coil. The only link between these two circuits is the magnetic field that exists within the common core of both coils. Just as a generator works when there is a changing magnetic field within the loops of the coil on its armature, a current can be induced to flow in the secondary coil only if a magnetic field is changing within the loops of the secondary coil. The alternating current in the primary coil ensures that the magnetic field within the core is always changing. This changing magnetic field then produces an alternating current in the secondary coil. These are the reasons why both the primary coil and the secondary coil of a transformer operate with alternating current.

4. Calculate the current.

$$R = 14.0 \ \Omega$$

$$V = IR$$

$$V = 120 \ V$$

$$I = \frac{V}{R}$$

$$I = ?$$

$$= \frac{120 \ V}{14.0 \ V/A}$$

$$= 8.571 \ 428 \ 571 \ A$$

$$= 8.57 \ A$$

The current flowing through the toaster is 8.57 A.

Calculate the power.

$$V = 120 \text{ V}$$
 $P = IV$ $I = 8.571 \ 428 \ 571 \text{ A}$ $= (8.571 \ 428 \ 571 \text{ A})(120 \text{ V})$ $P = ?$ $= 1.03 \times 10^3 \text{ W}$

The toaster will dissipate 1.03×10^3 W of power.

5. Calculate the energy required.

$$P = 5.0 \text{ W} \times \frac{1 \text{ kW}}{1000 \text{ W}} \qquad P = \frac{E}{t}$$

= 0.0050 kW
$$t = 365 \text{ d} \times \frac{24 \text{ h}}{1 \text{ d}} \qquad = (0.0050 \text{ kW})(8.76 \times 10^3 \text{ h})$$

= 8.76 × 10³ h
$$E = ?$$

The energy required by the clock in one year is 43.8 kW•h.

Calculate the cost.

units of energy = 43.8 kW•h cost per unit of energy = 8.7¢/kW•h = \$0.087/kW•h cost of energy = ? cost of energy = units of energy × cost per unit of energy = (43.8 kW•h)(\$0.087/kW•h) = \$3.81

The cost of the energy to operate the clock for one full year is \$3.81.

6. a.
$$N_{p} = 100$$

 $V_{p} = 100$
 $V_{s} = 1000$
 $V_{p} = 120 V$
 $I_{p} = 10.0 A$
 $V_{s} = ?$
 $I_{s} = \frac{N_{p}I_{p}}{N_{s}}$
 $I_{s} = \frac{N_{p}I_{p}}{N_{s}}$
 $I_{s} = \frac{N_{p}I_{p}}{N_{s}}$
 $I_{s} = \frac{(100)(10.0 \text{ A})}{1000}$
 $I_{0} = 1.20 \times 10^{3} V$
 $I_{s} = ?$

The voltage and current in the secondary coil are 1.20×10^3 V and 1.00 A, respectively.

b.
$$V_{\rm p} = 120 \text{ V}$$

 $I_{\rm p} = 10.0 \text{ A}$
 $P_{\rm p} = ?$
 $P = IV$
 $P_{\rm p} = I_{\rm p}V_{\rm p}$
 $= (10.0 \text{ A})(120 \text{ V})$
 $= 1.20 \times 10^{3} \text{ W}$

The power in the primary coil is 1.20×10^3 W. Since this is an ideal transformer, this is also the power in the secondary coil.

- 7. It is advantageous to transmit power at high voltages over long distances because, for a given value of power to be transmitted, the higher the voltage, the lower the corresponding current value can be. Lowering the current is beneficial because this value plays a dominant role in determining the amount of power lost to heating effects in the transmission cables.
- **8. a.** Determine the units of energy saved.

old fridge: units of energy = $605 \text{ kW} \cdot \text{h}$ - new fridge: units of energy = $450 \text{ kW} \cdot \text{h}$ units of energy saved = $155 \text{ kW} \cdot \text{h}$

The family saves 155 kW•h every year by using the new refrigerator.

Calculate the money saved.

```
units of energy = 155 kW•h

cost per unit of energy = 8.5¢/kW•h

= $0.085/kW•h

cost of energy = ?

cost of energy = units of energy × cost per unit of energy
```

 $= (155 \text{ kW} \cdot \text{h})(\$0.085/\text{kW} \cdot \text{h})$ = \$13

The family will save about \$13 every year by using the new refrigerator.

units of energy saved = $155 \text{ kW} \cdot \text{h}$

rate of emission =
$$1.0 \times 10^3 \frac{g}{kW \cdot h} \times \frac{1 \text{ kg}}{1000 \text{ g}}$$

 $=1.0 \text{ kg/kW} \cdot h$

mass of emissions reduced = ?

mass of emissions reduced = units of energy saved \times rate of emission

=
$$(155 \text{ kW} \cdot \text{h})(1.0 \text{ kg/kW} \cdot \text{h})$$

= $1.6 \times 10^2 \text{ kg}$

The family will reduce their $CO_2(g)$ emissions by 1.6×10^2 kg every year by using the new refrigerator.

SO_v(g) Emissions

units of energy saved = $155 \text{ kW} \cdot \text{h}$

rate of emission =
$$1.9 \frac{g}{kW \cdot h} \times \frac{1 \text{ kg}}{1000 \text{ g}}$$

= 0.0019 kg/kW \cdot h

mass of emissions reduced = ?

mass of emissions reduced = units of energy saved × rate of emission

=
$$(155 \text{ kW} \cdot \text{h})(0.0019 \text{ kg/kW} \cdot \text{h})$$

= 0.29 kg

The family will reduce their $SO_{x}(g)$ emissions by 0.29 kg.

NO_r(g) Emissions

units of energy saved = $155 \text{ kW} \cdot \text{h}$

rate of emission =
$$1.4 \frac{g}{kW \cdot h} \times \frac{1 \text{ kg}}{1000 \text{ g}}$$

= 0.0014 kg/kW \cdot h

mass of emissions reduced = ?

mass of emissions reduced = units of energy saved × rate of emission

=
$$(155 \text{ kW} \cdot \text{h})(0.0014 \text{ kg/kW} \cdot \text{h})$$

= 0.22 kg

The family will reduce their $NO_x(g)$ emissions by 0.22 kg.

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Particulate-Matter Emissions

units of energy saved = $155 \text{ kW} \cdot \text{h}$

rate of emission =
$$0.14 \frac{g}{kW \cdot h} \times \frac{1 \text{ kg}}{1000 \text{ g}}$$

 $= 1.4 \times 10^{-4} \text{ kg/kW} \cdot \text{h}$

mass of emissions reduced = ?

mass of emissions reduced = units of energy saved × rate of emission

=
$$(155 \text{ kW} \cdot \text{h})(1.4 \times 10^{-4} \text{ kg/kW} \cdot \text{h})$$

= 0.022 kg

The family will reduce their particulate-matter emissions by 0.022 kg.

c. Since the answer to this question involves stating an opinion, answers will vary. A sample response is provided.

The family will save \$13 each year by using the new refrigerator. Although this money could be used to purchase something useful for the family—or could be donated to a local charity—in my opinion, the reduction in emissions is by far the most significant change.

The reductions in emissions for $CO_2(g)$, $SO_x(g)$, $NO_x(g)$, and particulate matter are 1.6×10^2 kg, 0.29 kg, 0.22 kg, and 0.022 kg, respectively. The reduction in the emissions of these substances is a small step in the direction of a healthier environment for this generation and the next.