Chapter 22

Current Electricity

What You'll Learn

- You will explain energy transfer in circuits.
- You will solve problems involving current, potential difference, and resistance.
- You will diagram simple electric circuits.

Why It's Important

The electric tools and appliances that you use are based upon the ability of electric circuits to transfer energy resulting from potential difference, and thus, perform work.

Power Transmission Lines Transmission lines crisscross our country to transfer energy to where it is needed. This transfer is accomplished at high potential differences, often as high as 500,000 V.

Think About This ▶

Transmission line voltages are too high to use safely in homes and businesses. Why are such high voltages used in transmission lines?

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LAUNCH Lab

Can you get a lightbulb to light?

Question

Given a wire, a battery, and a lightbulb, can you get the bulb to light?

Procedure

1. Obtain a lightbulb, a wire, and a battery. Try to find as many ways as possible to get the lightbulb to light. ***Caution: Wire is sharp and can cut skin. Wire can also get hot if connected across the battery.***
2. Diagram two ways in which you are able to get the lightbulb to work. Be sure to label the battery, the wire, and the bulb.
3. Diagram at least three ways in which you are not able to get the bulb to light.

Analysis

How did you know if electric current was flowing? What do your diagrams of the lit bulb have in common? What do your diagrams of the unlit bulb have in common? From your observations, what conditions seem to be necessary in order for the bulb to light?

Critical Thinking What causes electricity to flow through the bulb?

22.1 Current and Circuits

As you learned in Chapter 11, flowing water at the top of a waterfall has both potential and kinetic energy. However, the large amount of natural potential and kinetic energy available from resources such as Niagara Falls are of little use to people or manufacturers who are 100 km away, unless that energy can be transported efficiently. Electric energy provides the means to transfer large quantities of energy great distances with little loss. This transfer usually is done at high potential differences through power lines, such as those shown in the photo on the left. Once this energy reaches the consumer, it can easily be converted into another form or combination of forms, including sound, light, thermal energy, and motion.

Because electric energy can so easily be changed into other forms, it has become indispensable in our daily lives. Even quick glances around you will likely generate ample examples of the conversion of electric energy. Inside, lights to help you read at night, microwaves and electric ranges to cook food, computers, and stereos all rely on electricity for power. Outside, street lamps, store signs, advertisements, and the starters in cars all use flowing electric charges. In this chapter, you will learn how potential differences, resistance, and current are related. You also will learn about electric power and energy transfer.

► Objectives

- **Describe** conditions that create current in an electric circuit.
- **Explain** Ohm's law.
- **Design** closed circuits.
- **Differentiate** between power and energy in an electric circuit.

► Vocabulary

electric current
conventional current
battery
electric circuit
ampere
resistance
resistor
parallel connection
series connection

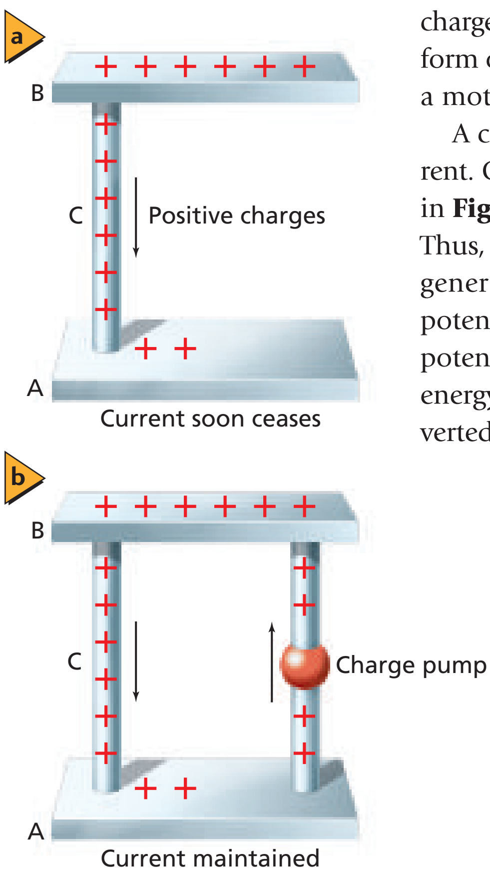
Horizons Companies

Producing Electric Current

In Chapter 21, you learned that when two conducting spheres touch, charges flow from the sphere at a higher potential to the one at a lower potential. The flow continues until there is no potential difference between the two spheres.

A flow of charged particles is an **electric current.** In **Figure 22-1a,** two conductors, A and B, are connected by a wire conductor, C. Charges flow from the higher potential difference of B to A through C. This flow of positive charge is called **conventional current.** The flow stops when the potential difference between A, B, and C is zero. You could maintain the electric potential difference between B and A by pumping charged particles from A back to B, as illustrated in **Figure 22-1b.** Since the pump increases the electric potential energy of the charges, it requires an external energy source to run. This energy could come from a variety of sources. One familiar source, a voltaic or galvanic cell (a common dry cell), converts chemical energy to electric energy. Several galvanic cells connected together are called a **battery.** A second source of electric energy—a photovoltaic cell, or solar cell—changes light energy into electric energy.

Figure 22-1 Conventional current is defined as positive charges flowing from the positive plate to the negative plate **(a).** A generator pumps the positive charges back to the positive plate and maintains the current **(b).** In most metals, negatively-charged electrons actually flow from the negative to the positive plate, creating the appearance of positive charges that are moving in the opposite direction.



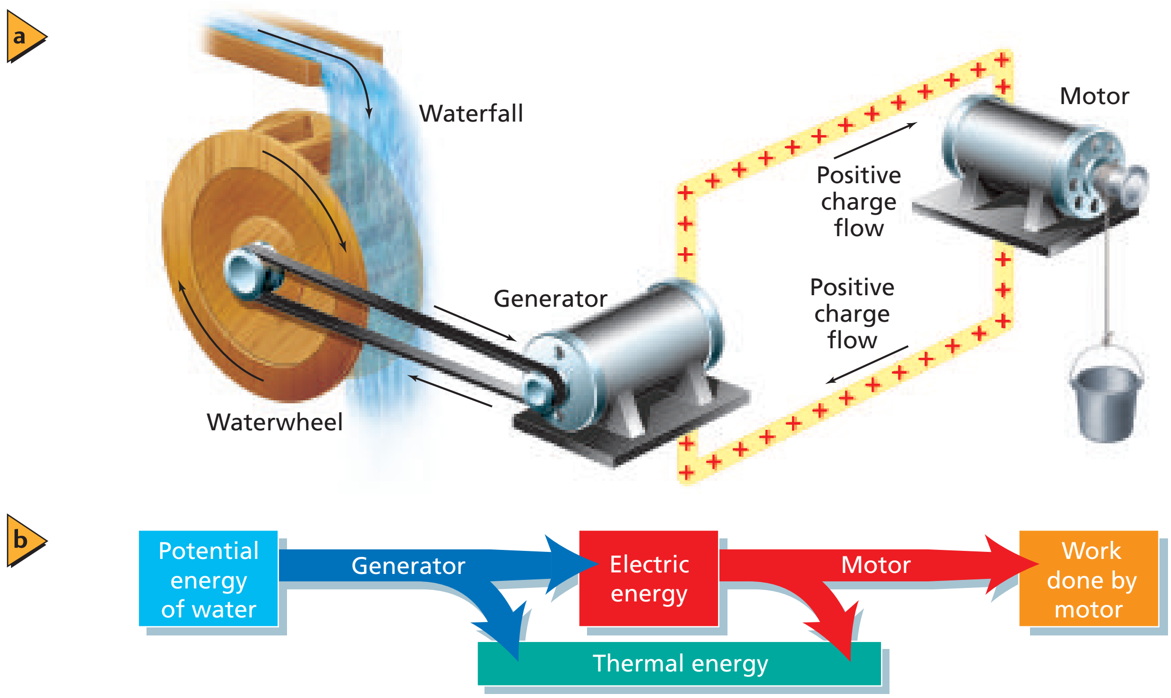
Electric Circuits

The charges in Figure 22-1b move around a closed loop, cycling from the pump to B, through C, to A and back to the pump. Any closed loop or conducting path allowing electric charges to flow is called an **electric circuit.** A circuit includes a charge pump, which increases the potential energy of the charges flowing from A to B, and a device that reduces the potential energy of the charges flowing from B to A. The potential energy lost by the charges, qV, moving through the device is usually converted into some other form of energy. For example, electric energy is converted to kinetic energy by a motor, to light energy by a lamp, and to thermal energy by a heater.

A charge pump creates the flow of charged particles that make up a current. Consider a generator driven by a waterwheel, such as the one pictured in **Figure 22-2a.** The water falls and rotates the waterwheel and generator. Thus, the kinetic energy of the water is converted to electric energy by the generator. The generator, like the charge pump, increases the electric potential difference, V. Energy in the amount qV is needed to increase the potential difference of the charges. This energy comes from the change in energy of the water. Not all of the water's kinetic energy, however, is converted to electric energy, as shown in **Figure 22-2b.**

If the generator attached to the waterwheel is connected to a motor, the charges in the wire flow into the motor. The flow of charges continues through the circuit back to the generator. The motor converts electric energy to kinetic energy.

Conservation of charge Charges cannot be created or destroyed, but they can be separated. Thus, the total amount of charge—the number of negative electrons and positive ions—in the circuit does not change. If one coulomb flows through the generator in 1 s, then one coulomb also will flow through the motor in 1 s. Thus, charge is a conserved quantity. Energy also is conserved. The change in electric energy, ΔE, equals qV. Because q is conserved,



■ **Figure 22-2** The potential energy of the waterfall is eventually converted into work done on the bucket **(a).** The production and use of electric current is not 100 percent efficient. Some thermal energy is produced by the splashing water, friction, and electric resistance **(b).**

the net change in potential energy of the charges going completely around the circuit must be zero. The increase in potential difference produced by the generator equals the decrease in potential difference across the motor.

If the potential difference between two wires is 120 V, the waterwheel and the generator must do 120 J of work on each coulomb of charge that is delivered. Every coulomb of charge moving through the motor delivers 120 J of energy to the motor.

Rates of Charge Flow and Energy Transfer

Power, which is defined in watts, W, measures the rate at which energy is transferred. If a generator transfers 1 J of kinetic energy to electric energy each second, it is transferring energy at the rate of 1 J/s, or 1 W. The energy carried by an electric current depends on the charge transferred, q, and the potential difference across which it moves, V. Thus, $E = qV$. Recall from Chapter 20 that the unit for the quantity of electric charge is the coulomb. The rate of flow of electric charge, q/t, called electric current, is measured in coulombs per second. Electric current is represented by I, so $I = q/t$. A flow of 1 C/s is called an **ampere,** A.

The energy carried by an electric current is related to the voltage, $E = qV$. Since current, $I = q/t$, is the rate of charge flow, the power, $P = E/t$, of an electric device can be determined by multiplying voltage and current. To derive the familiar form of the equation for the power delivered to an electric device, you can use $P = E/t$ and substitute $E = qV$ and $q = It$.

Power $P = IV$

Power is equal to the current times the potential difference.

If the current through the motor in Figure 22-2a is 3.0 A and the potential difference is 120 V, the power in the motor is calculated using the expression $P = (3.0\ \text{C/s})(120\ \text{J/C}) = 360\ \text{J/s}$, which is 360 W.

EXAMPLE Problem 1

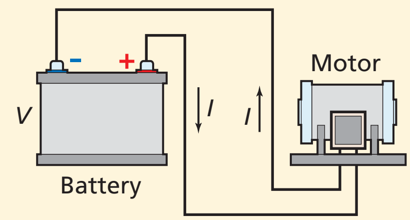
Electric Power and Energy A 6.0-V battery delivers a 0.50-A current to an electric motor connected across its terminals.

a. What power is delivered to the motor?

b. If the motor runs for 5.0 min, how much electric energy is delivered?

1 Analyze and Sketch the Problem

- Draw a circuit showing the positive terminal of a battery connected to a motor and the return wire from the motor connected to the negative terminal of the battery.
- Show the direction of conventional current.



Known:	Unknown:
$V = 6.0$ V	$P = ?$
$I = 0.50$ A	$E = ?$
$t = 5.0$ min	

2 Solve for the Unknown

a. Use $P = IV$ to find the power.

$$P = IV$$

$$P = (0.50 \text{ A})(6.0 \text{ V}) \quad \text{Substitue } I = 0.50 \text{ A, } V = 6.0 \text{ V}$$

$$= 3.0 \text{ W}$$

b. In Chapter 10, you learned that $P = E/t$. Solve for E to find the energy.

$$E = Pt$$

$$= (3.0 \text{ W})(5.0 \text{ min}) \quad \text{Substitute } P = 3.0 \text{ W, } t = 5.0 \text{ min}$$

$$= (3.0 \text{ J/s})(5.0 \text{ min})\left(\frac{60 \text{ s}}{1 \text{ min}}\right)$$

$$= 9.0\times10^2 \text{ J}$$

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Significant Digits
page 834

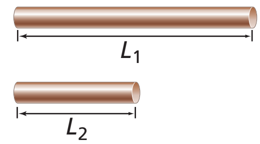
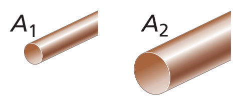
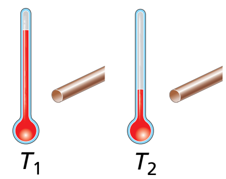
3 Evaluate the Answer

- **Are the units correct?** Power is measured in watts, and energy is measured in joules.
- **Is the magnitude realistic?** With relatively low voltage and current, a few watts of power is reasonable.

PRACTICE Problems

Additional Problems, Appendix B

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.)
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?
3. What is the current through a 75-W lightbulb that is connected to a 125-V outlet?
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?
5. A flashlight bulb is rated at 0.90 W. If the lightbulb drops 3.0 V, how much current goes through it?

Table 22-1		
Changing Resistance		
Factor	**How resistance changes**	**Example**
Length	Resistance increases as length increases.	 $R_{L1} > R_{L2}$
Cross-sectional area	Resistance increases as cross-sectional area decreases.	 $R_{A1} > R_{A2}$
Temperature	Resistance increases as temperature increases.	 $R_{T1} > R_{T2}$
Material	Keeping length, cross-sectional area, and temperature constant, resistance varies with the material used.	*R* increases ↑: Platinum, Iron, Aluminum, Gold, Copper, Silver

Resistance and Ohm's Law

Suppose two conductors have a potential difference between them. If they are connected with a copper rod, a large current is created. On the other hand, putting a glass rod between them creates almost no current. The property determining how much current will flow is called **resistance. Table 22-1** lists some of the factors that impact resistance. Resistance is measured by placing a potential difference across a conductor and dividing the voltage by the current. The resistance, *R*, is defined as the ratio of electric potential difference, *V*, to the current, *I*.

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

Resistance is equal to voltage divided by current.

The resistance of the conductor, *R*, is measured in ohms. One ohm (1 Ω) is the resistance permitting an electric charge of 1 A to flow when a potential difference of 1 V is applied across the resistance. A simple circuit relating resistance, current, and voltage is shown in **Figure 22-3.** A 12-V car battery is connected to one of the car's 3-Ω brake lights. The circuit is completed by a connection to an ammeter, which is a device that measures current. The current carrying the energy to the lights will measure 4 A.

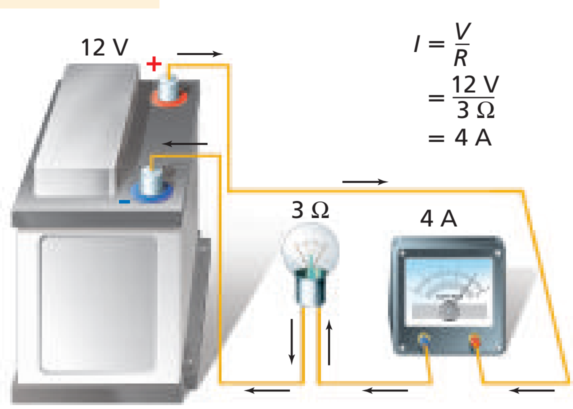
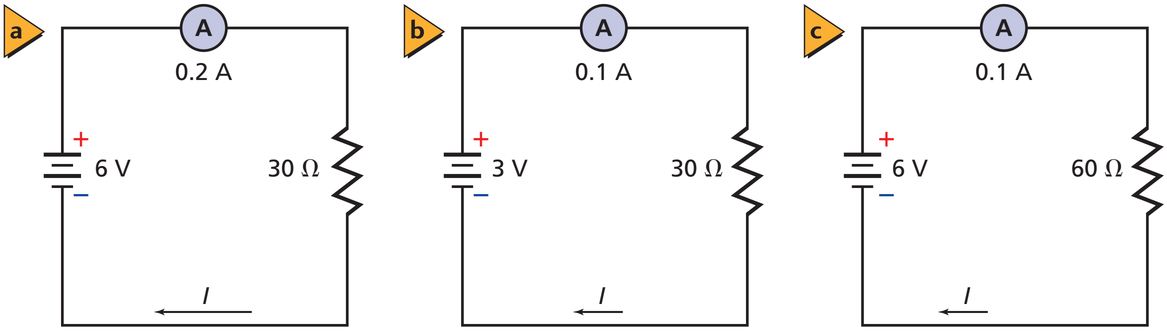


Figure 22-3 One ohm, Ω, is defined as 1 V/A. In a circuit with a 3-Ω resistance and a 12-V battery, there is a 4-A current.



■ **Figure 22-4** The current through a simple circuit **(a)** can be regulated by removing some of the dry cells **(b)** or by increasing the resistance of the circuit **(c).**

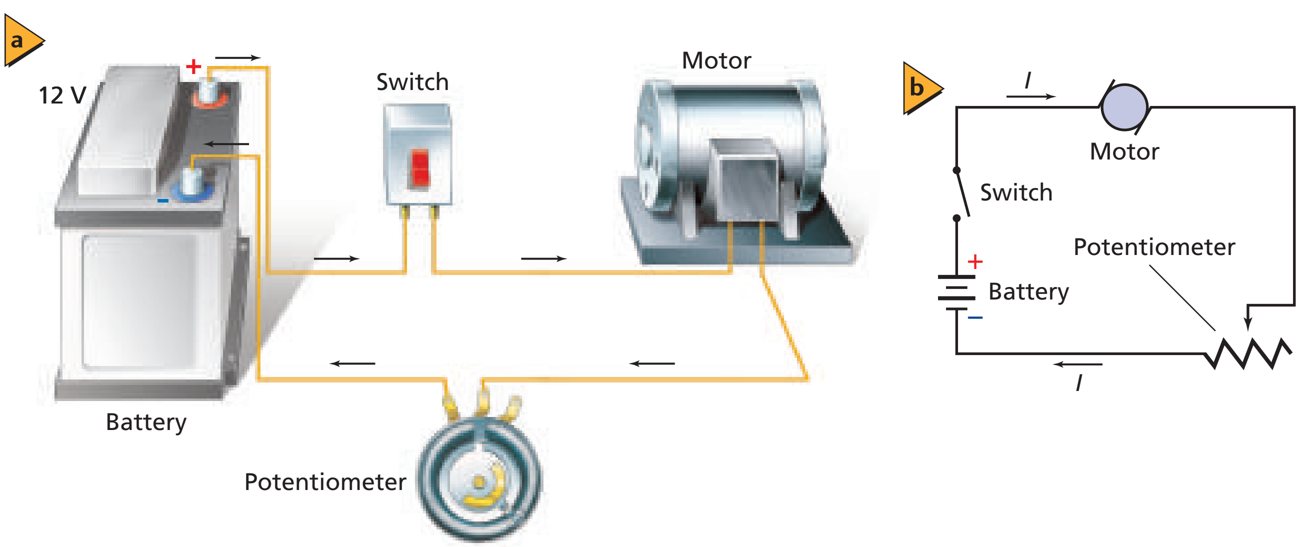
The unit for resistance is named for German scientist Georg Simon Ohm, who found that the ratio of potential difference to current is constant for a given conductor. The resistance for most conductors does not vary as the magnitude or direction of the potential applied to it changes. A device having constant resistance independent of the potential difference obeys Ohm's law.

Most metallic conductors obey Ohm's law, at least over a limited range of voltages. Many important devices, however, do not. A radio and a pocket calculator contain many devices, such as transistors and diodes, that do not obey Ohm's law. Even a lightbulb has resistance that depends on its temperature and does not obey Ohm's law.

Wires used to connect electric devices have low resistance. A 1-m length of a typical wire used in physics labs has a resistance of about 0.03 Ω. Wires used in home wiring offer as little as 0.004 Ω of resistance for each meter of length. Because wires have so little resistance, there is almost no potential drop across them. To produce greater potential drops, a large resistance concentrated into a small volume is necessary. A **resistor** is a device designed to have a specific resistance. Resistors may be made of graphite, semiconductors, or wires that are long and thin.

There are two ways to control the current in a circuit. Because $I = V/R$, I can be changed by varying V, R, or both. **Figure 22-4a** shows a simple circuit. When V is 6 V and R is 30 Ω, the current is 0.2 A. How could the current be reduced to 0.1 A? According to Ohm's law, the greater the voltage placed across a resistor, the larger the current passing through it. If the current through a resistor is cut in half, the potential difference also is cut

■ **Figure 22-5** A potentiometer can be used to change current in an electric circuit.



in half. In **Figure 22-4b,** the voltage applied across the resistor is reduced from 6 V to 3 V to reduce the current to 0.1 A. A second way to reduce the current to 0.1 A is to replace the 30-Ω resistor with a 60-Ω resistor, as shown in **Figure 22-4c.**

Resistors often are used to control the current in circuits or parts of circuits. Sometimes, a smooth, continuous variation of the current is desired. For example, the speed control on some electric motors allows continuous, rather than step-by-step, changes in the rotation of the motor. To achieve this kind of control, a variable resistor, called a potentiometer, is used. A circuit containing a potentiometer is shown in **Figure 22-5.** Some variable resistors consist of a coil of resistance wire and a sliding contact point. Moving the contact point to various positions along the coil varies the amount of wire in the circuit. As more wire is placed in the circuit, the resistance of the circuit increases; thus, the current changes in accordance with the equation $I = V/R$. In this way, the speed of a motor can be adjusted from fast, with little wire in the circuit, to slow, with a lot of wire in the circuit. Other examples of using variable resistors to adjust the levels of electrical energy can be found on the front of a TV: the volume, brightness, contrast, tone, and hue controls are all variable resistors.

The human body The human body acts as a variable resistor. When dry, skin's resistance is high enough to keep currents that are produced by small and moderate voltages low. If skin becomes wet, however, its resistance is lower, and the electric current can rise to dangerous levels. A current as low as 1 mA can be felt as a mild shock, while currents of 15 mA can cause loss of muscle control and currents of 100 mA can cause death.

Biology Connection

APPLYING PHYSICS

Resistance The resistance of an operating 100-W lightbulb is about 140 Ω. When the lightbulb is turned off and at room temperature, its resistance is only about 10 Ω. This is because of the great difference between room temperature and the lightbulb's operating temperature.

Diagramming Circuits

A simple circuit can be described in words. It can also be depicted by photographs or artists' drawings of the parts. Most frequently, however, an electric circuit is drawn using standard symbols for the circuit elements. Such a diagram is called a circuit schematic. Some of the symbols used in circuit schematics are shown in **Figure 22-6.**

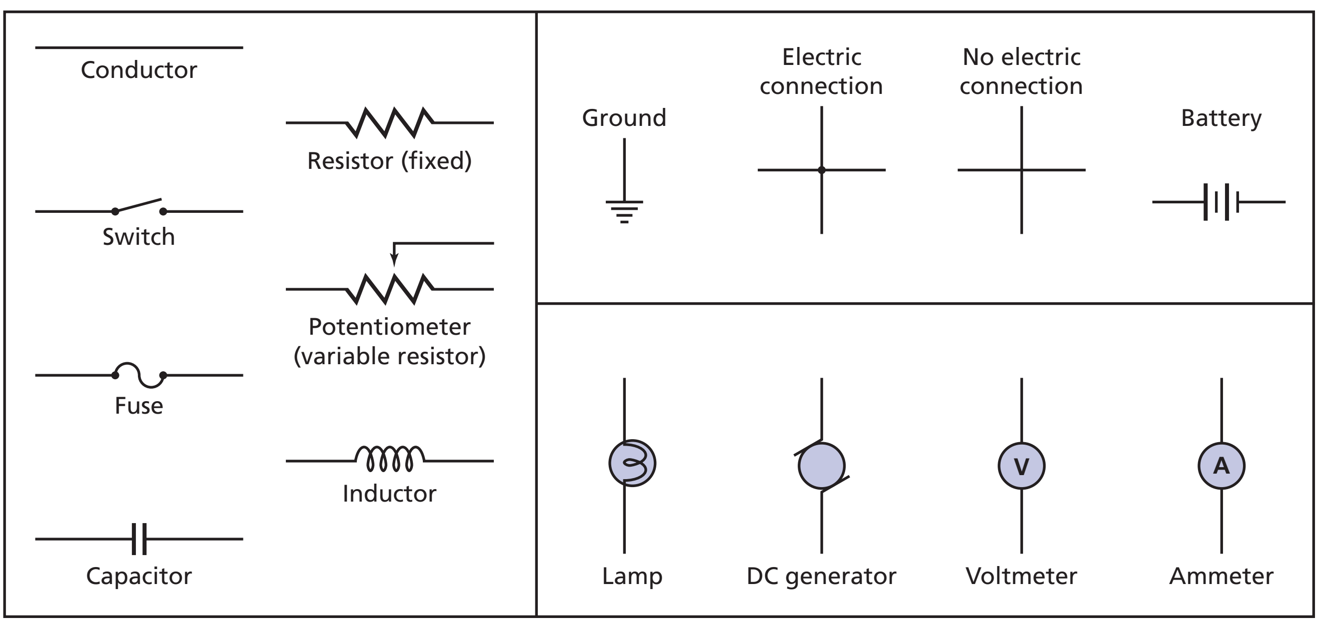


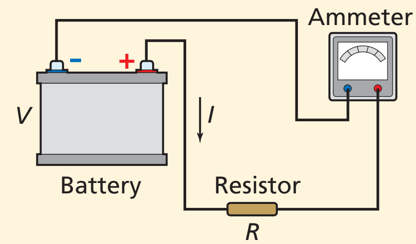
Figure 22-6 These symbols commonly are used to diagram electric circuits.

EXAMPLE Problem 2

Current Through a Resistor A 30.0-V battery is connected to a 10.0-Ω resistor. What is the current in the circuit?

1 Analyze and Sketch the Problem

- Draw a circuit containing a battery, an ammeter, and a resistor.
- Show the direction of the conventional current.



Known:	Unknown:
$V = 30.0\ \text{V}$	$I = ?$
$R = 10.0\ \Omega$	

2 Solve for the Unknown

Use $I = V/R$ to determine the current.

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

$$= \frac{30.0\ \text{V}}{10.0\ \Omega} \qquad \text{Substitute } V = 30.0\ \text{V}, R = 10.0\ \Omega$$

$$= 3.00\ \text{A}$$

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Operations with Significant Digits
pages 835–836

3 Evaluate the Answer

- **Are the units correct?** Current is measured in amperes.
- **Is the magnitude realistic?** There is a fairly large voltage and a small resistance, so a current of 3.00 A is reasonable.

PRACTICE Problems

Additional Problems, Appendix B

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?

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?

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?

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?

b. What is the power consumption of the lamp?

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

a. What is the current through the lamp?

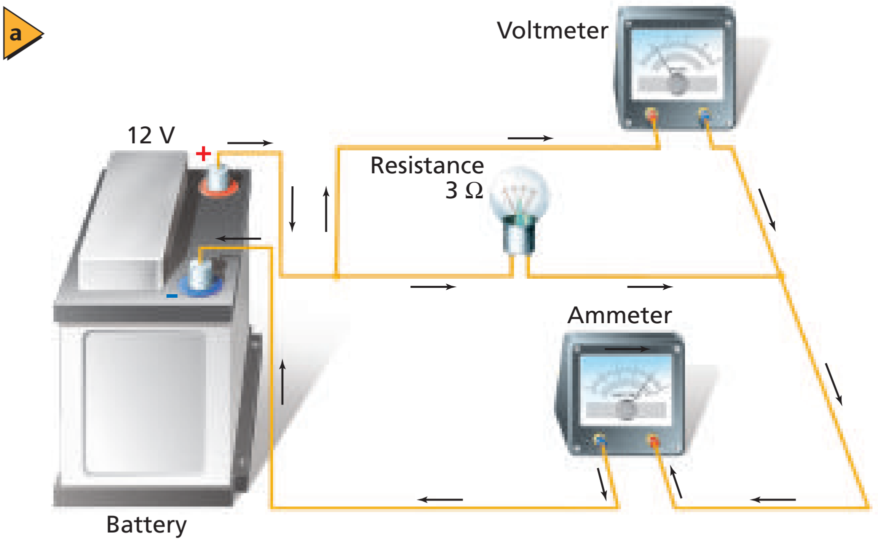
b. What is the resistance of the lamp?

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?

b. How much resistance was added to the circuit?

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



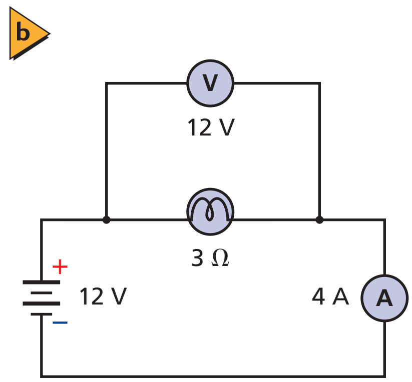


Figure 22-7 A simple electric circuit is represented pictorially **(a)** and schematically **(b).**

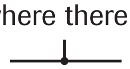
An artist's drawing and a schematic of the same circuit are shown in **Figures 22-7a** and **22-7b.** Notice in both the drawing and the schematic that the electric charge is shown flowing out of the positive terminal of the battery. To draw schematic diagrams, use the problem-solving strategy below, and always set up a conventional current.

You learned that an ammeter measures current and a voltmeter measures potential differences. Each instrument has two terminals, usually labeled + and −. A voltmeter measures the potential difference across any component of a circuit. When connecting the voltmeter in a circuit, always connect the + terminal to the end of the circuit component that is closer to the positive terminal of the battery, and connect the − terminal to the other side of the component.

PROBLEM-SOLVING **Strategies**

Drawing Schematic Diagrams

Follow these steps when drawing schematic diagrams.

1. Draw the symbol for the battery or other source of electric energy, such as a generator, on the left side of the page. Put the positive terminal on top.
2. Draw a wire coming out of the positive terminal. When you reach a resistor or other device, draw the symbol for it.
3. If you reach a point where there are two current paths, such as at a voltmeter, draw a  in the diagram. Follow one path until the two current paths join again. Then draw the second path.
4. Follow the current path until you reach the negative terminal of the battery.
5. Check your work to make sure that you have included all parts and that there are complete paths for the current to follow.

MINI LAB

Current Affairs

Do you think that current diminishes as it passes through different elements in the circuit? As a scientist, you can test this question.

1. Draw a circuit that includes a power supply and two miniature lamps.

2. Draw the circuit again and include an ammeter to measure the current between the power supply and the lamps.

3. In a third diagram, show the ammeter at a position to measure the current between the lamps.

Analyze and Conclude

4. Predict if the current between the lamps will be more than, less than, or the same as the current before the lamps. Explain.

5. Test your prediction by building the circuits. ***CAUTION: Wire is sharp and can cut skin.***

PRACTICE Problems

Additional Problems, Appendix B

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.

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.

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

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.

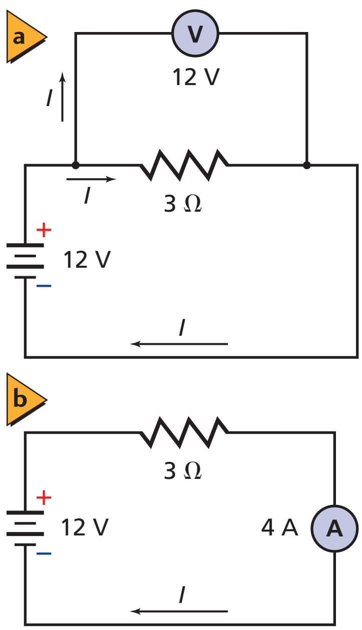


Figure 22-8 These schematics show a parallel **(a)** and a series circuit **(b)**.

When a voltmeter is connected across another component, it is called a **parallel connection** because the circuit component and the voltmeter are aligned parallel to each other in the circuit, as diagrammed in **Figure 22-8a.** Any time the current has two or more paths to follow, the connection is labeled *parallel.* The potential difference across the voltmeter is equal to the potential difference across the circuit element. Always associate the words *voltage across* with a parallel connection.

An ammeter measures the current through a circuit component. The same current going through the component must go through the ammeter, so there can be only one current path. A connection with only one current path, called a **series connection,** is shown in **Figure 22-8b.** To add an ammeter to a circuit, the wire connected to the circuit component must be removed and connected to the ammeter instead. Then, another wire is connected from the second terminal of the ammeter to the circuit component. In a series connection, there can be only a single path through the connection. Always associate the words *current through* with a series connection.

22.1 Section Review

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.

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.

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.

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.

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?

22.2 Using Electric Energy

Many familiar household appliances convert electric energy to some other form, such as light, kinetic energy, sound, or thermal energy. When you turn on one of these appliances, you complete a circuit and begin converting electric energy. In this section, you will learn to determine the rate of energy conversion and the amount that is converted.

▶ **Objectives**

- **Explain** how electric energy is converted into thermal energy.
- **Explore** ways to deliver electric energy to consumers near and far.
- **Define** kilowatt-hour.

▶ **Vocabulary**

superconductor
kilowatt-hour

Energy Transfer in Electric Circuits

Energy that is supplied to a circuit can be used in many different ways. A motor converts electric energy to mechanical energy, and a lamp changes electric energy into light. Unfortunately, not all of the energy delivered to a motor or a lamp ends up in a useful form. Lightbulbs, especially incandescent lightbulbs, become hot. Motors are often far too hot to touch. In each case, some of the electric energy is converted into thermal energy. You will now examine some devices that are designed to convert as much energy as possible into thermal energy.

Heating a resistor Current moving through a resistor causes it to heat up because flowing electrons bump into the atoms in the resistor. These collisions increase the atoms' kinetic energy and, thus, the temperature of the resistor. A space heater, a hot plate, and the heating element in a hair dryer all are designed to convert electric energy into thermal energy. These and other household appliances, such as those pictured in **Figure 22-9,** act like resistors when they are in a circuit. When charge, q, moves through a resistor, its potential difference is reduced by an amount, V. As you have learned, the energy change is represented by qV. In practical use, the rate at which energy is changed—the power, $P = E/t$—is more important. Earlier, you learned that current is the rate at which charge flows, $I = q/t$, and that power dissipated in a resistor is represented by $P = IV$. For a resistor, $V = IR$. Thus, if you know I and R, you can substitute $V = IR$ into the equation for electric power to obtain the following.

Power $P = I^2R$

Power is equal to current squared times resistance.

Thus, the power dissipated in a resistor is proportional both to the square of the current passing through it and to the resistance. If you know V and R, but not I, you can substitute $I = V/R$ into $P = IV$ to obtain the following equation.

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

Power is equal to the voltage squared divided by the resistance.

Figure 22-9 These appliances are designed to change electric energy into thermal energy.

Hutchings Photography

The power is the rate at which energy is converted from one form to another. Energy is changed from electric to thermal energy, and the temperature of the resistor rises. If the resistor is an immersion heater or burner on an electric stovetop, for example, heat flows into cold water fast enough to bring the water to the boiling point in a few minutes.

If power continues to be dissipated at a uniform rate, then after time t, the energy converted to thermal energy will be $E = Pt$. Because $P = I^2R$ and $P = V^2/R$, the total energy to be converted to thermal energy can be written in the following ways.

Thermal Energy

$$E = Pt$$
$$E = I^2Rt$$
$$E = \left(\frac{V^2}{R}\right)t$$

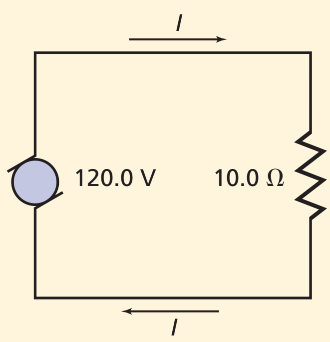
Thermal energy is equal to the power dissipated multiplied by the time. It is also equal to the current squared multiplied by resistance and time as well as the voltage squared divided by resistance multiplied by time.

EXAMPLE Problem 3

Electric Heat A heater has a resistance of 10.0 Ω. It operates on 120.0 V.

a. What is the power dissipated by the heater?

b. What thermal energy is supplied by the heater in 10.0 s?



1 Analyze and Sketch the Problem

- Sketch the situation.
- Label the known circuit components, which are a 120.0-V potential difference source and a 10.0-Ω resistor.

Known:

R = 10.0 Ω

V = 120.0 V

t = 10.0 s

Unknown:

P = ?

E = ?

2 Solve for the Unknown

a. Because R and V are known, use $P = V^2/R$.

$$P = \frac{(120.0\ \text{V})^2}{10.0\ \Omega}$$ **Substitute V = 120.0 V, R = 10.0 Ω**

$$= 1.44\ \text{kW}$$

Math Handbook
Exponents
page 839

b. Solve for the energy.

$$E = Pt$$
$$= (1.44\ \text{kW})(10.0\ \text{s})$$ **Substitute P = 1.44 kW, t = 10.0 s**
$$= 14.4\ \text{kJ}$$

3 Evaluate the Answer

- **Are the units correct?** Power is measured in watts, and energy is measured in joules.
- **Are the magnitudes realistic?** For power, $10^2 \times 10^2 \times 10^{-1} = 10^3$, so kilowatts is reasonable. For energy, $10^3 \times 10^1 = 10^4$, so an order of magnitude of 10,000 joules is reasonable.

PRACTICE Problems — Additional Problems, Appendix B

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

   a. What is the current through the heater?

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

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

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

   a. What is the current in the circuit?

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

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?

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

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?

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

   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?

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?

Superconductors A **superconductor** is a material with zero resistance. There is no restriction of current in superconductors, so there is no potential difference, *V*, across them. Because the power that is dissipated in a conductor is given by the product *IV*, a superconductor can conduct electricity without loss of energy. At present, almost all superconductors must be kept at temperatures below 100 K. The practical uses of superconductors include MRI magnets and in synchrotrons, which use huge amounts of current and can be kept at temperatures close to 0 K.

Transmission of Electric Energy

Hydroelectric facilities, such as the one at Itaipú Dam, shown in **Figure 22-10,** are capable of producing a great deal of energy. This hydroelectric energy often must be transmitted over long distances to reach homes and industries. How can the transmission occur with as little loss to thermal energy as possible?

Thermal energy is produced at a rate represented by $P = I^2R$. Electrical engineers call this unwanted thermal energy the joule heating loss, or I^2R loss. To reduce this loss, either the current, *I*, or the resistance, *R*, must be reduced.

All wires have some resistance, even though their resistance is small. The large wire used to carry electric current into a home has a resistance of 0.20 Ω for 1 km.

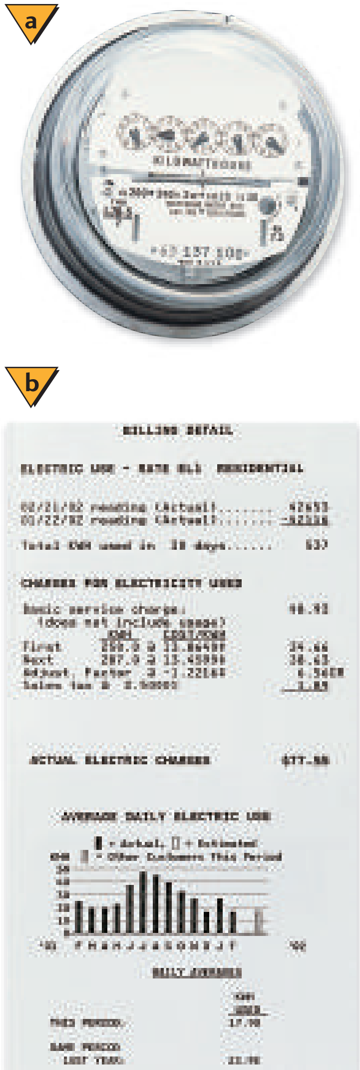
Figure 22-10 In the year 2000, energy produced by Itaipú Dam met 24 percent of Brazil's electric energy needs and 95 percent of Paraguay's.

Hans-Jurgen Burkard/Peter Arnold, Inc.

Suppose that a farmhouse were connected directly to a power plant 3.5 km away. The resistance in the wires needed to carry a current in a circuit to the home and back to the plant is represented by the following equation: $R = 2(3.5\ \text{km})(0.20\ \Omega/\text{km}) = 1.4\ \Omega$. An electric stove might cause a 41-A current through the wires. The power dissipated in the wires is represented by the following relationships: $P = I^2R = (41\ \text{A})^2\ (1.4\ \Omega) = 2400\ \text{W}$.

All of this power is converted to thermal energy and, therefore, is wasted. This loss could be minimized by reducing the resistance. Cables of high conductivity and large diameter (and therefore low resistance) are available, but such cables are expensive and heavy. Because the loss of energy is also proportional to the square of the current in the conductors, it is even more important to keep the current in the transmission lines low.

How can the current in the transmission lines be kept low? The electric energy per second (power) transferred over a long-distance transmission line is determined by the relationship $P = IV$. The current is reduced without the power being reduced by an increase in the voltage. Some long-distance lines use voltages of more than 500,000 V. The resulting lower current reduces the I^2R loss in the lines by keeping the I^2 factor low. Long-distance transmission lines always operate at voltages much higher than household voltages in order to reduce I^2R loss. The output voltage from the generating plant is reduced upon arrival at electric substations to 2400 V, and again to 240 V or 120 V before being used in homes.



■ **Figure 22-11** Watt-hour meters measure the amount of electric energy used by a consumer **(a).** Meter readings then are used in calculating the cost of energy **(b).**

The Kilowatt-Hour

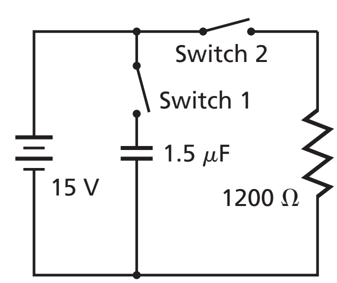
While electric companies often are called power companies, they actually provide energy rather than power. Power is the rate at which energy is delivered. When consumers pay their home electric bills, an example of which is shown in **Figure 22-11,** they pay for electric energy, not power.

The amount of electric energy used by a device is its rate of energy consumption, in joules per second (W) times the number of seconds that the device is operated. Joules per second times seconds, (J/s)s, equals the total amount of joules of energy. The joule, also defined as a watt-second, is a relatively small amount of energy, too small for commercial sales use. For this reason, electric companies measure energy sales in a unit of a

CHALLENGE PROBLEM

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?
2. Switch 1 is now opened, and Switch 2 remains open. What is the voltage across the capacitor? Why?
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?
4. As time goes on, what happens to the voltage across the capacitor and the current through the resistor?



(t)Bischel Studios, (b)Hutchings Photography large number of joules called a kilowatt-hour, kWh. A **kilowatt-hour** is equal to 1000 watts delivered continuously for 3600 s (1 h), or 3.6×10^6 J. Not many household devices other than hot-water heaters, stoves, clothes dryers, microwave ovens, heaters, and hair dryers require more than 1000 W of power. Ten 100-W lightbulbs operating all at once use only 1 kWh of energy when they are left on for one full hour.

PRACTICE Problems

Additional Problems, Appendix B

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?

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

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

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?

b. How much power does it use?

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

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.

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

You have learned several ways in which power companies solve the problems involved in transmitting electric current over great distances. You also have learned how power companies calculate electric bills and how to predict the cost of running various appliances in the home. The distribution of electric energy to all corners of Earth is one of the greatest engineering feats of the twentieth century.

22.2 Section Review

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.

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?

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

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

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?

PHYSICS LAB

Voltage, Current, and Resistance

In this chapter, you studied the relationships between voltage, current, and resistance in simple circuits. Voltage is the potential difference that pushes current through a circuit, while resistance determines how much current will flow if a potential difference exists. In this activity, you will collect data and make graphs in order to investigate the mathematical relationships between voltage and current and between resistance and current.

QUESTION

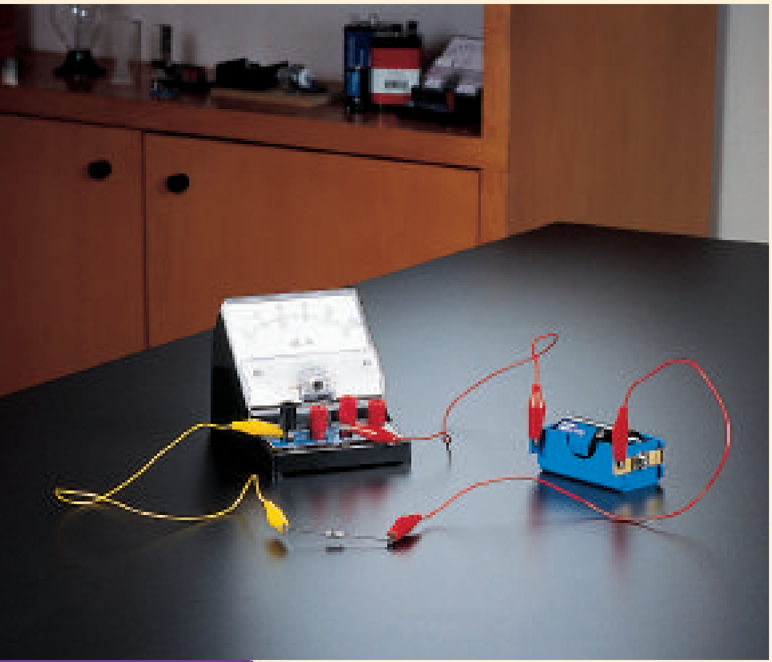
What are the relationships between voltage and current and resistance and current?

Objectives

- **Measure** current in SI.
- **Describe** the relationship between the resistance of a circuit and the total current flowing through a circuit.
- **Describe** the relationship between voltage and the total current flowing through a circuit.
- **Make and use graphs** to show the relationships between current and resistance and between current and voltage.

Safety Precautions

- ***CAUTION: Resistors and circuits may become hot.***
- ***CAUTION: Wires are sharp and can cut skin.***



Materials

four 1.5-V D batteries
four D-battery holders
one 10-kΩ resistor
one 500-μA ammeter
five wires with alligator clips
one 20-kΩ resistor
one 30-kΩ resistor
one 40-kΩ resistor

Procedure

Part A

1. Place the D battery in the D-battery holder.
2. Create a circuit containing the D battery, 10-kΩ resistor, and 500-μA ammeter.
3. Record the values for resistance and current in Data Table 1. For resistance, use the value of the resistor. For current, read and record the value given by the ammeter.
4. Replace the 10-kΩ resistor with a 20-kΩ resistor.
5. Record the resistance and the current in Data Table 1.
6. Repeat steps 4–5, but replace the 20-kΩ resistor with a 30-kΩ resistor.
7. Repeat steps 4–5, but replace the 30-kΩ resistor with a 40-kΩ resistor.

Part B

8. Recreate the circuit that you made in step 2. Verify the current in the circuit and record the values for voltage and current in Data Table 2.
9. Add a second 1.5-V D battery to the setup and record the values for voltage and current in Data Table 2. When you are using more than one battery, record the sum of the batteries' voltages as the voltage in Data Table 2.
10. Repeat step 9 with three 1.5-V D batteries.
11. Repeat step 9 with four 1.5-V D batteries.

Horizons Companies

Data Table 1

Voltage (V)	Resistance (kΩ)	Current (μA)
1.5		
1.5		
1.5		
1.5		

Data Table 2

Voltage (V)	Resistance (kΩ)	Current (μA)
	10	
	10	
	10	
	10	

Analyze

1. **Make and Use Graphs** Graph the current versus the resistance. Place resistance on the *x*-axis and current on the *y*-axis.
2. **Make and Use Graphs** Graph the current versus the voltage. Place voltage on the *x*-axis and current on the *y*-axis.
3. **Error Analysis** Other than the values of the resistors, what factors could have affected the current in Part A? How might the effect of these factors be reduced?
4. **Error Analysis** Other than the added batteries, what factors could have affected the current in Part B? How might the effect of these factors be reduced?

Conclude and Apply

1. Looking at the first graph that you made, describe the relationship between resistance and current?
2. Why do you suppose this relationship between resistance and current exists?
3. Looking at the second graph that you made, how would you describe the relationship between voltage and current?
4. Why do you suppose this relationship between voltage and current exists?

Going Further

1. What would be the current in a circuit with a voltage of 3.0 V and a resistance of 20 kΩ? How did you determine this?
2. Could you derive a formula from your lab data to explain the relationship among voltage, current, and resistance? *Hint: Look at the graph of current versus voltage. Assume it is a straight line that goes through the origin.*
3. How well does your data match this formula? Explain.

Real-World Physics

1. Identify some common appliances that use 240 V rather than 120 V.
2. Why do the appliances that you identified require 240 V? What would be the consequences for running such an appliance on a 120-V circuit?

Physics Online

To find out more about current electricity, visit the Web site: **physicspp.com**

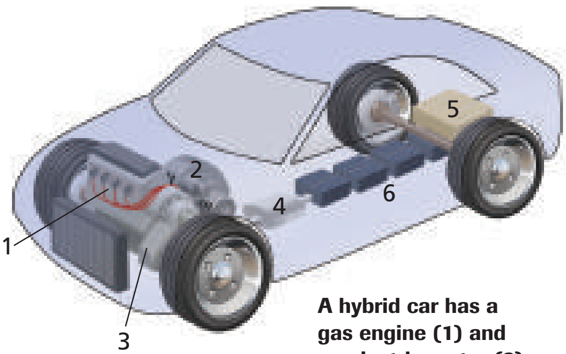
Technology and Society

Hybrid Cars

Meet the hybrid car. It is fuel-efficient, comfortable, safe, quiet, clean, and it accelerates well. Hybrid sales are growing and are expected to exceed 200,000 vehicles in 2005.

Why are they called hybrids? A vehicle is called a hybrid if it uses two or more sources of energy. For example, diesel-electric locomotives are hybrids. But the term *hybrid vehicle* usually refers to a car that uses gas and electricity.

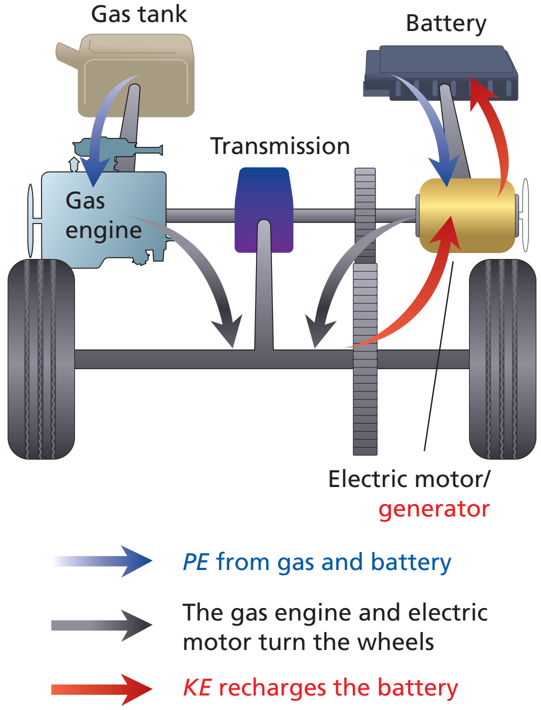
Conventional cars have large engines that enable them to accelerate quickly and to drive up steep hills. But the engine's size makes it inefficient. In a hybrid, a lighter, more efficient gas engine meets most driving needs. When extra energy is needed, it is supplied by electricity from rechargeable batteries.



A hybrid car has a gas engine (1) and an electric motor (2).

How do hybrids work? The illustration above shows one type of hybrid, called a parallel hybrid. The small internal combustion engine (1) powers the car during most driving situations. The gas engine and electric motor (2) are connected to the wheels by the same transmission (3). Computerized electronics (4) decide when to use the electric motor, when to use the engine, and when to use both.

This type of hybrid has no external power source besides the gas in the fuel tank (5). Unlike an electric car, you don't need to plug the hybrid into an electric outlet to recharge the batteries (6). Rather, the batteries are recharged by a process called regenerative braking, as shown in the schematic diagram. In conventional vehicles, the brakes apply friction to the wheels, converting a vehicle's kinetic energy into heat. However, a hybrid's electric motor can act as a generator. When the electric motor slows the car, kinetic energy is converted to electric energy, which then recharges the batteries.



In regenerative breaking, energy from the moving car recharges the batteries.

Can hybrids benefit society? Hybrid cars improve gas mileage and reduce tailpipe emissions. Improved gas mileage saves on the cost of operating the car. Tailpipe emissions include carbon dioxide and carbon monoxide, as well as various hydrocarbons and nitrogen oxides. These emissions can contribute to certain problems, such as smog. Because hybrids improve gas mileage and reduce tailpipe emissions, many people feel that these cars are one viable way to help protect air quality and conserve fuel resources.

Going Further

1. **Analyze and Conclude** What is regenerative braking?
2. **Predict** Will increased sales of hybrids benefit society? Support your answer.

Chapter 22

Study Guide

22.1 Current and Circuits

Vocabulary

- electric current (p. 592)
- conventional current (p. 592)
- battery (p. 592)
- electric circuit (p. 592)
- ampere (p. 593)
- resistance (p. 595)
- resistor (p. 596)
- parallel connection (p. 600)
- series connection (p. 600)

Key Concepts

- Conventional current is defined as current in the direction in which a positive charge would move.
- Generators convert mechanical energy to electric energy.
- A circuit converts electric energy to heat, light, or some other useful output.
- As charge moves through a circuit, resistors cause a drop in potential energy.
- An ampere is equal to one coulomb per second (1 C/s).
- Power can be found by multiplying voltage times current.

$$P = IV$$

- The resistance of a device is given by the ratio of the device's voltage to its current.

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

- Ohm's law states that the ratio of potential difference to current is a constant for a given conductor. Any resistance that does not change with temperature, voltage, or the direction of charge flow obeys Ohm's law.
- Circuit current can be controlled by changing voltage, resistance, or both.

22.2 Using Electric Energy

Vocabulary

- superconductor (p. 603)
- kilowatt-hour (p. 605)

Key Concepts

- The power in a circuit is equal to the square of the current times the resistance, or to the voltage squared divided by the resistance.

$$P = I^2R \text{ or } P = \frac{V^2}{R}$$

- If power is dissipated at a uniform rate, the thermal energy converted equals power multiplied by time. Power also can be represented by I^2R and V^2/R to give the last two equations.

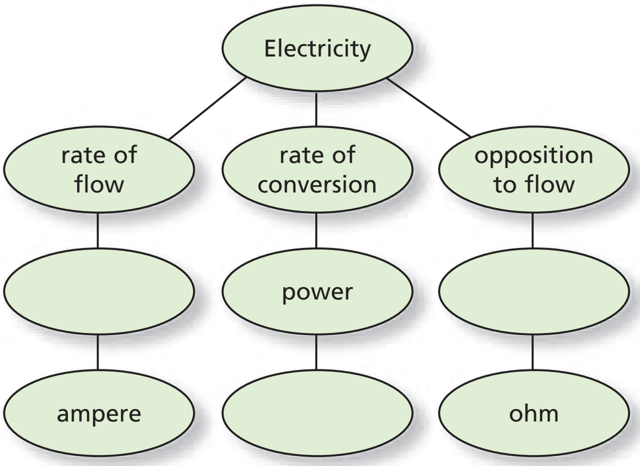
$$\begin{aligned} E &= Pt \\ &= I^2Rt \\ &= \left(\frac{V^2}{R}\right)t \end{aligned}$$

- Superconductors are materials with zero resistance. At present, the practical uses of superconductors are limited.
- Unwanted thermal energy produced in the transmission of electric energy is called the joule heating loss, or I^2R loss. The best way to minimize the joule heating loss is to keep the current in the transmission wires low. Transmitting at higher voltages enables current to be reduced without power being reduced.
- The kilowatt-hour, kWh, is an energy unit. It is equal to 3.6×10^6 J.

Assessment

Concept Mapping

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



Mastering Concepts

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

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

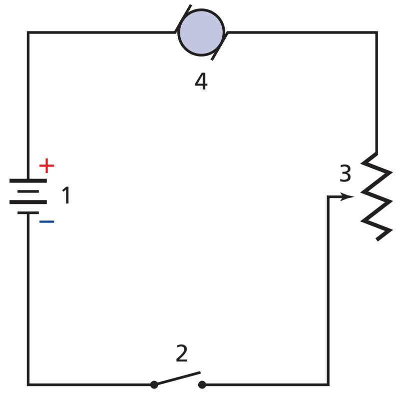


Figure 22-12

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

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

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

a. Which device converts electric energy to mechanical energy?
b. Which device converts chemical energy to electric energy?
c. Which device turns the circuit on and off?
d. Which device provides a way to adjust speed?

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

a. an incandescent lightbulb
b. a clothes dryer
c. a digital clock radio

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)

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

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

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)

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

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

Applying Concepts

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

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

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

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

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.

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?

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

 For more problems, go to Additional Problems, Appendix B.

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?

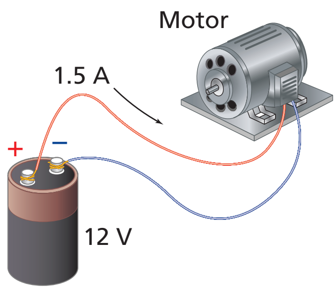
59. If the ammeter in Figure 22-4a on page 596 were moved to the bottom of the diagram, would the ammeter have the same reading? Explain.

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?

Mastering Problems

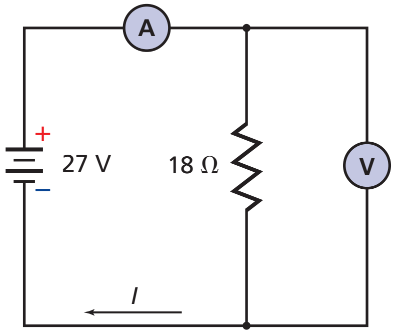
22.1 Current and Circuits

61. A motor is connected to a 12-V battery, as shown in **Figure 22-13.**
 a. How much power is delivered to the motor?
 b. How much energy is converted if the motor runs for 15 min?



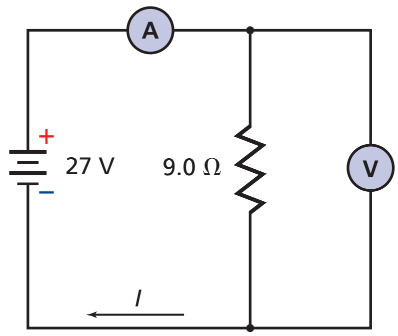
■ Figure 22-13

62. Refer to **Figure 22-14** to answer the following questions.
 a. What should the ammeter reading be?
 b. What should the voltmeter reading be?
 c. How much power is delivered to the resistor?
 d. How much energy is delivered to the resistor per hour?



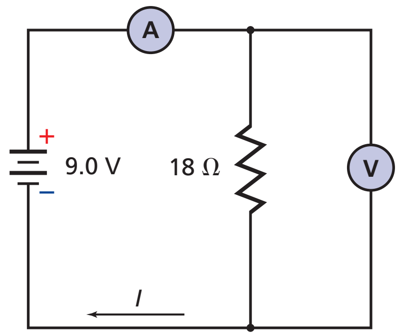
■ Figure 22-14

63. Refer to **Figure 22-15** to answer the following questions.
 a. What should the ammeter reading be?
 b. What should the voltmeter reading be?
 c. How much power is delivered to the resistor?
 d. How much energy is delivered to the resistor per hour?



■ Figure 22-15

64. Refer to **Figure 22-16** to answer the following questions.
 a. What should the ammeter reading be?
 b. What should the voltmeter reading be?
 c. How much power is delivered to the resistor?
 d. How much energy is delivered to the resistor per hour?



■ Figure 22-16

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?

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?

67. A lamp draws 0.50 A from a 120-V generator.
 a. How much power is delivered?
 b. How much energy is converted in 5.0 min?

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

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

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

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?

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

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

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

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.**
  a. For each measurement, calculate the resistance.
  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.

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	________

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.

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?
  b. How much power does the lamp dissipate when it is connected to the 6.0-V battery?
  c. How much power does it dissipate at 9.0 V?

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?

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?
  b. When the lamp is cold, its resistance is 1/5 as great as it is when the lamp is hot. What is the lamp's cold resistance?
  c. What is the current through the lamp as it is turned on if it is connected to a potential difference of 120 V?

80. The graph in **Figure 22-17** shows the current through a device called a silicon diode.
  a. A potential difference of +0.70 V is placed across the diode. What is the resistance of the diode?
  b. What is the diode's resistance when a +0.60-V potential difference is used?
  c. Does the diode obey Ohm's law?

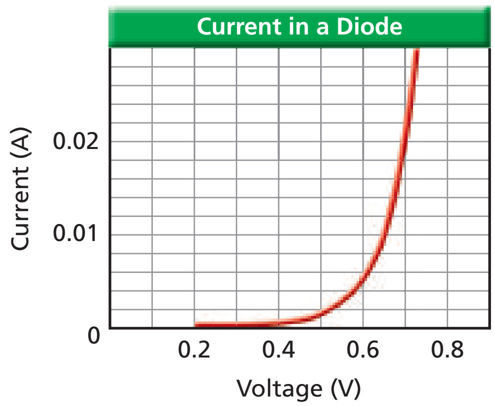


Figure 22-17

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.

22.2 Using Electric Energy

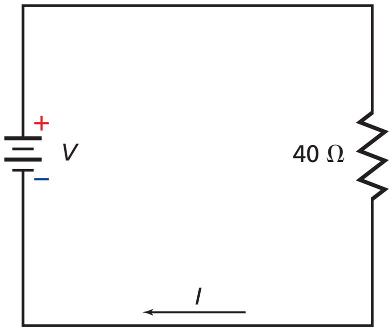
82. **Batteries** A 9.0-V battery costs $3.00 and will deliver 0.0250 A for 26.0 h before it must be replaced. Calculate the cost per kWh.

 For more problems, go to Additional Problems, Appendix B.

83. What is the maximum current allowed in a 5.0-W, 220-Ω resistor?

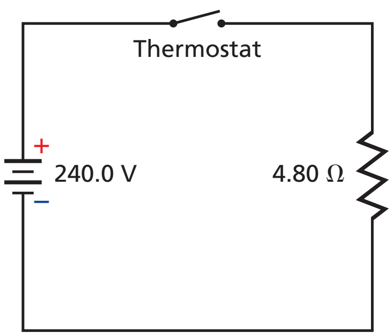
84. A 110-V electric iron draws 3.0 A of current. How much thermal energy is developed in an hour?

85. For the circuit shown in **Figure 22-18,** the maximum safe power is 50 W. Use the figure to find the following:
a. the maximum safe current
b. the maximum safe voltage



■ Figure 22-18

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

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.

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?
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?

Mixed Review

89. If a person has $5, how long could he or she play a 200 W stereo if electricity costs $0.15 per kWh?

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?

91. A 6.0-Ω resistor is connected to a 15-V battery.
a. What is the current in the circuit?
b. How much thermal energy is produced in 10.0 min?

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?
b. What is the current draw at the instant the bulb is turned on?
c. When does the lightbulb use the most power?

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?

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?
b. How efficient is the motor?

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?
b. What energy is supplied to the coil in 5.0 min?
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.
d. At $0.08 per kWh, how much does it cost to operate the heating coil 30 min per day for 30 days?

96. Appliances An electric heater is rated at 500 W.
a. How much energy is delivered to the heater in half an hour?
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?
c. At $0.08 per kWh, how much does it cost to run the heater 6.0 h per day for 30 days?

Thinking Critically

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.

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.

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.

d. Review your calculations carefully for the units used and discuss why your answer is in the correct form.

e. Discuss, in general terms, different ways in which you could increase the efficiency of microwave heating.

f. Discuss, in efficiency terms, why microwave ovens are not useful for heating everything.

g. Discuss, in general terms, why it is not a good idea to run microwave ovens when they are empty.

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.*

b. Formulate an argument to support the clerk's claim. *Hint: Think about heating a specific object.*

c. Formulate a diplomatic reply to the clerk.

100. Apply Concepts The sizes of 10-Ω resistors range from a pinhead to a soup can. Explain.

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.

102. Make and Use Graphs Based on what you have learned in this chapter, identify and prepare two parabolic graphs.

Writing in Physics

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.

104. In Chapter 13, you learned that matter expands when it is heated. Research the relationship between thermal expansion and high-voltage transmission lines.

Cumulative Review

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)

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)

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)

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)

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)

 For more problems, go to Additional Problems, Appendix B.

Standardized Test Practice

Multiple Choice

1. A 100-W lightbulb is connected to a 120-V electric line. What is the current that the lightbulb draws?

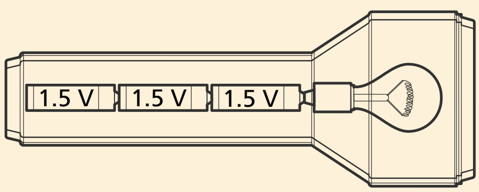
(A) 0.8 A (C) 1.2 A
(B) 1 A (D) 2 A

2. A 5.0-Ω resistor is connected to a 9.0-V battery. How much thermal energy is produced in 7.5 min?

(A) 1.2×10^2 J (C) 3.0×10^3 J
(B) 1.3×10^3 J (D) 7.3×10^3 J

3. The current in the flashlight shown below is 0.50 A, and the voltage is the sum of the voltages of the individual batteries. What is the power delivered to the bulb of the flashlight?

(A) 0.11 W (C) 2.3 W
(B) 1.1 W (D) 4.5 W



4. If the flashlight in the illustration above is left on for 3.0 min, how much electric energy is delivered to the bulb?

(A) 6.9 J (C) 2.0×10^2 J
(B) 14 J (D) 4.1×10^2 J

5. A current of 2.0 A flows through a circuit containing a motor with a resistance of 12 Ω. How much energy is converted if the motor runs for one minute?

(A) 4.8×10^1 J (C) 2.9×10^3 J
(B) 2.0×10^1 J (D) 1.7×10^5 J

6. What is the effect on the current in a simple circuit if both the voltage and the resistance are reduced by half?

(A) divided by 2 (C) multiplied by 2
(B) no change (D) multiplied by 4

7. A 50.0-Ω resistance causes a current of 5.00 mA to flow through a circuit connected to a battery. What is the power in the circuit?

(A) 1.00×10^{-2} W (C) 1.25×10^{-3} W
(B) 1.00×10^{-3} W (D) 2.50×10^{-3} W

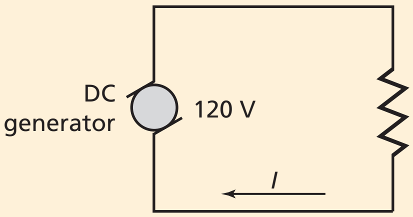
8. How much electric energy is delivered to a 60.0-W lightbulb if the bulb is left on for 2.5 hours?

(A) 4.2×10^{-2} J (C) 1.5×10^2 J
(B) 2.4×10^1 J (D) 5.4×10^5 J

Extended Answer

9. The diagram below shows a simple circuit containing a DC generator and a resistor. The table shows the resistances of several small electric devices. If the resistor in the diagram represents a hair dryer, what is the current in the circuit? How much energy does the hair dryer use if it runs for 2.5 min?

Device	Resistance (Ω)
Hair dryer	8.5 Ω
Heater	10.0 Ω
Small motor	12.0 Ω



✓ Test-Taking TIP

More Than One Graphic

If a test question has more than one table, graph, diagram, or drawing with it, use them all. If you answer based on just one graphic, you probably will miss an important piece of information.

Chapter 23 Series and Parallel Circuits

What You'll Learn

- You will distinguish among series circuits, parallel circuits, and series-parallel combinations, and solve problems involving them.
- You will explain the function of fuses, circuit breakers, and ground-fault interrupters, and describe how ammeters and voltmeters are used in circuits.

Why It's Important

Electric circuits are the basis of every electric device, from electric lights to microwave ovens to computers. Learning how circuits work will help you understand how countless electric devices function.

Electric Load Centers Electric load centers form the link between the utility company and the circuits in a building. Each circuit breaker protects an individual circuit, which has the various loads connected in parallel.

Think About This ▶

Why are the building loads connected in parallel? How are the circuit breakers connected?

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