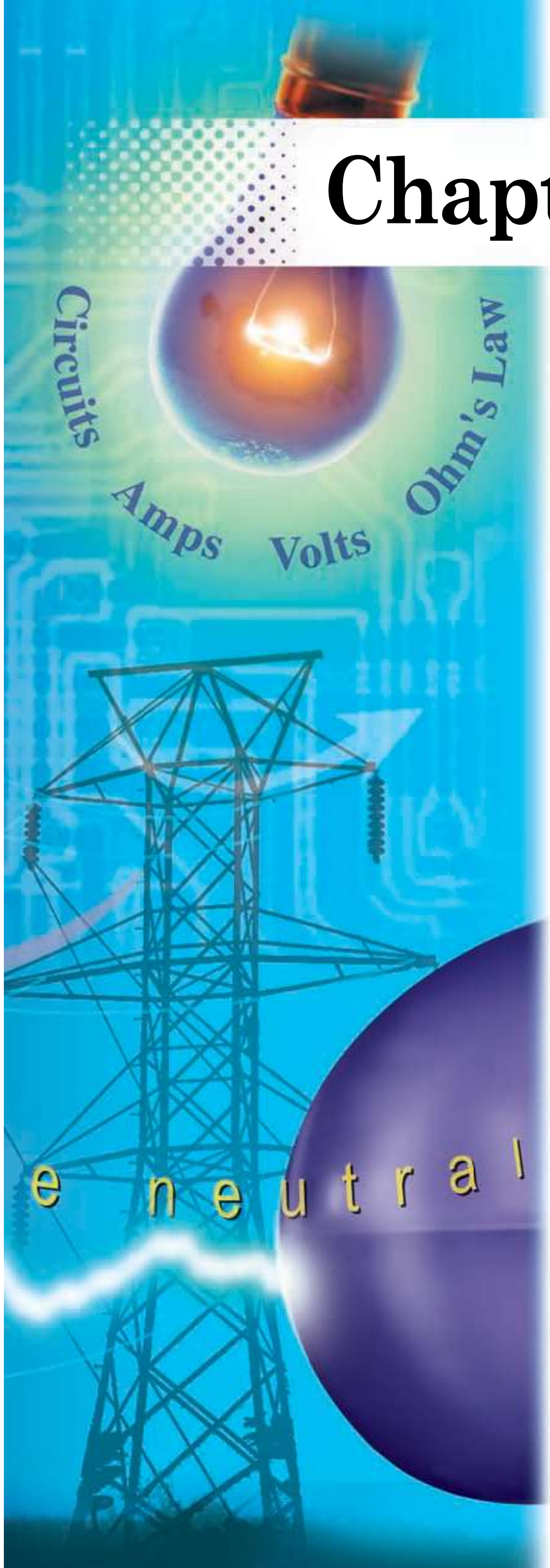
Table of Contents



Chapter 13

Electric Circuits

Suppose you had a stationary bicycle that was connected to a light bulb, so that when you pedal the bicycle, the energy from the turning wheels lights the bulb. How fast would you have to pedal the bicycle to generate enough electrical energy to light the bulb? You would be surprised at how hard you would have to pedal to do something as seemingly simply as lighting an ordinary household light bulb. Some science museums contain this type of exhibit to give everyone a good example of how much energy is needed to accomplish simple tasks in our daily lives.

What would your life be like without electricity? You can probably name at least a dozen aspects of your morning routine alone that would have to change if you didn't have electricity. Do you know how electrical circuits work? Do you know what the words voltage and current mean? This chapter will give you the opportunity to explore electricity, electrical circuits, and the nature of electrical energy. Electricity can be powerful and dangerous, but when you know some basic facts about how electricity works, you can use electricity safely with confidence.

Key Questions

- ✓ Are there electrical circuits in the human body? What about an electric eel?
- ✓ Why is the shock from a household outlet more dangerous to you if your skin is wet?
- ✓ What are semiconductors, and what common household items contain them?

13.1 Electric Circuits

Imagine your life without TV, radio, computers, refrigerators, or light bulbs. All of these things are possible because of electricity. The use of electricity has become so routine that most of us never stop to think about what happens when we switch on a light or turn on a motor. This section is about electricity and electric circuits. Circuits are usually made of wires that carry electricity and devices that use electricity.

Vocabulary

electric current, electric circuit, circuit diagram, electrical symbols, resistor, closed circuit, open circuit, switch

Objectives

- ✓ Explain how electrical energy is supplied to devices in a circuit.
- ✓ Use electrical symbols to draw simple circuit diagrams.
- ✓ Distinguish between open and closed circuits.

Electricity

What is electricity? Electricity usually means the flow of **electric current** in wires, motors, light bulbs, and other inventions. Electric current is what makes an electric motor turn or an electric stove heat up. Electric current is almost always invisible and comes from the motion of electrons or other charged particles. This chapter and the next will teach you the practical use of electricity. Chapter 15 will deal with electricity at the atomic level.

Electric current Electric current is similar to a current of water, but electric current is not visible because it usually flows inside solid metal wires. Electric current can carry energy and do work just as a current of water can. For example, a waterwheel turns when a current of water exerts a force on it (Figure 13.1). A waterwheel can be connected to a machine such as a loom for making cloth, or to a millstone for grinding wheat into flour. Before electricity was available, waterwheels were used to supply energy to many machines. Today, the same tasks are done using energy from electric current. Look around you right now and probably you see wires carrying electric current into buildings.

Electricity can be powerful and dangerous Electric current can carry great deal of energy. For example, an electric saw can cut wood much faster than a hand saw. An electric motor the size of a basketball can do as much work as five big horses or fifteen strong people. Electric current also can be dangerous. Touching a live electric wire can result in serious injury. The more you know about electricity, the easier it is to use it safely.

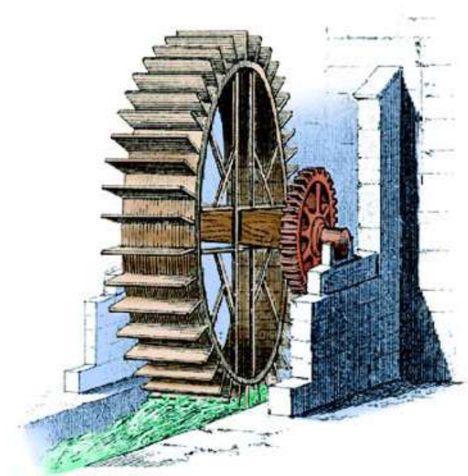
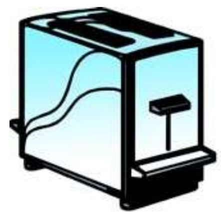


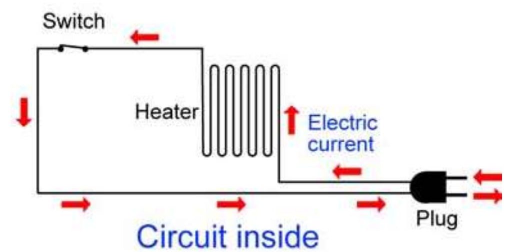
Figure 13.1: *A waterwheel uses the force of flowing water to run machines.*

Electric circuits

Electricity travels in circuits

An **electric circuit** is a complete path through which electricity travels. A good example of a circuit is the one in an electric toaster. Bread is toasted by heaters that convert electrical energy to heat. The circuit has a switch that turns on when the lever on the side of the toaster is pulled down. With the switch on, electric current enters through one side of the plug from the socket in the wall, and goes through the toaster and out the other side of the plug.





Wires are like pipes for electricity

Wires in electric circuits are similar in some ways to pipes and hoses that carry water (Figure 13.2). Wires act like pipes for electric current. Current enters the house on the supply wire and leaves on the return wire. The big difference between wires and water pipes is that you cannot get electricity to leave a wire the way water leaves a pipe. If you cut a water pipe, the water flows out. If you cut a wire, the electric current stops immediately.

Examples of circuits in nature

Circuits are not confined to appliances, wires, and devices built by people. The first experience humans had with electricity was in the natural world. These are some examples of natural circuits:

- The nerves in your body are an electrical circuit that carries messages from your brain to your muscles.
- The tail of an electric eel makes a circuit when it stuns a fish with a jolt of electricity.
- The Earth makes a gigantic circuit when lightning carries electric current between the clouds and the ground.

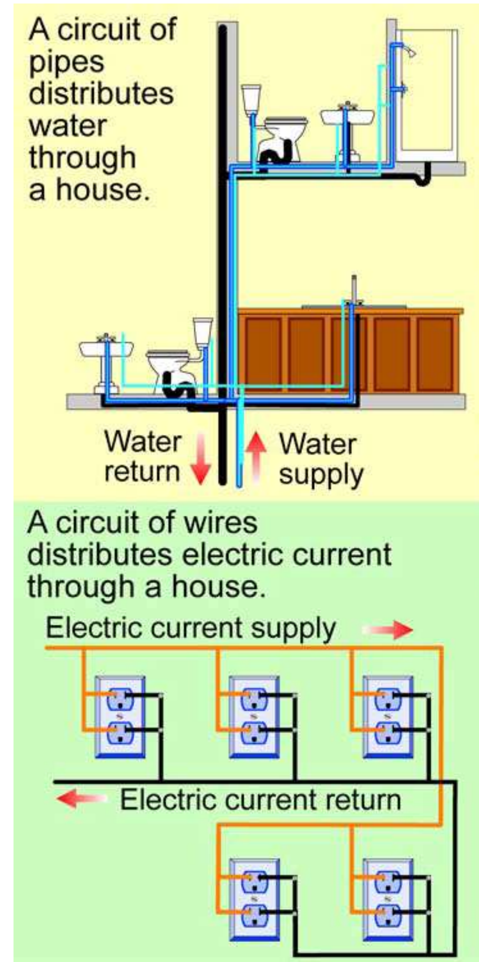
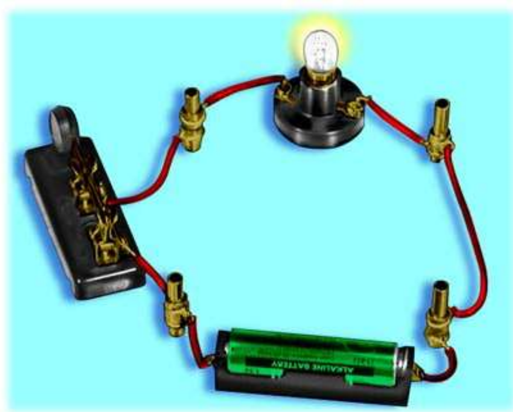


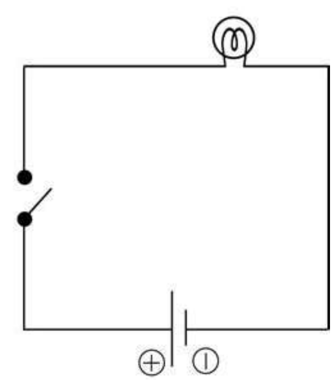
Figure 13.2: *In a house or other building, we use pipes to carry water and wires to carry electric current.*

Circuit diagrams and electrical symbols

Circuit diagrams Circuits are made up of wires and electrical parts such as *batteries*, *light bulbs*, *motors*, and *switches*. When designing a circuit people make drawings to show how the parts are connected. Electrical drawings are called **circuit diagrams**. When drawing a circuit diagram, symbols are used to represent each part of the circuit. These **electrical symbols** make drawing circuits quicker and easier than drawing realistic pictures.

Electrical symbols A circuit diagram is a shorthand method of describing a working circuit. The electric symbols used in circuit diagrams are standard so that anyone familiar with electricity can build the circuit by looking at the diagram. Figure 13.3 shows some common parts of a circuit and their electrical symbols. The picture below shows an actual circuit on the left and its circuit diagram on the right. Can you identify the real parts with their symbols? Note that the switch is open in the circuit diagram, but closed in the photograph. Closing the switch completes the circuit so the light bulb lights up.





Resistors A **resistor** is an electrical device that uses the energy carried by electric current in a specific way. In many circuit diagrams any electrical device that uses energy is shown with a resistor symbol. A light bulb, heating element, speaker, or motor can be drawn with a resistor symbol. When you analyze a circuit, many electrical devices may be treated as resistors when figuring out how much current is in the circuit.

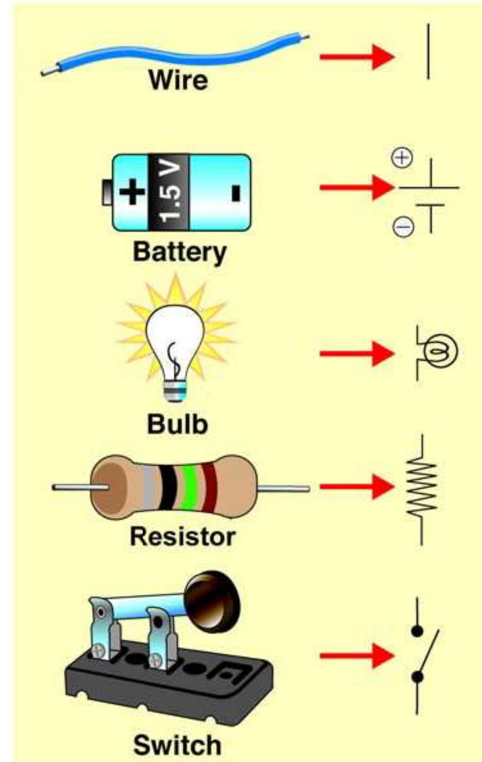


Figure 13.3: *These electrical symbols are used when drawing circuit diagrams.*

Open and closed circuits

Batteries All electric circuits must have a source of energy. Circuits in your home get their energy from power plants that generate electricity. Circuits in flashlights, cell phones, and portable radios get their energy from batteries. Some calculators have solar cells that convert energy from the sun or other lights into electrical energy. Of all the types of circuits, those with batteries are the easiest to learn. We will focus on battery circuits for now and will eventually learn how circuits in buildings work.

Open and closed circuits It is necessary to turn off light bulbs, radios, and most other devices in circuits. One way to turn off a device is to stop the current by "breaking" the circuit. Electric current can only flow when there is a complete and unbroken path from one end of the battery to the other. A circuit with no breaks is called a **closed circuit** (Figure 13.4). A light bulb will light only when it is part of a closed circuit. Opening a switch or disconnecting a wire creates a break in the circuit and stops the current. A circuit with any break in it is called an **open circuit**.

Switches **Switches** are used to turn electricity on and off. Flipping a switch to the "off" position creates an open circuit by making a break in the wire. The break stops the current because electricity cannot normally travel through air. Flipping a switch to the "on" position closes the break and allows the current to flow again, to supply energy to the bulb or radio or other device.

Breaks in circuits A switch is not the only way to make a break in a circuit. A light bulb burns out when the thin wire that glows inside it breaks. This also creates an open circuit and explains why a "burned out" bulb cannot light.

13.1 Section Review

1. List one way electric current is similar to water current and one way it is different.
2. Draw a circuit diagram for the circuit shown in Figure 13.5.
3. What is the difference between an open circuit and a closed circuit?

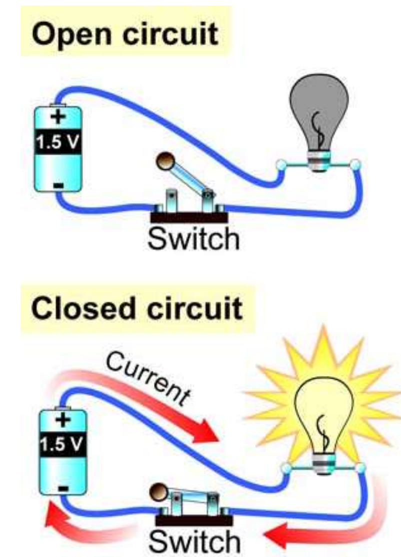


Figure 13.4: *There is current in a closed circuit but not in an open circuit.*

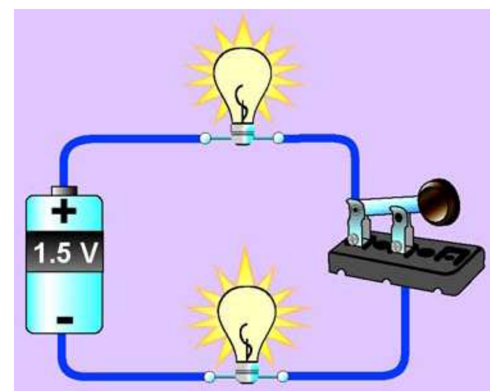


Figure 13.5: *What does the circuit diagram for this circuit look like?*

13.2 Current and Voltage

Current is what carries energy in a circuit. Like water current, electric current only flows when there is a difference in energy between two locations that are connected. Water flows downhill from high gravitational potential energy to low. Electric current flows from high electrical potential energy to low. Electrical *voltage* measures the difference in electrical potential energy between two places in a circuit. Differences in voltage are what cause electric currents to flow.

Vocabulary

ampere, voltage, volt, voltmeter, multimeter, battery, ammeter

Objectives

- ✓ List the units used to measure current and voltage.
- ✓ Describe how to measure current and voltage in a circuit.
- ✓ Explain the function of a battery in a circuit.

Current

Measuring electric current

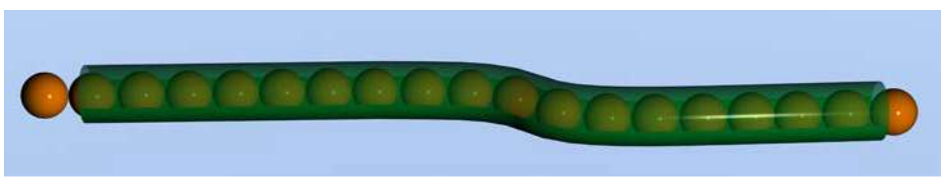
Electric current is measured in units called **amperes (A)**, or amps, for short. The unit is named in honor of Andre-Marie Ampere (1775-1836), a French physicist who studied electricity and magnetism. A small battery-powered flashlight bulb uses about 1/2 amp of electric current.

Current flows from positive to negative

Examine a battery and you will find a positive and a negative end. The positive end on a AA, C, or D battery has a raised bump, and the negative end is flat. A battery's electrical symbol uses a long line to show the positive end and a short line to show the negative end.

Current in equals current out

Electric current from a battery flows out of the positive end and returns back into the negative end. An arrow is sometimes used to show the direction of current on a circuit diagram (Figure 13.6). The amount of electric current coming out of the positive end of the battery must always be the same as the amount of current flowing into the negative end. You can picture this rule in your mind with steel balls flowing through a tube. When you push one in, one comes out. The rate at which the balls flow in equals the rate at which they flow out.



Current doesn't leak out

Electric current does not leak out of wires the way water sometimes leaks out of a hose or pipe. Electrical forces are so strong that current stops immediately if a circuit is broken.

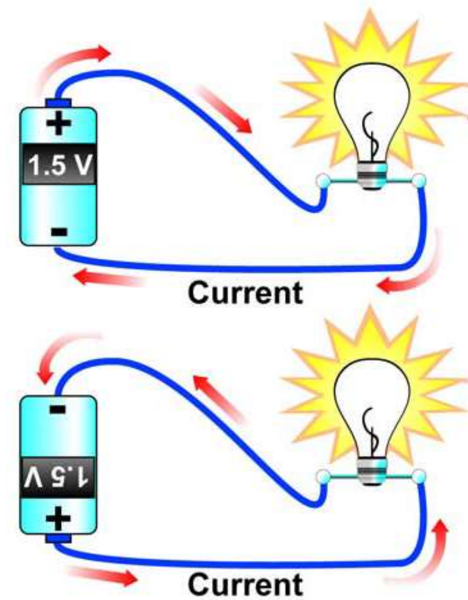


Figure 13.6: *Electric current flows in a circuit from the positive end of a battery and returns toward the negative end.*

Voltage

Energy and voltage

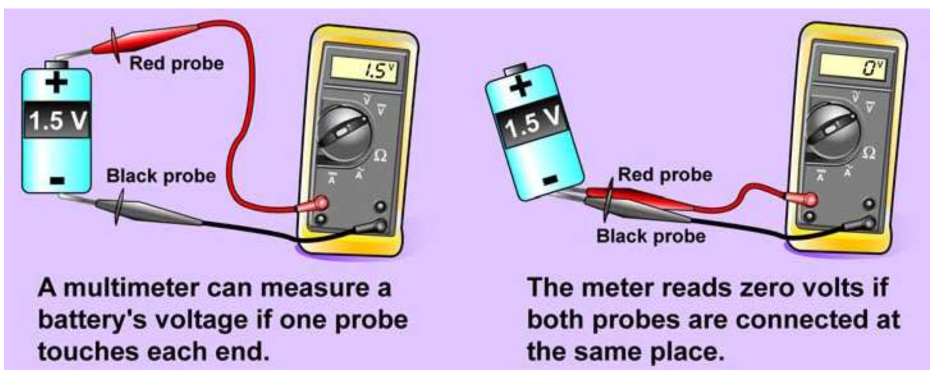
Voltage is a measure of electric potential energy, just like height is a measure of gravitational potential energy. Voltage is measured in **volts** (V). Like other forms of potential energy, a voltage difference means there is energy that can be used to do work. With electricity, the energy becomes useful when we let the voltage difference cause current to flow through a circuit. Current is what actually flows and does work. A difference in voltage provides the energy that causes current to flow.

What voltage means

A voltage difference of 1 volt means 1 amp of current does 1 joule of work in 1 second. Since 1 joule per second is a watt (power), *voltage is the power per amp of current that flows*. Every amp of current flowing out of a 1.5 V battery carries 1.5 watts of power. The voltage in your home electrical system is 120 volts, which means each amp of current carries 120 watts of power. The higher the voltage, the more power is carried by each amp of electric current.

Using a meter to measure voltage

Humans cannot see voltage, so we use an electrical meter to find the voltage in a circuit. A **voltmeter** measures voltage. A more useful meter is a **multimeter**, which can measure voltage or current. To measure voltage, the meter's probes are touched to two places in a circuit or across a battery. The meter shows the difference in voltage between the two places.



Meters measure voltage difference

The meter reads *positive* voltage if the red (positive) probe is at a higher voltage than the black probe. The meter reads negative when the black probe is at the higher voltage. The meter reads voltage *differences* between its probes. If both probes are connected to the same place the meter reads zero.

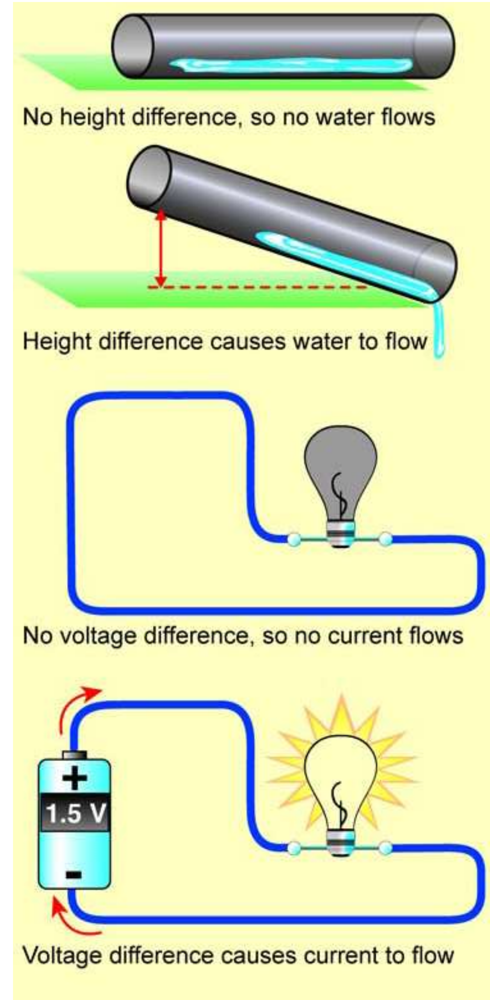


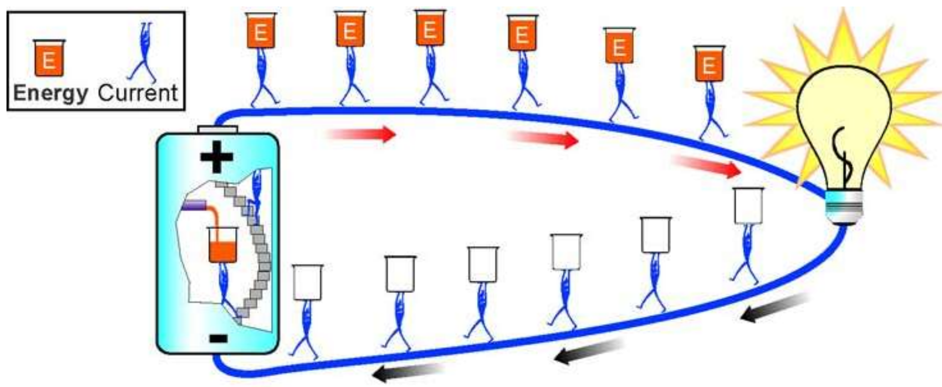
Figure 13.7: *A change in height causes water to flow in a pipe. Current flows in a circuit because a battery creates a voltage difference.*

Table of Contents

Batteries

Batteries

A **battery** uses chemical energy to create a voltage difference between its two terminals. When current leaves a battery, it carries energy. The current gives up its energy as it passes through an electrical device such as a light bulb. When a bulb is lit, the electrical energy is taken from the current and is transformed into light and heat energy. The current returns to the battery, where it gets more energy. You can think of the current as a stream of marching particles each carrying a bucket of energy (diagram below). A 1.5 volt battery means the marchers carry 1.5 joules out of the battery every second (1.5 watts).



Batteries are like pumps

Two water tanks connected with a pump make a good analogy for a battery in a circuit (Figure 13.8). The pump raises up the water, increasing its potential energy. As the water flows down, its potential energy is converted into kinetic energy. In a battery, chemical reactions provide the energy to the current. The current then flows through the circuit carrying the energy to any motors or bulbs. The current gets a "refill" of energy each time it passes through the battery, for as long as the battery's stored energy lasts.

Battery voltage

The voltage of a battery depends on how the battery is made. Household zinc-carbon batteries are 1.5 volts each. Lead acid batteries, like those used in cars, are usually 12 volts. Different voltages can also be made by combining multiple batteries. A flashlight that needs 4.5 volts to light its bulb uses three 1.5 volt batteries (Figure 13.9).

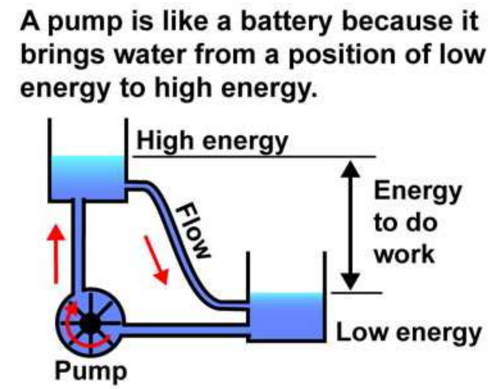


Figure 13.8: *A battery acts like a pump to give energy to flowing electrical current.*

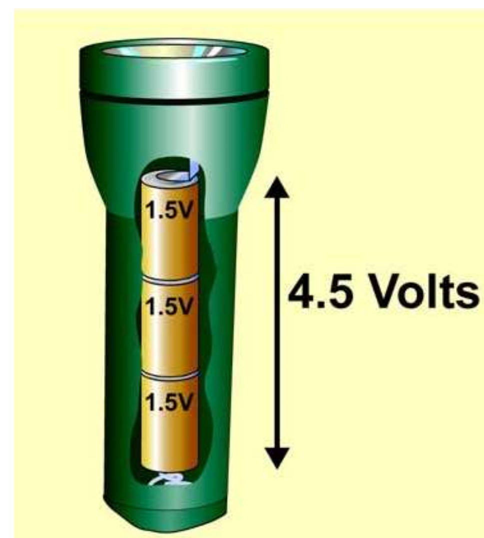


Figure 13.9: *Three 1.5-volt batteries can be stacked to make a total voltage of 4.5 volts c in a flashlight.*

Measuring current in a circuit

Measuring current with a meter

Electric current can be measured with a multimeter. However, if you want to measure current you must force the current to pass *through* the meter. That usually means you must break your circuit somewhere and rearrange wires so that the current must flow through the meter. For example, Figure 13.10 shows a circuit with a battery and bulb. The meter has been inserted into the circuit to measure current. If you trace the wires, the current comes out of the positive end of the battery, through the light bulb, *through the meter*, and back to the battery. The meter in the diagram measures 0.37 amps of current. Some electrical meters, called **ammeters**, are designed specifically to measure only current.

Setting up the meter

If you use a multimeter, you also must remember to set its dial to measure the type of current in your circuit. Multimeters can measure two types of electric current, called alternating current (AC) and direct current (DC). You will learn about the difference between alternating and direct current in Chapter 14. For circuits with light bulbs and batteries, you must set your meter to read direct current, or DC.

Be careful measuring current

The last important thing about measuring current is that the meter itself can be damaged if too much current passes through it. Your meter may contain a *circuit breaker* or *fuse*. Circuit breakers and fuses are two kinds of devices that protect circuits from too much current by making a break that stops the current. A circuit breaker can be reset the way a switch can be flipped. A broken fuse, however, is similar to a burned out light bulb and must be replaced for the meter to work again.

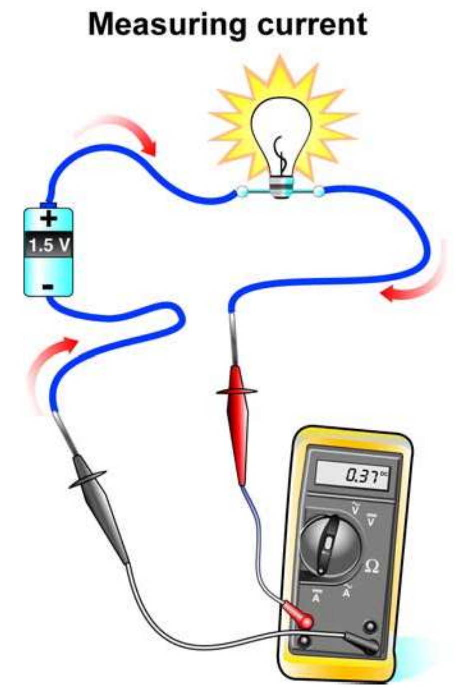


Figure 13.10: *Current must pass through the meter when it is being measured.*

13.2 Section Review

1. List the units for measuring current and voltage.
2. Why does a voltmeter display a reading of zero volts when both of its probes are touched to the same end of a battery?
3. What does a 1.5 V battery give to each amp of current in a circuit?
4. Draw a diagram showing how a meter is connected in a circuit to measure current.

Table of Contents

13.3 Resistance and Ohm's Law

You can apply the same voltage to different circuits and different amounts of current will flow. For example, when you plug in a desk lamp, the current through it is 1 amp. If a hair dryer is plugged into the same outlet (with the same voltage) the current is 10 amps. For a given voltage, the amount of current that flows depends on the *resistance* of the circuit.

Vocabulary

resistance, ohm, Ohm's law, conductor, insulator, semiconductor, potentiometer

Objectives

- ✓ Explain the relationships between current, voltage, and resistance.
- ✓ Use Ohm's law to calculate current, resistance, or voltage.
- ✓ Distinguish between conductors and insulators.

Electrical resistance

Current and resistance

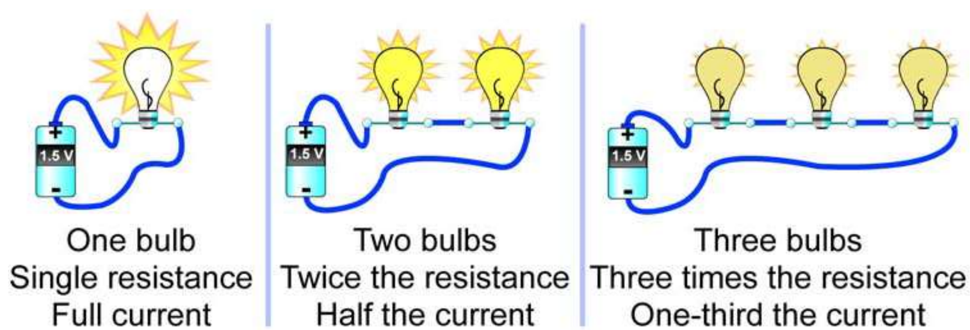
Resistance is the measure of how strongly a wire or other object resists current flowing through it. A device with low resistance, such as a copper wire, can easily carry a large current. An object with a high resistance, such as a rubber band, will only carry a current so tiny it can hardly be measured.

A water analogy

The relationship between electric current and resistance can be compared with water flowing from the open end of a bottle (Figure 13.11). If the opening is large, the resistance is low and lots of water flows out quickly. If the opening is small, the resistance is greater and the water flow is slow.

Circuits

The total amount of resistance in a circuit determines the amount of current in the circuit for a given voltage. Every device that uses electrical energy adds resistance to a circuit. The more resistance the circuit has, the less the current. For example, if you string several light bulbs together, the resistance in the circuit increases and the current decreases, making each bulb dimmer than a single bulb would be.



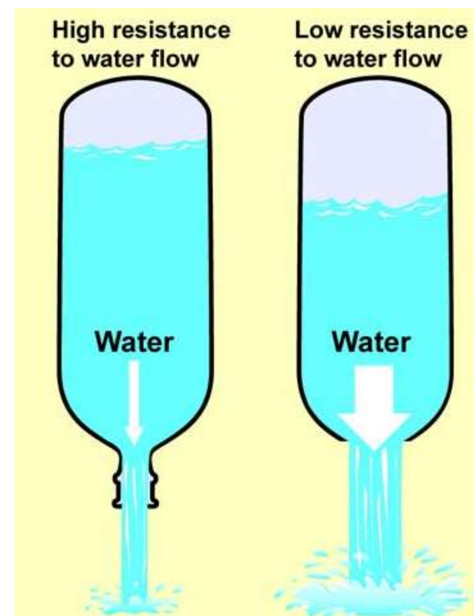
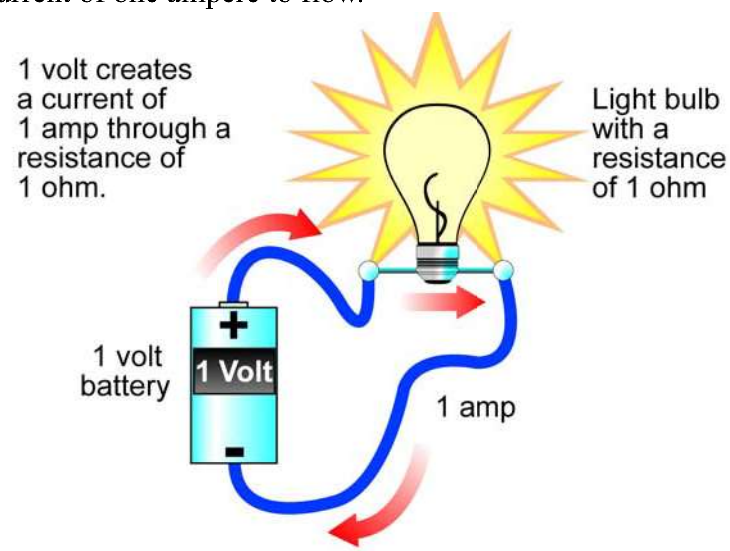


Figure 13.11: *The current is less when the resistance is great.*

Measuring resistance

The ohm Electrical resistance is measured in units called **ohms**. This unit is abbreviated with the Greek letter *omega* (Ω). When you see Ω in a sentence, think or read "ohms." For a given voltage, the greater the resistance, the lesser the current. If a circuit has a resistance of one ohm, then a voltage of one volt causes a current of one ampere to flow.



Resistance of wires The wires used to connect circuits are made of metals such as copper or aluminum that have low resistance. The resistance of wires is usually so low compared with other devices in a circuit that you can ignore wire resistances when measuring or calculating the total resistance. The exception is when there are large currents. If the current is large, the resistance of wires may be important.

Measuring resistance You can use a multimeter to measure the resistance of wires, light bulbs, and other devices (Figure 13.12). You must first remove the device from the circuit. Then set the dial on the multimeter to the resistance setting and touch the probes to each end of the device. The meter will display the resistance in ohms (Ω), kilo-ohms (×1,000 Ω), or mega-ohms (×1,000,000 Ω).

Figure 13.12: *A multimeter can be used to measure resistance of a device that has been completely removed from the circuit.*

How a multimeter measures resistance

A multimeter measures resistance by forcing a precise amount of current to flow through a electrical device. The meter then measures the voltage across the device. The resistance is calculated from the voltage and current. The currents used to measure resistance are typically small, 0.001 amps or less. Any other current through the device interferes with the meter's readings, and that is why a device must be removed from the circuit to measure its resistance.

Table of Contents

Ohm's law

Ohm's law

The current in a circuit depends on the battery's voltage and the circuit's resistance. Voltage and current are *directly* related. Doubling the voltage doubles the current. Resistance and current are *inversely* related. Doubling the resistance cuts the current in half. These two relationships form **Ohm's law**. The law relates current, voltage, and resistance with one formula. If you know two of the three quantities, you can use Ohm's law to find the third.

Equation	. . . gives you . . .	. . . if you know . . .
$I = V \div R$	current (I)	voltage and resistance
$V = I \times R$	voltage (V)	current and resistance
$R = V \div I$	resistance (R)	voltage and current

Ohm's law

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

Current (amps, A) → I

V ← *Voltage* (volts, V)

R ← *Resistance* (ohms, Ω)

Using Ohm's law

A toaster oven has a resistance of 12 ohms and is plugged into a 120-volt outlet. How much current does it draw?

1. Looking for: You are asked for the current in amperes.

2. Given: You are given the resistance in ohms and voltage in volts.

3. Relationships: Ohm's law: $I = \frac{V}{R}$

4. Solution: Plug in the values for V and R: $I = \frac{120\ \text{V}}{12\ \Omega} = 10\ \text{A}$

a. A laptop computer runs on a 24-volt battery. If the resistance of the circuit inside is 16 ohms, how much current does it use? **Answer:** 1.5 A

b. A motor in a toy car needs 2 amps of current to work properly. If the car runs on four 1.5-volt batteries, what is the motor's resistance? **Answer:** 3 ohms

The resistance of common objects

Resistance of common devices

The resistance of electrical devices ranges from small (0.001 Ω) to large (10×10^6 Ω). Every electrical device is designed with a resistance that causes the right amount of current to flow when the device is connected to the proper voltage. For example, a 60 watt light bulb has a resistance of 240 ohms. When connected to 120 volts from a wall socket, the current is 0.5 amps and the bulb lights (Figure 13.13).

Resistances match operating voltage

If you connect the same light bulb to a 1.5-volt battery it will not light because not enough current flows. According to Ohm's law, the current is only 0.00625 amps when 1.5 volts is applied to a resistance of 240 Ω. This amount of current at 1.5 volts does not carry enough power to make the bulb light. All electrical devices are designed to operate correctly at a certain voltage.

The resistance of skin

Electrical outlets are dangerous because you can get a fatal shock by touching the wires inside. So why can you safely handle a 9 V battery? The reason is Ohm's law. Remember, current is what flows and carries power. The typical resistance of dry skin is 100,000 ohms or more. According to Ohm's law, 9 V ÷ 100,000 Ω is only 0.00009 amps. This is not enough current to be harmful. On average, nerves in the skin can feel a current of around 0.0005 amps. You can get a dangerous shock from 120 volts from a wall socket because that is enough voltage to force 0.0012 amps (120 V ÷ 100,000 Ω) through your skin, more than twice the amount you can feel.

Water lowers skin resistance

Wet skin has much lower resistance than dry skin. Because of the lower resistance, the same voltage will cause more current to pass through your body when your skin is wet. The combination of water and 120-volt electricity is especially dangerous because the high voltage and lower resistance make it possible for large (possibly fatal) currents to flow.

Changing resistance

The resistance of many electrical devices varies with temperature and current. For example, a light bulb's resistance increases when there is more current through the bulb. This change occurs because the bulb gets hotter when more current passes through it. The resistance of many materials, including those in light bulbs, increases as temperature increases.

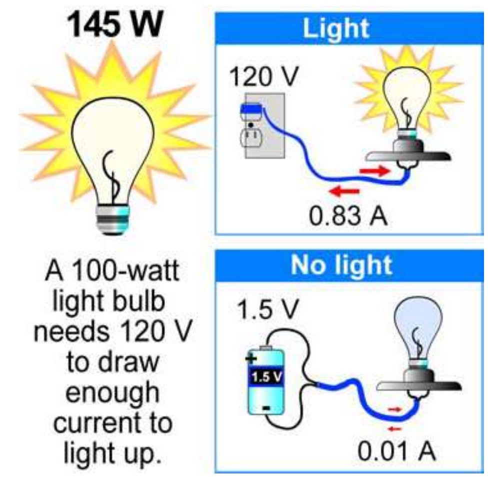


Figure 13.13: *A light bulb designed for use in a 120-volt household circuit does not light when connected to a 1.5-volt battery.*

Conductors and insulators

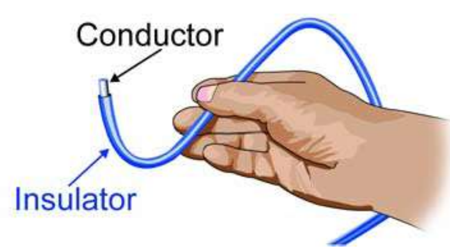
Conductors Current passes easily through some materials, such as copper, which are called conductors. A **conductor** can *conduct*, or carry, electric current. The electrical resistance of wires made from conductors is low. Most metals are good conductors.

Insulators Other materials, such as rubber, glass, and wood, do not allow current to easily pass through them. These materials are called **insulators**, because they insulate against, or block, the flow of current.

Semiconductors Some materials are in between conductors and insulators. These materials are called **semiconductors** because their ability to carry current is higher than an insulator but lower than a conductor. Computer chips, televisions, and portable radios are among the many devices that use semiconductors. You may have heard of a region in California called "Silicon Valley." Silicon is a semiconductor commonly used in computer chips. An area south of San Francisco is called Silicon Valley because there are many semiconductor and computer companies located there.

Comparing materials No material is a perfect conductor or insulator. Some amount of current will always flow in any material if a voltage is applied. Even copper (a good conductor) has some resistance. Figure 13.14 shows how the resistances of various conductors, semiconductors, and insulators compare.

Applications of conductors and insulators Both conductors and insulators are necessary materials in human technology. For example, a wire has one or more conductors on the inside and an insulator on the outside. An electrical cable may have twenty or more conductors, each separated from the others by a thin layer of insulator. The insulating layer prevents the other wires or other objects from being exposed to the current and voltage carried by the conducting core of the wire.



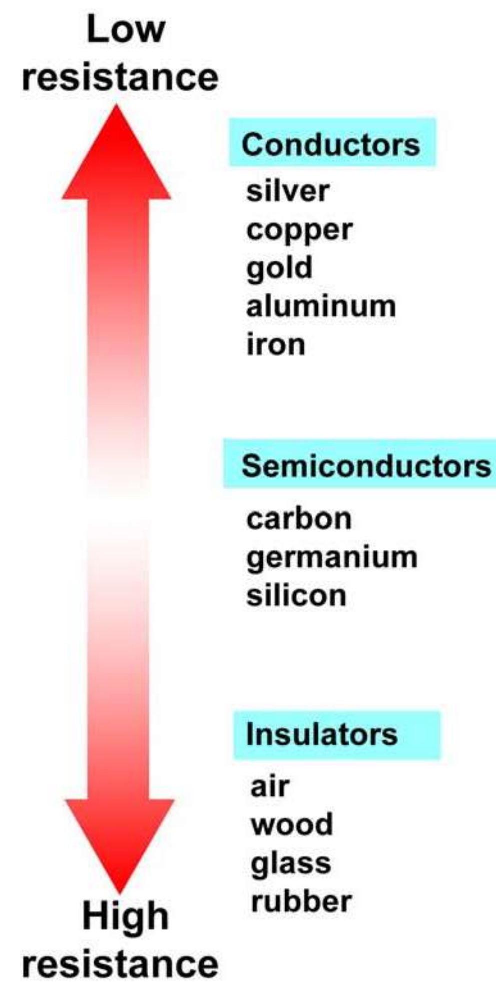


Figure 13.14: *Comparing the resistances of materials.*

Resistors

Resistors are used to control current

Resistors are electrical components that are designed to have a specific resistance that remains the same over a wide range of currents. Resistors are used to control the current in circuits. They are found in many common electronic devices such as computers, televisions, telephones, and stereos.

Fixed resistors

There are two main types of resistors, fixed and variable. Fixed resistors have a resistance that cannot be changed. If you have ever looked at a circuit board inside a computer or other electrical device, you have seen fixed resistors. They are small skinny cylinders or rectangles with colored stripes on them. Because resistors are so tiny, it is impossible to label each one with the value of its resistance in numbers. Instead, the colored stripes are a code that tells you the resistance (Figure 13.15).

Variable resistors

Variable resistors, also called **potentiometers**, can be adjusted to have a resistance within a certain range. If you have ever turned a dimmer switch or volume control, you have used a potentiometer. When the resistance of a dimmer switch increases, the current decreases, and the bulb gets dimmer. Inside a potentiometer is a circular resistor and a little sliding contact called a wiper (Figure 13.16). If the circuit is connected at A and C, the resistance is always 10 Ω. But if the circuit is connected at A and B, the resistance can vary from 0 Ω to 10 Ω. Turning the dial changes the resistance between A and B and also changes the current (or voltage) in the circuit.

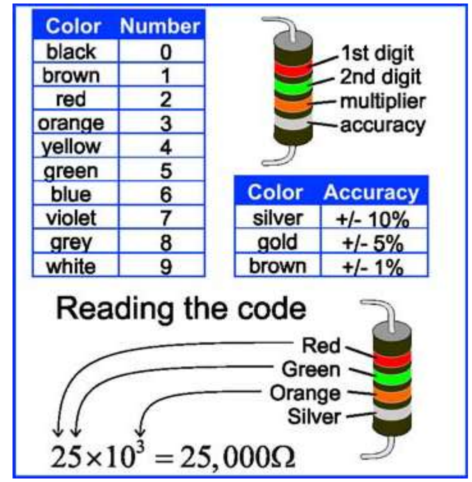


Figure 13.15: *The color code for resistors.*

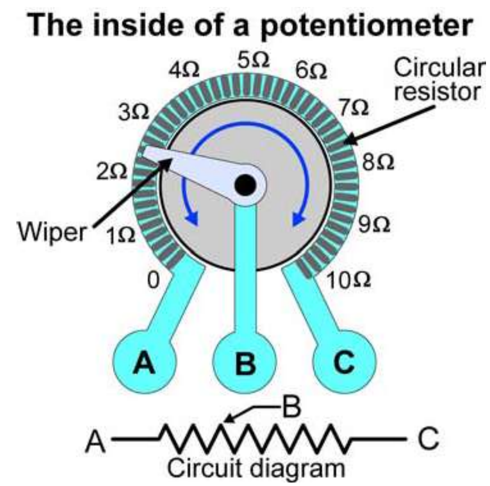


Figure 13.16: *The resistance of this potentiometer can vary from 0 Ω to 10 Ω.*

13.3 Section Review

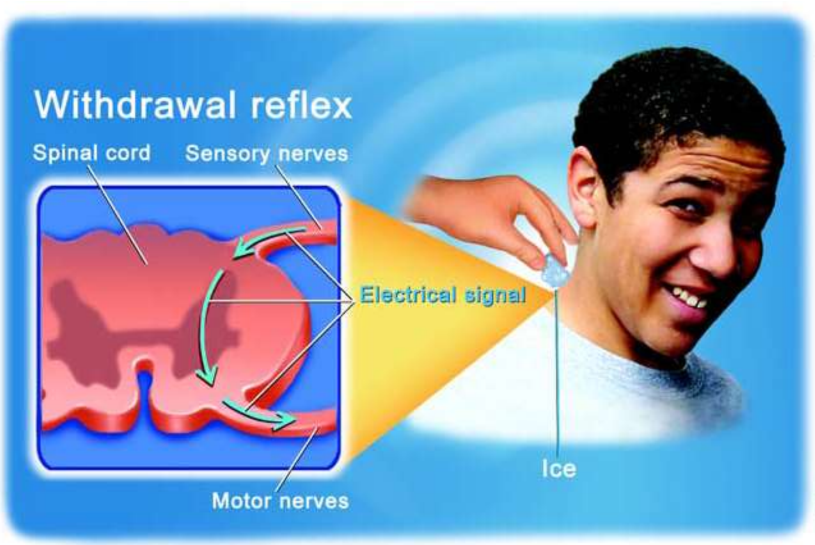
1. What happens to the current if a circuit's resistance increases? What if the voltage increases instead?
2. List the units used to measure resistance, voltage, and current. Then give the abbreviation for each unit.
3. Classify as a conductor, semiconductor, or insulator each of the following: air, gold, silicon, rubber, aluminum.

Electric Circuits in Your Body

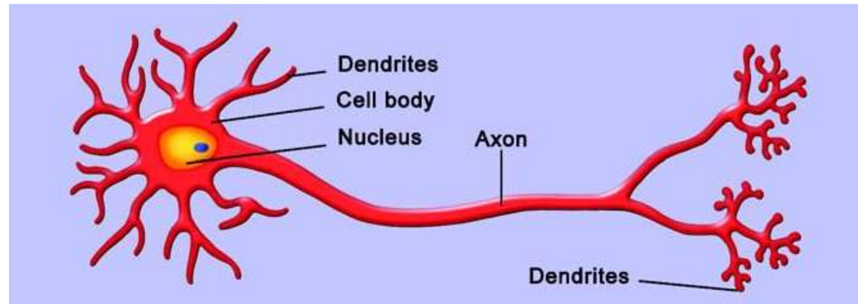
Imagine you're relaxing on the couch, watching your favorite television show. You're so absorbed in the action that you fail to notice your younger sister sneaking up behind you. Suddenly she reaches over the back of the couch and touches the back of your neck with a wet, frosty ice cube.

Before you even have a chance to think "who did that?" your body springs into action. The ice cube triggers a *withdrawal reflex* that happens automatically, without a conscious decision on your part.

A withdrawal reflex happens because electrical signals are sent through "circuits" in your body. When an ice cube touches the back of your neck, an electrical signal is sent through wire-like nerve fibers to your spinal cord. In the spinal cord, the signal is transferred to nerve fibers that control the muscles in your neck and shoulders, causing them to contract, jerking your body away from the ice cube. All of this happens in a split second!



Your body sends electrical signals using specialized cells called neurons. A neuron has three basic parts: the cell body, a long stalk called the axon, and finger-like projections called dendrites.



Unlike the components of a wire-and-battery circuit, most neurons don't touch one another. Instead, as the electrical signal reaches the end of the axon, a chemical is released. The chemical is picked up by receptors on another cell's dendrite. The dendrite then activates its own cell body to continue sending the signal through its axon.

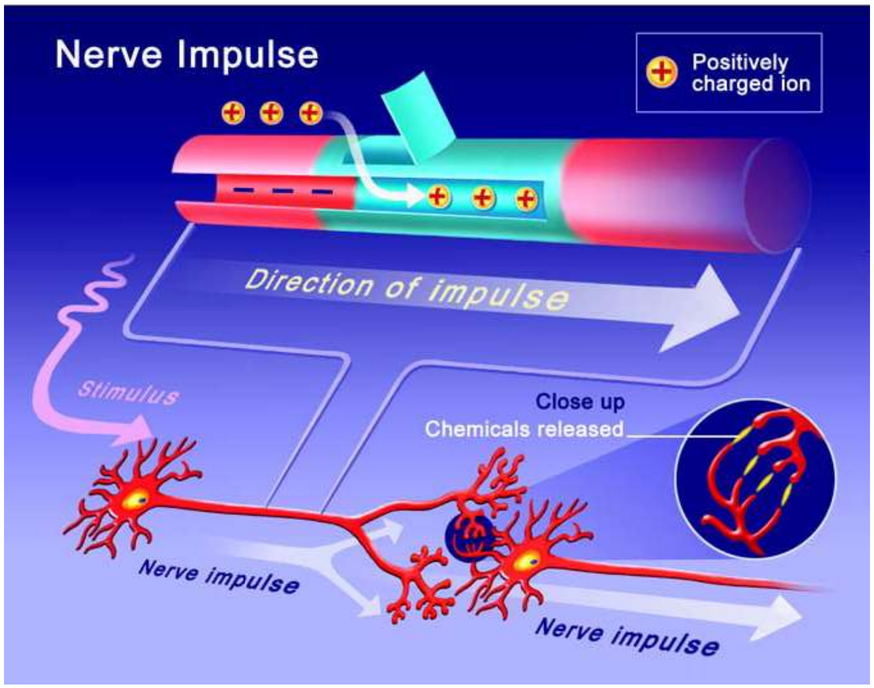
Nerve impulse: a wave of electrical changes

A withdrawal reflex starts when sensory neurons in your skin receive some kind of stimulus from outside the body. In our example, the stimulus is a change in temperature caused by the ice cube. That stimulus starts a wave of electrical change called a nerve impulse along the cell membrane.

When a neuron is at rest, the inside of the cell membrane is electrically negative compared with the outside. A nerve impulse works like this:

1. The outside stimulus causes the cell membrane to open tiny channels that let positively-charged ions into the cell. The inside of the cell becomes positively charged relative to the outside.

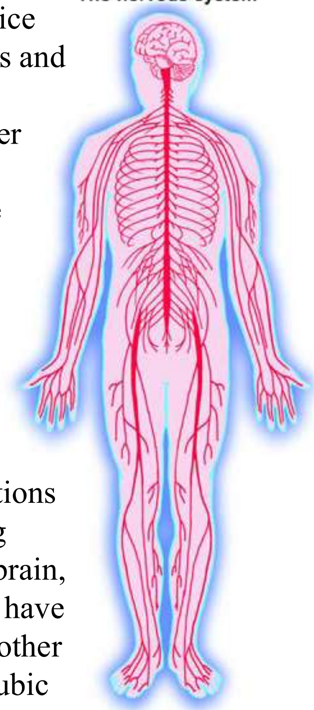
2. Other channels open and let positively-charged ions out of the cell. As the ions leave, the inside the cell membrane once again becomes negatively-charged compared with the outside.
3. The nerve impulse travels down the axon like dominoes falling. When the impulse reaches the end of the axon, chemicals are released and picked up by an adjacent neuron, causing the nerve impulse to continue.



Your complex nervous system

The withdrawal reflex takes only a fraction of a second. In fact, the signal travels from the sensory nerve to the spinal cord and out to the nerves that control your muscles at about 250 miles per hour!

It's unlikely, however, that the withdrawal reflex would be your only response to the ice cube. Sensory neurons located in your eyes and ears would send messages to your brain as you turn to see and hear your sister scamper away. Your brain processes these in milliseconds, and billions of neurons there are activated as you decide how best to respond. Maybe you feel annoyed and chase after her with an ice cube of your own. Or you might just laugh at the clever way she "paid you back" for an earlier prank.



Your emotions, decisions, and physical actions all happen through nerve impulses sending electrical signals through neurons in your brain, spinal cord and body. A single neuron can have up to ten thousand dendrites connecting to other neurons, and it is estimated that just one cubic millimeter of brain tissue contains a billion connections between cells. Each second, your body fires off about five trillion nerve impulses, making possible all the things that make us human: thoughts, memories, decisions, emotions, and actions.

Questions:

1. Describe the similarities and differences between an electric circuit and the human nervous system.
2. How is an electrical signal sent in a nerve impulse?
3. Why are chemical signals necessary to keep a nerve impulse traveling through nerve fibers?

Table of Contents

Chapter 13 Review

Understanding Vocabulary

Select the correct term to complete the sentences.

ohm	electric current	conductor
closed circuit	voltage	electrical symbols
resistance	potentiometer	battery
ampere	resistor	Ohm's law
switch	volt	open circuit

Section 13.1

1. _____ is what flows and carries power in a circuit.
2. _____ are used when drawing circuit diagrams.
3. A _____ is used to create a break in a circuit.
4. A(n) _____ has a break it, so there is no current.
5. A _____ has a complete path for the current and contains no breaks.
6. A light bulb, motor, or speaker acts as a _____ in a circuit.

Section 13.2

7. The unit for current is the _____.
8. A _____ provides voltage to a circuit.
9. _____ is the difference in the amount of energy carried by current at two points in a circuit.
10. The _____ is the unit for measuring voltage.

Section 13.3

11. The _____ is the unit for measuring resistance.
12. _____ explains the relationship between current, voltage, and resistance in a circuit.
13. _____ is the measure of how strongly a material resists current.
14. A _____ has a resistance that can be changed.
15. Wires in a circuit are made of a material that is a _____, such as copper.

Reviewing Concepts

Section 13.1

1. How are electric circuits and systems for carrying water in buildings similar?
2. Give one example of a circuit found in nature and one example of a circuit created by people.
3. Why are symbols used in circuit diagrams?
4. Draw the electrical symbol for each of the following devices.
   a. battery
   b. resistor
   c. switch
   d. wire
5. List three devices that could be a resistor in a circuit.
6. List two sources of energy that a circuit might use and give an example of a circuit that uses each type.
7. Will a bulb light if it is in an open circuit? Why?
8. Is flipping a switch the only way to create an open circuit? Explain.

Section 13.2

9. The direction of electric current in a circuit is away from the _____ end of the battery and toward the _____ end.
10. How are voltage and energy related?
11. A voltage of one volt means one _____ of _____ does one _____ of work in one second.
12. Explain how a battery in a circuit is similar to a water pump.
13. What are the differences between a multimeter, a voltmeter, and an ammeter?
14. Suppose you have a closed circuit containing a battery that is lighting a bulb. Why must you first create a break in the circuit before using an ammeter to measure the current?

Section 13.3

15. The greater the resistance in a circuit, the less the _____.

16. A circuit contains one light bulb and a battery. What happens to the total resistance in the circuit if you replace the one light bulb with a string of four identical bulbs? Why?
17. What is the unit for resistance? What symbol is used to represent this unit?
18. What does is mean to say that current and resistance in a circuit are inversely related?
19. What does it mean to say that current and voltage in a circuit are directly related?
20. According to Ohm's law, the current in a circuit increases if the _____ increases. The current decreases if the _____ increases.
21. A battery is connected to a light bulb, creating a simple circuit. Explain what will happen to the current in the circuit if
    a. the bulb is replaced with a bulb having a higher resistance.
    b. the bulb is replaced with a bulb having a lower resistance.
    c. the battery is replaced with a battery having a greater voltage.
22. Why does a light bulb's resistance increase if it is left on for a period of time?
23. Why can you safely handle a 1.5-V battery without being electrocuted?
24. What is the difference between a conductor and an insulator?
25. Why is it important to always have dry hands when working with electric circuits?
26. Explain why electrical wires are made of copper covered in a layer of plastic.
27. What is a semiconductor?
28. Classify each of the following as a conductor, semiconductor, or insulator.
    a. copper
    b. plastic
    c. rubber
    d. silicon
    e. iron
    f. glass
29. What is the difference between a fixed resistor and a variable resistor?
30. What is another name for a variable resistor?

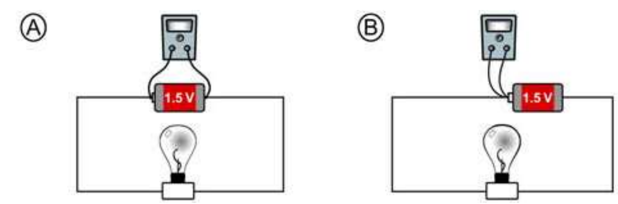
Solving Problems

Section 13.1

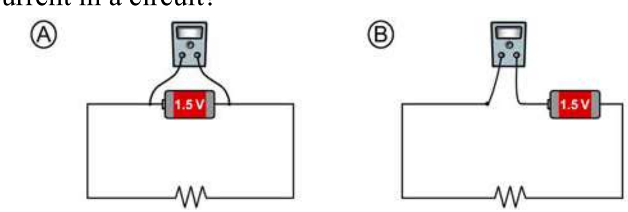
1. Draw a circuit diagram of a circuit with a battery, three wires, a light bulb, and a switch.

Section 13.2

2. What voltage would the electrical meter show in each of the diagrams below?



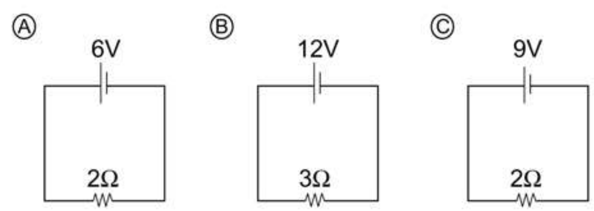
3. Which of the following diagrams shows the correct way to measure current in a circuit?



4. A portable radio that runs on AA batteries needs 6 volts to work properly. How many batteries does it use?

Section 13.3

5. What happens to the current in a circuit if the resistance doubles? What if the resistance triples?
6. What happens to the current in a circuit if the voltage doubles? What if it triples?
7. A hair dryer draws a current of 10 A when plugged into a 120 V outlet. What is the resistance of the hair dryer?
8. A television runs on 120 volts and has a resistance of 60 ohms. What current does it draw?
9. A digital camera uses one 6 V battery. The circuit that runs the flash and takes the pictures has a resistance of 3 ohms. What is the current in the circuit?
10. The motor in a toy car has a resistance of 3 ohms and needs 1.5 amperes of current to run properly.
    a. What battery voltage is needed?
    b. How many AA batteries would the car require?
11. Find the current in each of the circuits shown below.



12. Household circuits in the United States run on 120 volts of electricity. Circuit breakers commonly break a circuit if the current is greater than 15 amperes. What is the minimum amount of resistance needed in a circuit to prevent the circuit breaker from activating?
13. A flashlight bulb has a resistance of approximately 6 ohms. It works in a flashlight with two C batteries. How much current is in the flashlight's circuit when the bulb is lit?

Applying Your Knowledge

Section 13.1

1. Write a paragraph explaining how your life would be different if electricity didn't exist.
2. Research Benjamin Franklin's experiments with electricity. Make a poster that describes one of his experiments.

Section 13.2

3. Brain and nerve cells communicate through the movement of charged chemicals that create electrical currents. Some conditions, such as epilepsy, occur because these currents are sometimes present when they shouldn't be. Research electrical currents in the body and problems that occur when the body's circuits don't work properly.
4. Ask an adult to show you the circuit breaker box in your home. Does it contain switches or fuses? How many?
5. There are many different kinds of batteries in use today. Research to answer following questions.
    a. Are all 1.5 volt household batteries the same on the inside?
    b. Why can some 1.5 batteries be recharged and used over and over again?
    c. Which type of batteries is used in portable electronics such as cell phones and laptop computers?
6. Do an experiment in which you determine whether more expensive household batteries last longer than cheaper ones. Why is it important to test the batteries in the same electrical device and to use it in the same way each time?

Section 13.3

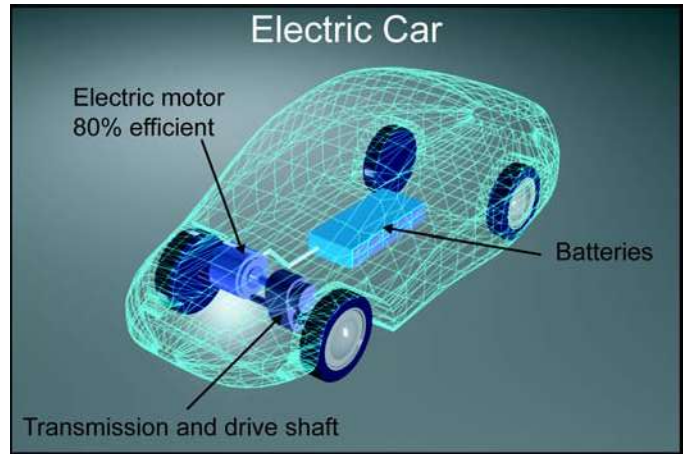
7. Look on the back or underside of different appliances in your home to find information about the current and voltage each uses. Find two appliances that list the current and voltage. Calculate the resistance of each.

Table of Contents

Chapter 14

Electrical Systems

You may recognize the abbreviations AC and DC. There is a classic rock music group called AC/DC that has helped to make the acronym famous. Did you know that in the late 1800's, a major disagreement over the use of AC and DC methods for transmitting electricity erupted between two famous inventors?



Thomas Edison favored the direct current (DC) method of moving electrical energy from electrical generation stations to homes and buildings. George Westinghouse argued that the alternating current (AC) method worked better. The feud became quite public, as each inventor tried to win support. The DC method works well over short distances, as between buildings in a densely populated city. AC works well over long distances but uses higher voltages than DC technology. Edison used some morbid methods for demonstrating his views of the danger involved with high voltage electrical transmission through his opponent's AC method.

Which inventor won the AC/DC debate? Does the United States rely on AC or DC technology for transmitting electrical energy? In this chapter, you will find out how our country distributes electricity, what the difference is between AC and DC current. You will also learn how electricity is "purchased" and paid for, as well as how simple electrical circuits are constructed and how they work.

Key Questions

- ✓ Why does a string of inexpensive holiday lights stop working when one bulb burns out?
- ✓ What is a "short circuit", and why can it be dangerous?
- ✓ How is electricity generated, and how does it get to your house?

14.1 Series Circuits

We use electric circuits for thousands of things from flashlights to computers to cars to satellites. There are two basic ways circuits can be built to connect different devices. These two types of circuits are called *series* and *parallel*. Series circuits have only one path for the current. Parallel circuits have branching points and multiple paths for the current. This section discusses series circuits. You will learn about parallel circuits in the next section.

Vocabulary

series circuit, voltage drop, Kirchhoff's voltage law

Objectives

- ✓ Describe a series circuit.
- ✓ Calculate the resistance and current in a series circuit.
- ✓ Explain how the voltage changes across each resistor in a series circuit.

What is a series circuit?

A series circuit has one path

A **series circuit** contains only one path for electric current to flow. That means the current is the same at all points in the circuit. All the circuits you have studied so far have been series circuits. For example, a battery, three bulbs, and a switch connected in a loop form a series circuit because there is only one path through the circuit (Figure 14.1). The current is the same in each bulb, so they are equally bright.

A series circuit has only one path for the current so the current is the same at any point in the circuit.

Stopping the current

If there is a break at any point in a series circuit, the current will stop everywhere in the circuit. Inexpensive strings of holiday lights are wired with the bulbs in series. When one bulb burns out, the current stops and none of the bulbs will light until the bad bulb is replaced. The lights are connected this way because it requires the least amount of wire and therefore costs the least to manufacture.

Using series circuits

There are times when devices are connected in series for specific purposes. On-off switches are placed in series with the other components in most electrical devices. When a switch is turned to the off position, it breaks the circuit and stops current from reaching all of the components in series with the switch. Dimmer switches placed in series with light bulbs adjust the brightness by changing the amount of current in the circuit.

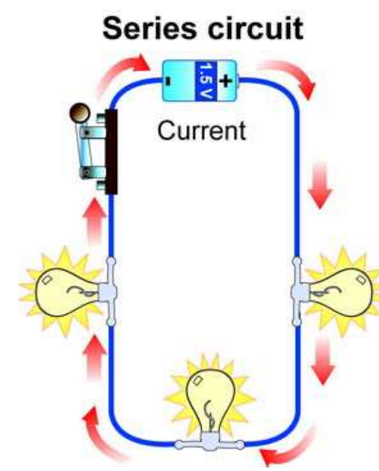


Figure 14.1: *Three bulbs, a battery, and a switch are connected in series.*

Current and resistance in a series circuit

Use Ohm's law You can use Ohm's law to calculate the current in a circuit if you know the voltage and resistance. If you are using a battery you know the voltage from the battery. If you know the resistance of each device, you can find the total resistance of the circuit by adding up the resistance of each device.

Adding resistances You can think of adding resistances like adding pinches to a hose (Figure 14.2). Each pinch adds some resistance. The total resistance is the sum of the resistances from each pinch. To find the total resistance in a series circuit, you add the individual resistances.

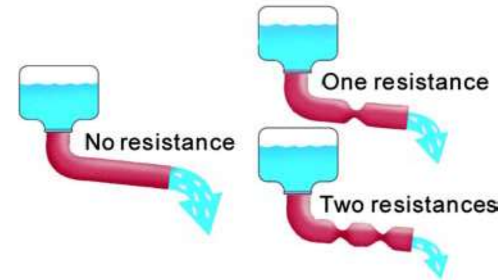


Figure 14.2: *Adding resistors in a circuit is like adding pinches in a hose. The greater the number of pinches or resistors, the greater the resistance to current.*

ADDING RESISTANCES IN SERIES

$$\underbrace{R_{total}}_{\text{Total resistance }(\Omega)} = \underbrace{R_1 + R_2 + R_3 + \cdots}_{\text{Individual resistances }(\Omega)}$$

Ignoring resistances Everything has some resistance, even wires. However, the resistance of a wire is usually so small compared with the resistance of light bulbs and other devices that we can ignore the resistance of the wire.

Calculating current

A series circuit contains a 12-V battery and three bulbs with resistances of 1Ω, 2 Ω, and 3 Ω. What is the current in the circuit?

1. Looking for: You are asked for the current in amps.

2. Given: You are given the voltage in volts and resistances in ohms.

3. Relationships: $R_{tot}=R_1+R_2+R_3$ Ohm's law: $I=V/R$

4. Solution: $R_{tot} = 1\ \Omega + 2\ \Omega + 3\ \Omega = 6\ \Omega$ $I = (12\text{ V})/(6\ \Omega) = 2\text{ A}$

Your turn...

a. A string of 5 lights runs on a 9-V battery. If each bulb has a resistance of 2 Ω, what is the current? **Answer:** 0.9 A

b. A series circuit operates on a 6-V battery and has two 1 Ω resistors. What is the current? **Answer:** 3 A

Energy and voltage in a series circuit

Energy changes forms

Energy cannot be created or destroyed. The devices in a circuit convert electrical energy carried by the current into other forms of energy. As each device uses power, the power carried by the current is reduced. As a result, the *voltage gets lower after each device that uses power*. This is known as the **voltage drop**. The voltage drop is the difference in voltage across an electrical device that has current flowing through it.

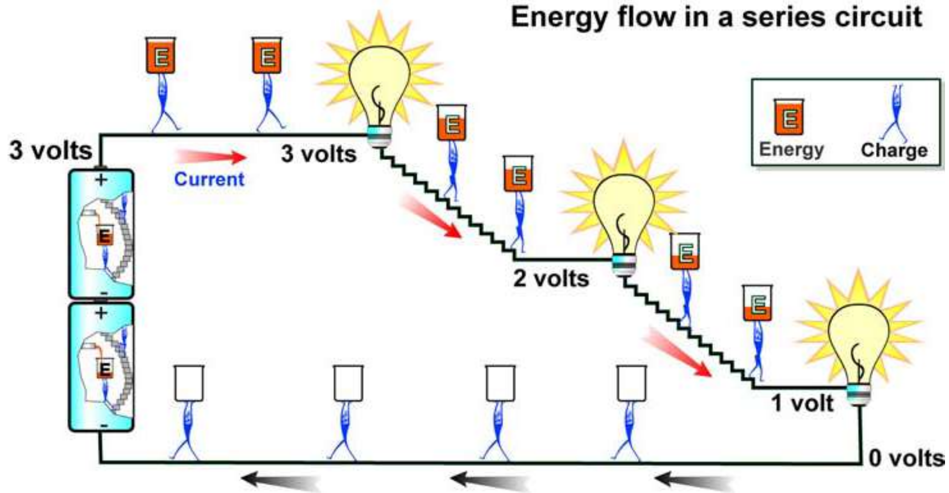
Charges lose their energy

Consider a circuit with three bulbs and two batteries. The voltage is 3 V so each amp of current leaves the battery carrying 3 watts. As the current flows through the circuit, each bulb changes 1/3 of the power into light and heat. Because the first bulb uses 1 watt, the voltage drops from 3 V to 2 V as the current flows through the first bulb. Remember, the current in a series circuit is the same everywhere! As power gets used, the voltage gets lower.

Voltage

If the three bulbs are identical, each gives off the same amount of light and heat. Each uses the same amount of power. A meter will show the voltage drop from 3 volts to 2 volts to 1 volt, and finally down to zero volts after the last bulb. After passing through the last bulb, the current returns to the battery where it is given more power and the cycle starts over.

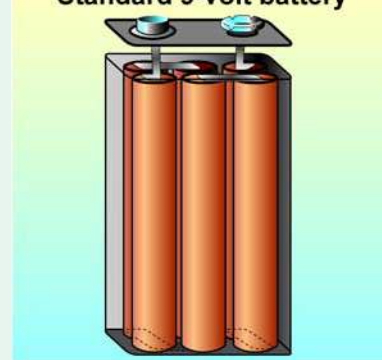
Energy flow in a series circuit



Batteries and cells

You may have heard a D battery called a "D cell." The terms "battery" and "cell" are often used interchangeably. However, technically there is a difference between the two. Cells are the building blocks of batteries; AAA, AA, C, and D batteries each contain a single 1.5- volt cell. A chemical reaction inside a cell supplies electric current to devices connected to it.

Standard 9-volt battery



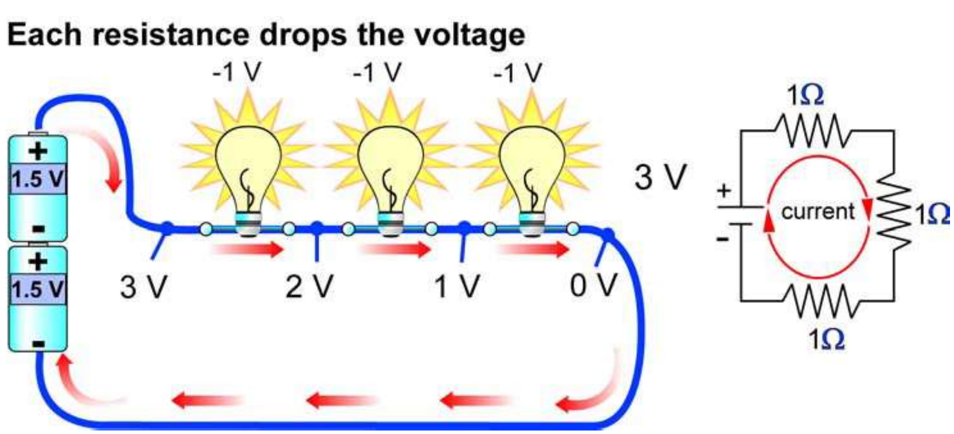
A 9-volt battery like the kind used in smoke detectors contains six tiny 1.5-volt cells connected in series. Each cell adds 1.5 volts to the total. You can make 9V yourself by connecting six 1.5V batteries. Can you figure out how to connect them?

Voltage drops and Ohm's law

Voltage drops Each separate bulb or resistor creates a voltage drop. The voltage drop across a bulb is measured by connecting an electrical meter's leads at each side of the bulb (Figure 14.3). The greater the voltage drop, the greater the amount of power being used per amp of current flowing through the bulb.

Ohm's law The voltage drop across a resistance is determined by Ohm's law in the form $V = IR$. The voltage drop (V) equals the current (I) multiplied by the resistance (R) of the device. In a series circuit, the current is the same at all points, but devices may have different resistances. In the circuit below each bulb has a resistance of 1 ohm, so each has a voltage drop of 1 volt when 1 amp flows through the circuit.

Applying Kirchhoff's law In the circuit below, three identical bulbs are connected in series to two 1.5-volt batteries. The total resistance of the circuit is 3Ω. The current flowing in the circuit is 1 amp ($I = 3\text{V} \div 3\Omega$). Each bulb creates a voltage drop of 1 volt ($\text{V} = \text{IR} = 1\ \text{A} \times 1\Omega$). The total of all the voltage drops is 3 V, which is the same as the voltage of the battery.



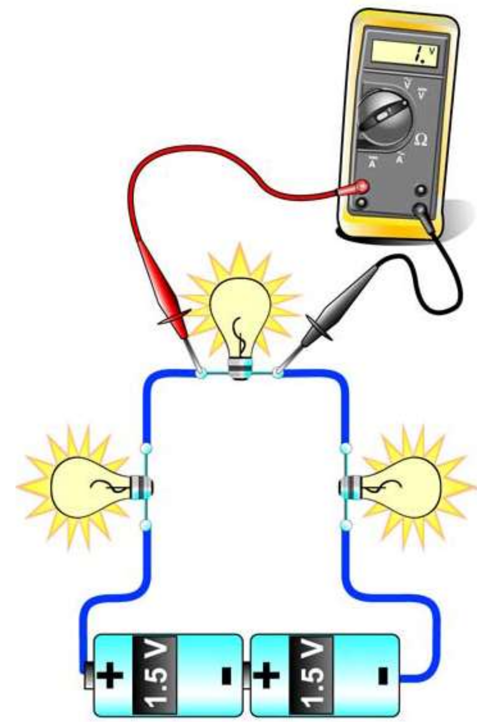


Figure 14.3: *Using a multimeter to measure the voltage drop across a bulb in a circuit.*

Energy conservation The law of conservation of energy also applies to a circuit. Over the entire circuit, the power used by all the bulbs must equal the power supplied by the battery. This means the total of all the voltage drops must add up to the battery's voltage. This rule is known as **Kirchhoff's voltage law**, after German physicist Gustav Robert Kirchhoff (1824-87).

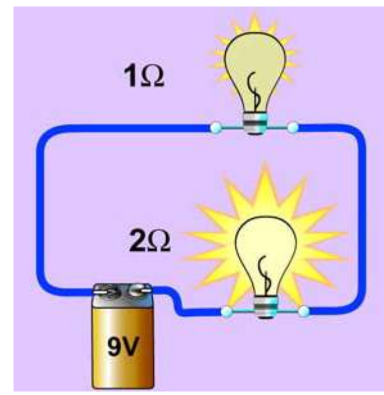
Solving series circuit problems

Unequal resistances

Ohm's law is especially useful in series circuits where the devices do *not* have the same resistance. A device with a larger resistance has a greater voltage drop. However, the sum of all the voltage drops must still add up to the battery's voltage. The example below shows how to find the voltage drops in a circuit with two different light bulbs.

Calculating voltage drops

The circuit shown at right contains a 9-volt battery, 1-ohm bulb, and a 2-ohm bulb. Calculate the circuit's total resistance and current. Then find each bulb's voltage drop.



1. Looking for: You are asked for the total resistance, current, and voltage drops.

2. Given: You are given the battery's voltage and the resistance of each bulb.

3. Relationships: Total resistance in a series circuit: $R_{tot} = R_1 + R_2$
Ohm's law: $I = V/R$ or $V = IR$

4. Solution: Calculate the total resistance: $R_{tot} = 1\ \Omega + 2\ \Omega = 3\ \Omega$
Use Ohm's law to calculate the current:
$I = (9\ V)/(3\ \Omega) = 3\ A$
Use Ohm's law to find the voltage across the 1 Ω bulb:
$V = (3\ A)(1\ \Omega) = 3\ V$
Use Ohm's law to find the voltage across the 2 Ω bulb:
$V = (3\ A)(3\ \Omega) = 6\ V$

Your turn...

a. The battery in the circuit above is replaced with a 12-volt battery. Calculate the new current and bulb voltages.
Answer: 4 A, 4 V across 1 Ω bulb, 8 V across 2 Ω bulb

b. A 12-volt battery is connected in series to 1 Ω and 5 Ω bulbs. What is the voltage across each bulb? **Answer:** 2 V, 10 V

14.1 Section Review

1. What do you know about the current at different points in a series circuit?
2. Three bulbs are connected in series with a battery and a switch. Do all of the bulbs go out when the switch is opened? Explain.
3. What happens to a circuit's resistance as more resistors are added in series?
4. A series circuit contains a 9-volt battery and three identical bulbs. What is the voltage drop across each bulb?

14.2 Parallel Circuits

It would be a real problem if your refrigerator went off when you turned out the light! That is why houses are wired with parallel circuits instead of series circuits. Parallel circuits provide each device with a separate path back to the power source. This means each device can be turned on and off independently from the others. It also means that each device sees the full voltage of the power source without voltage drops from other devices.

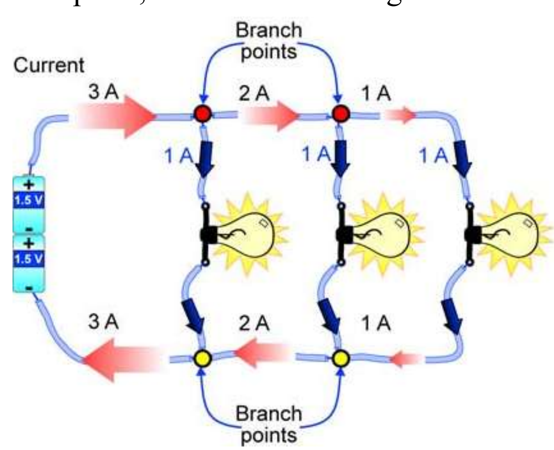
What is a parallel circuit?

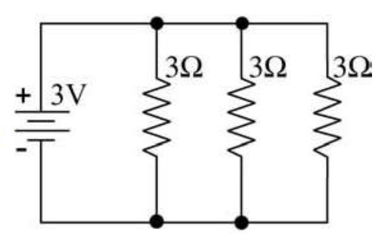
Parallel branches

A **parallel circuit** is a circuit with more than one path for the current. Each path in the circuit is sometimes called a *branch*. The current through a branch is also called the *branch current*. The current supplied by the battery in a parallel circuit splits at one or more branch points.

Example: three bulbs in parallel

All of the current entering a branch point must exit again. This rule is known as **Kirchhoff's current law** (Figure 14.4). For example, suppose you have three identical light bulbs connected in parallel as shown below. The circuit has two branch points where the current splits (red dots). There are also two branch points where the current comes back together (yellow dots). You measure the branch currents and find each to be 1 amp. The current supplied by the battery is the sum of the three branch currents, or 3 amps. At each branch point, the current entering is the same as the current leaving.





Vocabulary

parallel circuit, Kirchhoff's current law, short circuit

Objectives

- ✓ Describe how current divides in a parallel circuit.
- ✓ Determine the voltage across and current through each branch of a parallel circuit.
- ✓ Explain why circuit breakers and fuses are used in homes.

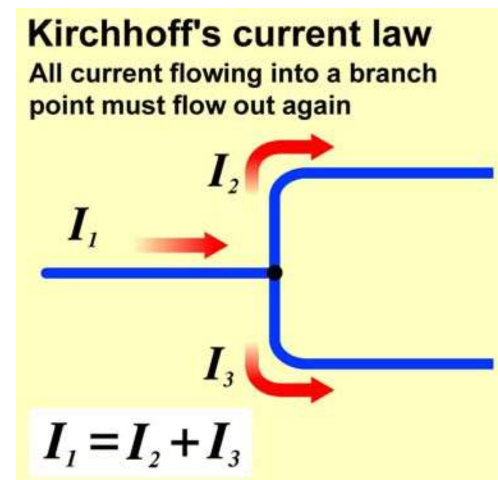


Figure 14.4: *All the current entering a branch point in a circuit must also exit the point.*

Voltage and current in a parallel circuit

Each branch has the same voltage

The voltage is the same anywhere along the same wire. This is true as long as the resistance of the wire itself is very small compared to the rest of the circuit. If the voltage is the same along a wire, then the *same voltage appears across each branch of a parallel circuit.* This is true even when the branches have different resistances (Figure 14.5). Both bulbs in this circuit see 3 V from the battery since each is connected back to the battery by wires without any other electrical devices in the way.

The voltage is the same across each branch of a parallel circuit.

Parallel circuits have two big advantages over series circuits.

1. Each device in the circuit has a voltage drop equal to the full battery voltage.
2. Each device in the circuit may be turned off independently without stopping the current in the other devices in the circuit.

Parallel circuits in homes

Parallel circuits need more wires to connect, but are used for most of the wiring in homes and other buildings. Parallel circuits allow you to turn off one lamp without all of the other lights in your home going out. They also allow you to use many appliances at once, each at full power.

Current in branches

Because each branch in a parallel circuit has the same voltage, the current in a branch is determined by the branch resistance and Ohm's law, $I = V/R$ (Figure 14.6). The greater the resistance of a branch, the smaller the current. Each branch works independently so the current in one branch does not depend on what happens in other branches

Total current

The total current in a parallel circuit is the sum of the currents in each branch. The only time branches have an effect on each other is when the total current is more than the battery or wall outlet can supply. A battery has a maximum amount of current it can supply at one time. If the branches in a circuit try to draw too much current the battery voltage will drop and less current will flow.

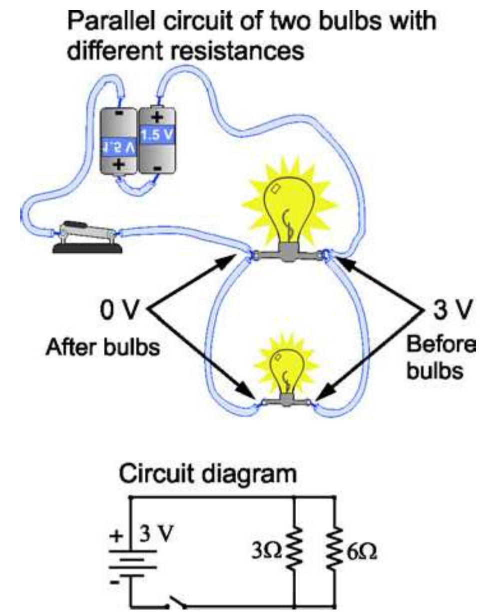


Figure 14.5: *The voltage across each branch of a parallel circuit is the same.*

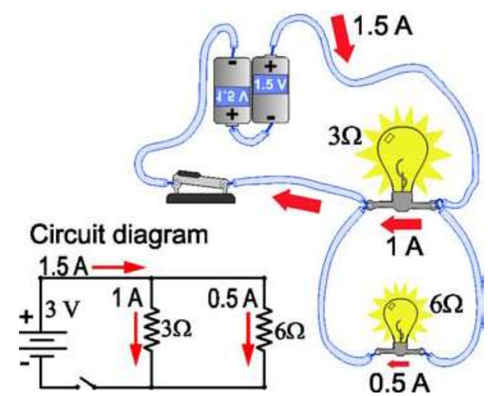


Figure 14.6: *The current in each branch depends on the branch resistance. The current may be different for each branch.*

Calculating current and resistance in a parallel circuit

More branches mean less resistance

In series circuits, adding an extra resistor increases the total resistance of the circuit. The opposite is true in parallel circuits. Adding a resistor in a parallel circuit provides another independent path for current. More current flows for the same voltage so the total resistance is *less*.

Example of a parallel circuit

Figure 14.7 compares a series circuit with a parallel circuit. In the series circuit, the current is 6 amps ($I = V/R = 12V \div 2\Omega$). In the parallel circuit, the current is 6 amps *in each branch*. The total current is 12 amps. So what is the total resistance of the parallel circuit? Ohm's law solved for resistance is $R = V \div I$. The total resistance of the parallel circuit is the voltage (12 V) divided by the total current (12 A) or 1 ohm. The resistance of the parallel circuit is *half* that of the series circuit.

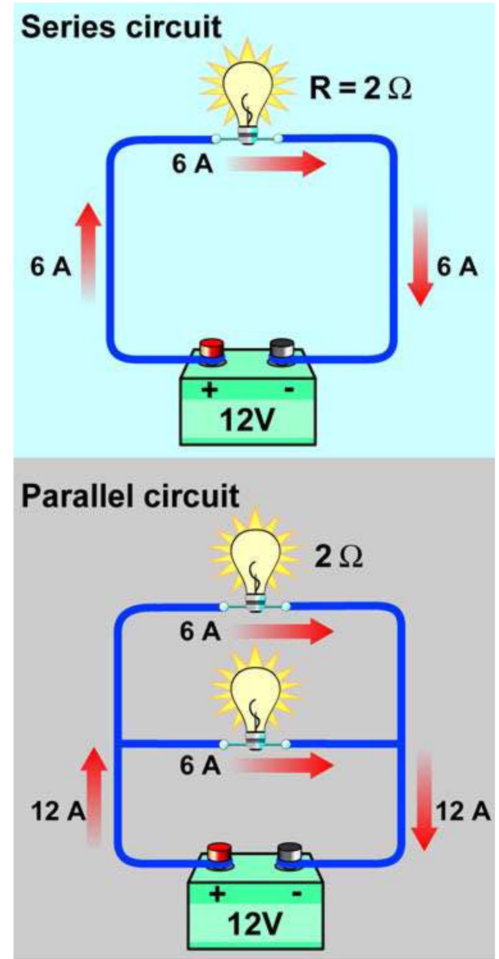


Figure 14.7: *The parallel circuit has twice the current and half the total resistance of the series circuit.*

Current in parallel circuits

All of the electrical outlets in Jonah's living room are on one parallel circuit. The circuit breaker cuts off the current if it exceeds 15 amps. Will the breaker trip if he uses a light (240 Ω), stereo (150 Ω), and an air conditioner (10 Ω)?

1. Looking for: You are asked whether the current will exceed 15 amps.

2. Given: You are given the resistance of each branch and the circuit breaker's maximum current.

3. Relationships: Ohm's law: $I=V/R$

4. Solution: Because the devices are plugged into electrical outlets, the voltage is 120 volts for each.
I_{light}=(120 V)/(240 Ω)=0.5 A
I_{stereo}=(120 V)/(150 Ω)=0.8 A
I_{AC}=(120 V)/(10 Ω)=12 A
The total is 13.3 A, so the circuit breaker will not trip.

Your turn...

a. Will the circuit breaker trip if Jonah also turns on a computer (R = 60 Ω)? **Answer:** Yes. The additional current is 2 A, so the total is 15.3 A.

b. What is the total current in a parallel circuit containing a 12-V battery, a 2 Ω resistor, and a 4 Ω resistor? **Answer:** 9 A

Short circuits, circuit breakers, and fuses

Heat and wires When electric current flows through a resistance, some of the power carried by the current becomes heat. Toasters and electric stoves are designed to use electric current to make heat. Although the resistance of wires is low, it is not zero and so wires heat up when current flows through them. If too much current flows through too small a wire, the wire overheats and may melt or start a fire.

Short circuits A **short circuit** is a parallel path in a circuit with very low resistance. A short circuit can be created accidentally by making a parallel branch with a wire (Figure 14.8). A plain wire may have a resistance as low as 0.001Ω. Ohm's law tells us that with a resistance this low, 1.5 V from a battery results in a (theoretical) current of 1,500 A! A short circuit is dangerous because currents this large melt wires and burn anyone working with the circuit.

Parallel circuits in homes Appliances and electrical outlets in homes are connected in many parallel circuits. Each circuit has its own fuse or circuit breaker that stops the current if it exceeds the safe amount, usually 15 or 20 amps (Figure 14.9). If you turn on too many appliances in one circuit at the same time, the circuit breaker or fuse cuts off the current. To restore the current, you must first disconnect some or all of the appliances. Then, either flip the tripped circuit breaker (in newer homes) or replace the blown fuse (in older homes). Fuses are also used in car electrical systems and in electrical devices such as televisions.

14.2 Section Review

1. Is the voltage across each branch of a parallel circuit the same? Is the current in each branch the same?
2. Why do home electrical systems use parallel wiring?
3. What happens to the total current in a parallel circuit as more branches are added? Why?
4. What is the total resistance of two 12-ohm resistors in parallel? What is the total for three 12-ohm resistors in parallel?

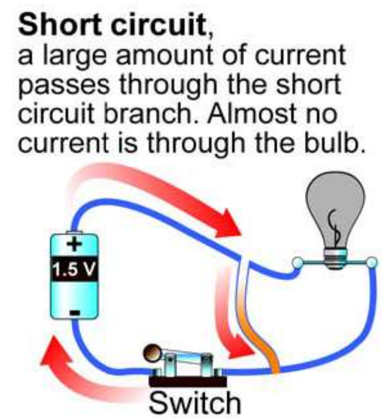


Figure 14.8: *A short circuit is created when there is a parallel branch of very low resistance. The current in this branch can be dangerously large.*

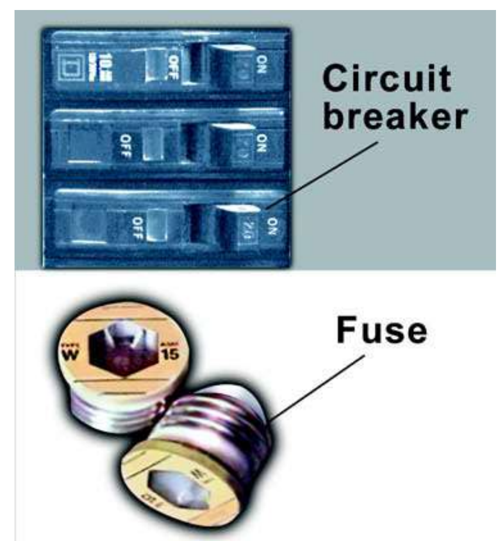


Figure 14.9: *Houses and other buildings use either circuit breakers or fuses to cut off the current if it gets too high.*

14.3 Electrical Power, AC, and DC Electricity

If you look at a stereo, hair dryer, or other household appliance, you may find a label giving its power in watts. In this section you will learn what the power ratings on appliances mean, and how to figure out the electricity costs of using various appliances.

Vocabulary

kilowatt, kilowatt-hour, direct current, alternating current, transformer

Objectives

✓ Calculate power in a circuit.
✓ Calculate the cost of running an appliance.
✓ Distinguish between alternating and direct current.

Electric power

A watt is a unit of power

Electrical power is measured in watts, just like mechanical power you learned about in Chapter 4. Electrical power is the rate at which electrical energy is changed into other forms of energy such as heat, sound, or light. Anything that "uses" electricity is actually converting electrical energy into some other type of energy. The watt is an abbreviation for one joule per second. A 100-watt light bulb uses 100 joules of energy *every second* (Figure 14.10).

The three electrical quantities

We have now learned three important electrical quantities:

Current (I)	Current is what carries power in a circuit. Current is measured in amperes (A).
Voltage (V)	Voltage measures the difference in energy carried by charges at two points in a circuit. A difference in voltage causes current to flow. Voltage is measured in volts (V). One volt is one watt per amp of current.
Resistance (R)	Resistance measures the ability to resist current. Resistance is measured in ohms (Ω). One amp of current flows if a voltage of 1 V is applied across a resistance of 1 Ω.

Paying for electricity

Electric bills sent out by utility companies don't charge by the volt, the amp, or the ohm. Electrical appliances in your home usually include another unit – the *watt*. Most appliances have a label that lists the number of watts or kilowatts. You may have purchased 60-watt light bulbs, a 1000-watt hair dryer, or a 1200-watt toaster oven. Electric companies charge for the energy you use, which depends on how many watts each appliance consumes and the amount of time each is used during the month.

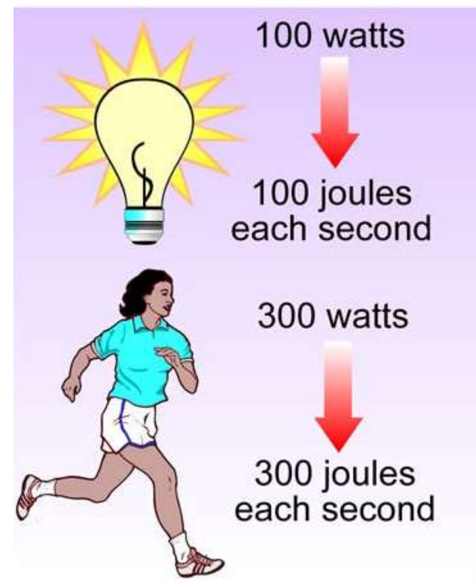


Figure 14.10: *One watt equals one joule per second.*

Table of Contents

Calculating power in a circuit

Calculating power Since one volt is a watt per amp, to calculate power in an electric circuit you multiply the voltage by the current. To calculate the power of a device in a circuit, multiply the voltage drop across the device by the current.

ELECTRICAL POWER

$$P = IV$$

Power (watts) → P; *Current* (amps) → I; *Voltage* (volts) → V

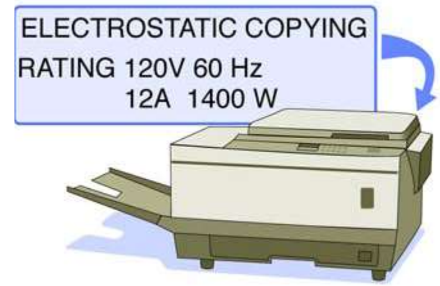


Figure 14.11: *Most appliances have a label that lists the power in watts.*

Equation	. . . gives you . . .	. . . if you know . . .
$P = I \times V$	power (P)	current and voltage
$I = P \div V$	current (I)	power and voltage
$V = P \div I$	voltage (V)	power and current

Watts and kilowatts Most electrical appliances have a label that lists the power in watts (Figure 14.11) or kilowatts (kW). The **kilowatt** is used for large amounts of power. One kilowatt (kW) equals 1,000 watts. Another common unit of power, especially on electric motors, is the horsepower. One horsepower is 746 watts. The range in power for common electric motors is from 1/25th of a horsepower (30 watts) for a small electric fan to 1 horsepower (746 watts) for a garbage disposal.

+ − × ÷

Calculating power

A 12-volt battery is connected in series to two identical light bulbs. The current in the circuit is 3 amps. Calculate the power output of the battery.

1. Looking for: You are asked for the power in watts supplied by the battery.

2. Given: You are given the battery voltage in volts and current in amps.

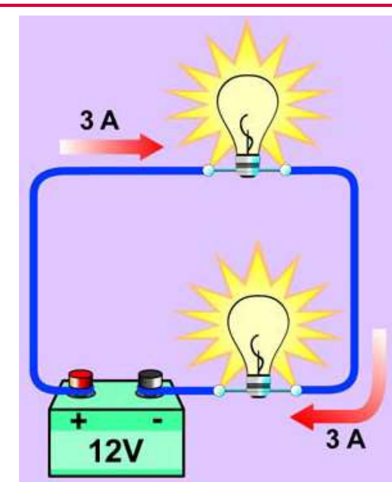
3. Relationships: Power: $P=IV$

4. Solution: Battery: $P = (3\ \text{A})(12\ \text{V}) = 36\ \text{W}$

Your turn...

a. A 12-volt battery is connected in parallel to the same identical light bulbs as used in the example. The current through each bulb is now 6 amps. Calculate the power output of the battery. **Answer:** 144 W for battery

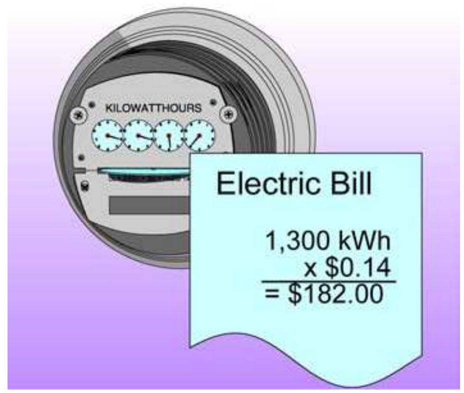
b. The label on the back of a television states that it uses 300 watts of power. How much current does it draw when plugged into a 120-volt outlet? **Answer:** 2.5 amps



Buying electricity

Kilowatt-hours

Utility companies charge customers for the number of **kilowatt-hours** (abbreviated kWh) used each month. One kilowatt-hour means that a kilowatt of power has been used for one hour. A kilowatt-hour is not a unit of power but a unit of *energy.* A kilowatt-hour is a relatively large amount of energy, equal to 3.6 million joules. If you leave a 1,000-watt hair dryer on for one hour, you have used one kilowatt-hour of energy. You could also use 1 kilowatt-hour by using a 100-watt light bulb for 10 hours. The number of kilowatt-hours used equals the number of kilowatts multiplied by the number of hours the appliance was turned on.



You pay for kilowatt-hours

Electric companies charge for kilowatt-hours used during a period of time, often a month. Your home is connected to a meter that counts up total number of kilowatt-hours used and a person comes to read the meter once a month. If you know the cost per kilowatt-hour the utility company charges, you can estimate the cost of operating any electrical appliance.

Appliance	Power (watts)
Electric stove	3,000
Electric heater	1,500
Toaster	1,200
Hair dryer	1,000
Iron	800
Washing machine	750
Television	300
Light	100
Small fan	50
Clock radio	10

Figure 14.12: *Typical power usage of some common appliances.*

Electricity costs

How much does it cost to run an electric stove for 2 hours? Use the power in Figure 14.12 and a cost of $0.15 per kilowatt-hour.

1. Looking for: You are asked for the cost to run a stove for 2 hours.

2. Given: You are given the time, the power, and the price per kilowatt-hour.

3. Relationships: 1 kilowatt = 1000 watts number of kilowatt-hours = (# of kilowatts) x (hours appliance is used)

4. Solution:

$$3000\text{ W} = 3\text{ kW} \qquad 3\text{ kW} \times 2\text{ hr} = 6\text{ kWh} \qquad 6\text{ kWh} \times \frac{\$0.15}{\text{kWh}} = \$0.90$$

Your turn...

a. At $0.15 per kilowatt-hour, what is the cost of running an electric heater for 4 hours? **Answer:** $0.90

b. At $0.15 per kilowatt-hour, what is the cost of running a clock radio for 24 hours? **Answer:** $0.04 (rounded to nearest cent)

Table of Contents

Alternating (AC) and direct (DC) current

Direct current The current from a battery is always in the same direction, from the positive to the negative end of the battery. This type of current is called **direct current** or DC. Although the letters “DC” stand for “direct current” the abbreviation “DC” is used to describe both voltage and current. A DC voltage is one that stays the same sign over time. The terminal that is positive stays positive and the terminal that is negative stays negative. Your experiments in the lab use DC since they use batteries.

Alternating current The electrical system in your house uses **alternating current** or AC. Alternating current constantly switches direction. You can theoretically create alternating current with a battery if you keep reversing the way it is connected in a circuit (Figure 14.13). In the electrical system used in the United States, the current reverses direction 60 times per second. It would be hard to flip a battery this fast!

A DC current or voltage keeps the same sign over time.

An AC current or voltage reverses sign, usually 60 times per second in the US.

Electricity in other countries For large amounts of electricity, we use alternating current because it is easier to generate and to transmit over long distances. All the power lines you see overhead carry alternating current. Other countries also use alternating current. However, in many other countries, the current reverses itself 50 times per second rather than 60, and wall sockets are at a different voltage. When visiting Asia, Africa, or Europe, you need special adapters to use electrical appliances you bring with you from the United States.

Peak and average voltages The 120 volt AC (VAC) electricity used in homes and businesses alternates between peak values of +170 V and -170 V (Figure 14.14). This kind of electricity is called 120 VAC because +120V is the *average* positive voltage and -120V is the *average* negative voltage. AC electricity is usually described by the average voltage, not the peak voltage.

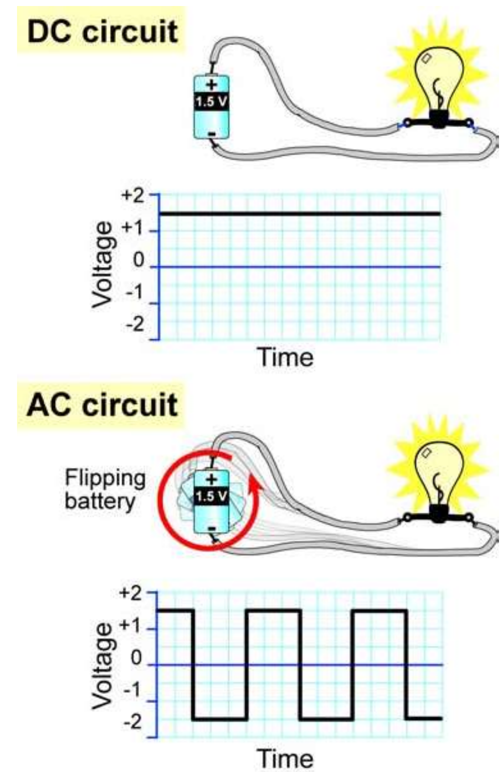


Figure 14.13: *Direct current is in one direction, but alternating current reverses.*

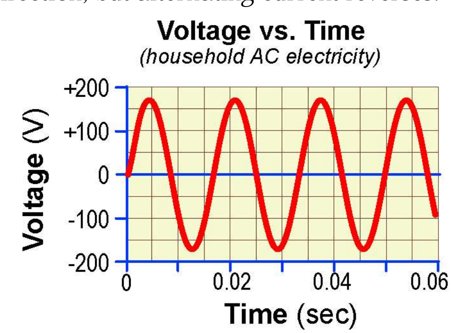


Figure 14.14: *The voltage in your wall outlets goes from +170 V to -170 V.*

Electricity, power, and heat

How do you get more power?

How do you get more power when you need it? From the power formula, we can see that increasing voltage or current will increase power. The problem with raising voltage is that the electricity in a standard wall outlet is 120 volts and it is hard to change. While certain appliances use 240 volts, the higher voltage is more dangerous so 120 volts is used for most electrical appliances.

Higher power usually means more current

The most common way to get higher power is to use more current. However, heat becomes a problem when wires carry large currents. A wire's voltage drop (from Ohm's law) equals the current multiplied by the wire's resistance. Because a wire's resistance is small, the voltage drop is usually small enough to be ignored. But if there is a large current, there can be a significant voltage drop. Remember, power is voltage drop multiplied by current. In a wire, this power is converted into heat. A small amount of heat can safely be transferred away from the wire by conduction or convection. Too much heat could melt the wire or start a fire.

Reducing heat in electrical wires

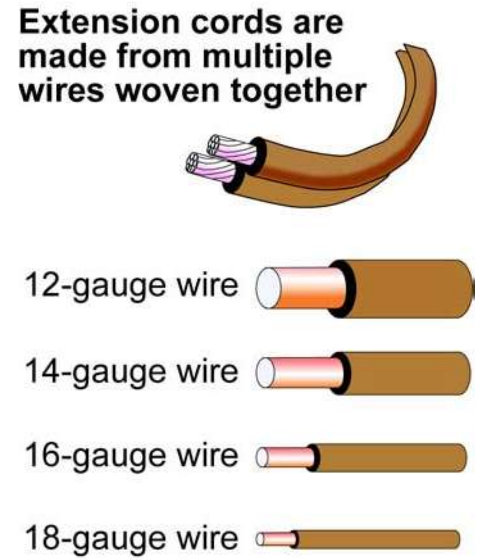
Wires are made in different sizes to carry different amounts of current. A large diameter wire has less resistance and can safely carry more current than a smaller, thinner wire. A 12-gauge wire is thicker than a 14-gauge wire and can carry more current (Figure 14.15). You should always use the right wire for the current that is flowing. This includes extension cords, which you may use without thinking about whether they are safe or not. Extension cords are made with 18-gauge wire, 16-gauge, 14-gauge, and 12-gauge wire.

Length and resistance

The length of a wire also affects its resistance. The longer a wire is, the more resistance it has. Think about moving around your school and how you can get through a short, crowded hallway quickly. But it takes a long time to get down a long, crowded hallway.

Check your extension cords for safety

All extension cords are rated for how many amps of current they can carry safely. *Always* check to see if the extension cord can carry *at least* as much current as the device you are using requires. For powerful tools, such as a saw, you should use a 14-gauge or 12-gauge heavy-duty extension cord that is rated to carry 15-20 amps. Many fires have been caused by using the wrong extension cord.



Wire gauge	Maximum current (amps)
12	20
14	15
16	10

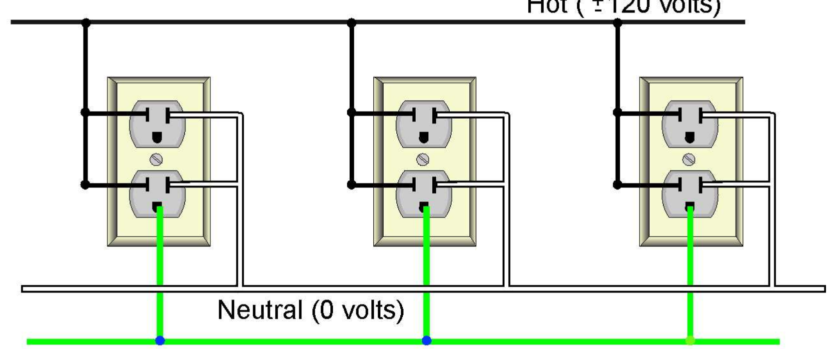
Figure 14.15: *The larger the gauge of a wire, the smaller its diameter, and the smaller the amount of current the wire can safely carry.*

Table of Contents

Electricity in homes and buildings

Circuit breaker panel

The 120 VAC electricity comes into a normal home or building through a circuit breaker panel. The circuit breakers protect against wires overheating and causing fires. Each circuit breaker protects one parallel circuit which may connect many wall outlets, lights, switches, or other appliances.



Hot, neutral, and ground wires

Each wall socket has three wires feeding it. The hot wire carries 120 volts AC. The neutral wire stays at zero volts. When you plug something in, current flows in and out of the hot wire, through your appliance (doing work) and back through the neutral wire. The ground wire is for safety and is connected to the ground (0 V) near your house. If there is a short circuit in your appliance, the current flows through the ground wire rather than through you.

Ground fault interrupt (GFI) outlets

Electrical outlets in bathrooms, kitchens, or outdoors are now required to have ground fault interrupt (GFI) outlets installed (Figure 14.16). A GFI outlet contains a circuit that compares the current flowing out on the hot wire and back on the neutral wire. If everything is working properly, the two currents should be exactly the same. If they are different, some current must be flowing to ground through another path, such as through your hand. The ground fault interrupter detects any difference in current and immediately breaks the circuit. GFI outlets are excellent protection against electric shocks, especially in wet locations.

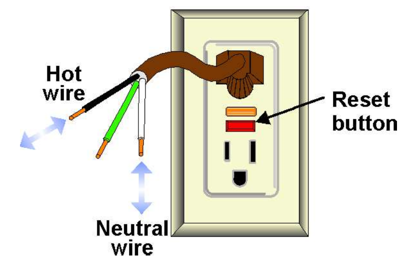
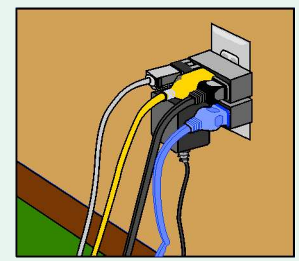


Figure 14.16: *A ground fault interrupt outlet might be found in bathrooms and kitchens where water may be near electricity.*

Too many plugs!



If you plug too many appliances into the same circuit or outlet, you will eventually use more current than the wires can carry without overheating. Your circuit breaker will click open and stop the current. You should unplug things to reduce the current in the circuit before resetting the circuit breaker.

Distributing electricity

Why electricity is valuable

Electricity is a valuable form of energy because electrical power can be moved easily over large distances. You would not want a large power plant in your backyard! One large power plant converts millions of watts of chemical or nuclear energy into electricity. The transmission lines carry the electricity to homes and businesses, often hundreds of miles away.

Power transmission lines

Overhead power lines use a much higher voltage than 120V. That is because the losses due to the resistance of wires depend on the current. At 100,000 volts each amp of current carries 100,000 watts of power, compared to the 120 watts per amp of household electricity. Big electrical transmission lines operate at very high voltages for this reason (Figure 14.17). The wires are supported high on towers because voltages this high are *very dangerous*. Air can become a conductor over distances of a meter at high voltages. *Never* go near a power line that has fallen on the ground in a storm or other accident.

Transformers

A device called a **transformer** converts high-voltage electricity to lower voltage electricity. Within a few kilometers of your home or school the voltage is lowered to 13,800 V or less. Right near your home or school the voltage is lowered again to the 120 V or 240 V that actually come into the circuits connecting your wall outlets and appliances.

Changing AC to DC

Many electronic devices, like cell phones or laptop computers, use DC electricity inside, but also can be plugged into the AC electricity from a wall outlet with an *AC adapter* (Figure 14.18). An "AC adapter" is a device that changes the AC voltage from the wall outlet into DC voltage for the device. The adapter also steps the voltage down from 120 volts to the battery voltage, which is usually between 6 and 20 volts.

14.3 Section Review

1. How is an appliance's power related to the amount of energy it uses?
2. How many watts or joules are a horsepower, kilowatt, and kilowatt-hour.
3. What does the electric utility company charge you for each month?
4. What is the difference between direct current and alternating current?

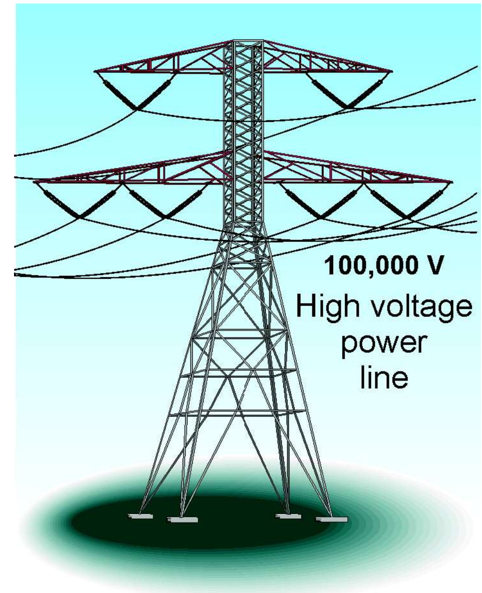


Figure 14.17: *Electrical power lines may operate at voltages of 100,000 volts or greater.*

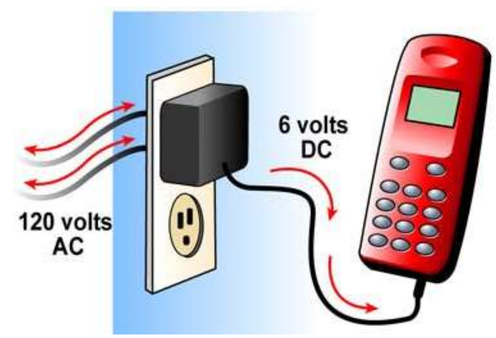


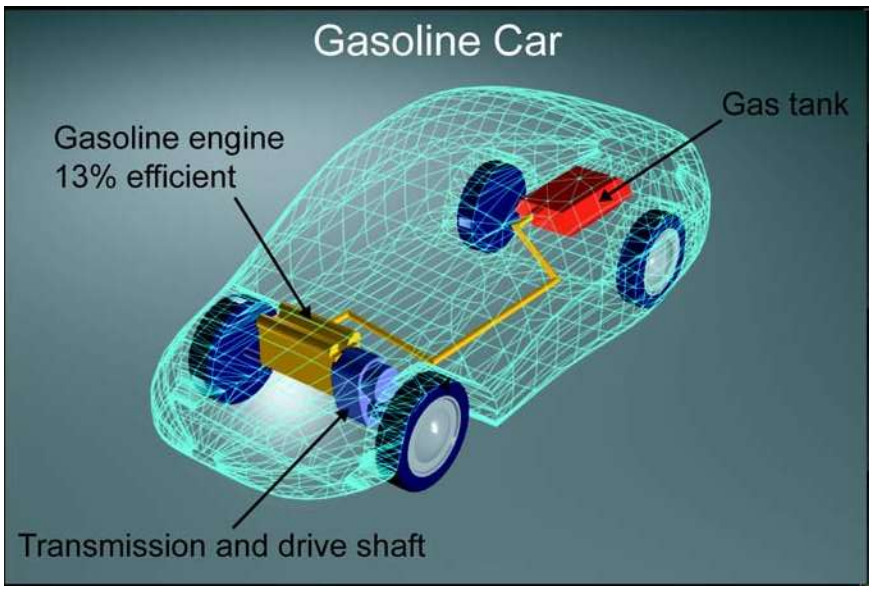
Figure 14.18: *Special adapters can change AC into DC and lower the voltage.*

How do Hybrid Cars Work?

Gas-electric hybrid cars look and drive about like any other car, but use 20-30% less gas than their non-hybrid counterparts. For example, a hybrid car's gas mileage is about 50 miles per gallon. The gas mileage for standard cars ranges from 10 to 30 miles per gallon. To understand how hybrid cars get better gas mileage, we have to look at the engines.

Cars powered by gasoline

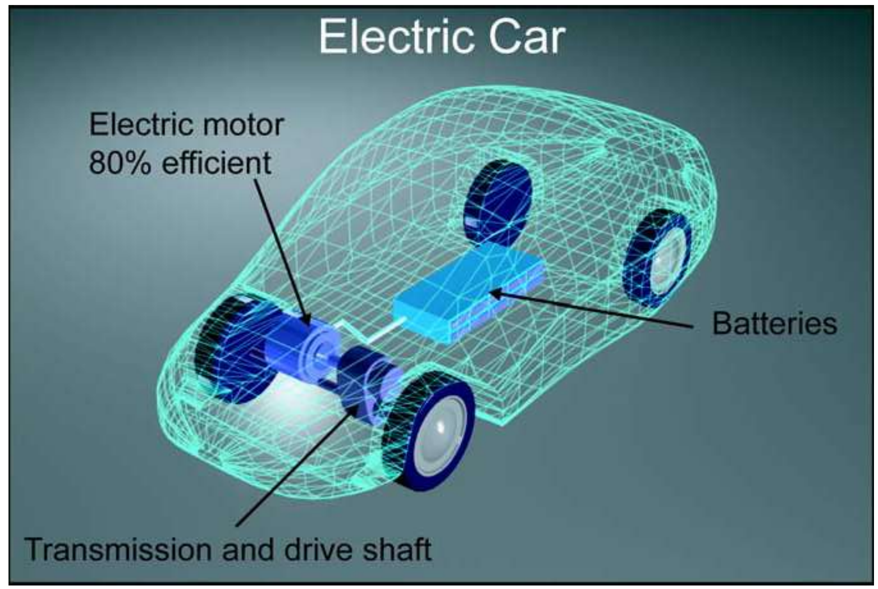
The efficiency of a gasoline engine is about 13%. This means that when the car is in motion, it only uses about 13% of the available energy from a tank of gas. The rest of the available energy from a tank of gas is lost as heat. The more energy that is lost as heat, the less efficient an engine or any system is.



Although the combustion of a gasoline engine produces many pollutants, gasoline is very energy-rich and easy for a car to carry. These two features have made the gasoline engine so easily adopted when oil was inexpensive and there was less concern for the impact of cars on the global environment.

Cars powered by electricity

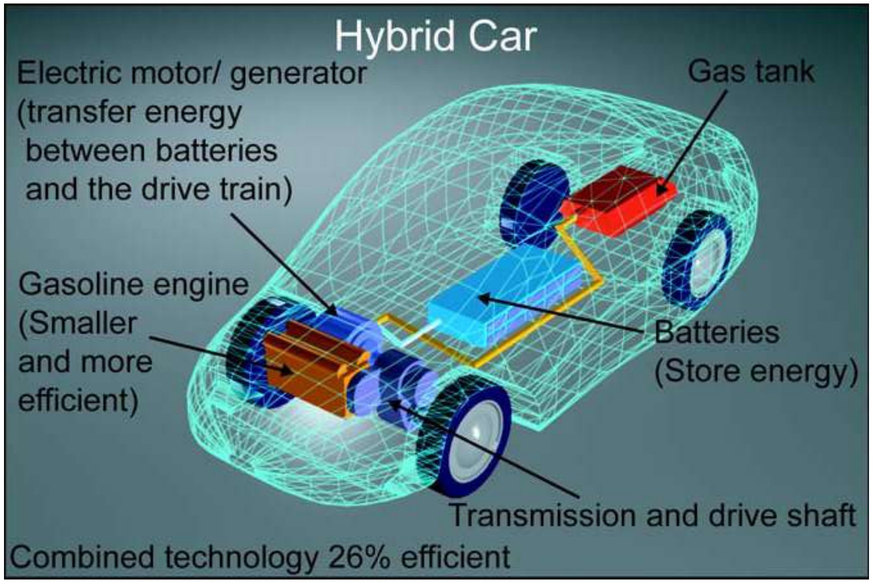
Compared to gasoline-powered cars, electric motors are very efficient — 80% from batteries — and they produce no pollutants.



To run an electric car, the batteries need to be charged, often this is done by plugging in the car during the night. Unfortunately, batteries are heavy and don't have as much energy as gasoline. For instance, the available energy in a typical car battery is equivalent to about a small cupful of gasoline. Until there is a better electrical storage system, cars powered by electricity from a battery must be small and only used to travel short distances.

The best of both technologies

A hybrid car uses the best of both worlds—a gasoline-powered engine and an electric motor. By combining technologies, the efficiency is improved to about 26%. The electric motor helps the gas-powered system be more efficient by using electricity to transfer energy within the system.



How do hybrids compare?

In a hybrid car, the gasoline engine and electric motor work together to accelerate the car. This allows the gasoline engine to be smaller and more efficient. Every time a standard car slows down, kinetic energy is lost as the brakes heat up. In contrast, the hybrid's electric motor operates as a generator during braking. When the car slows down, kinetic energy is converted to electrical energy that charges the batteries. Then, to speed up the car, the stored energy in the batteries is converted into useful kinetic energy by the motor.

In addition to getting great gas mileage, hybrid cars are rated as ulta-low emissions vehicles (ULEVs). This means that they do not produce as many pollutants as standard cars. Hybrid cars produce less pollution because the engine is smaller and simply uses less gasoline. Also, when a hybrid car comes to a stop, the engine automatically shuts off to save gas. When it is time to go again, the car turns on instantly. At very low speeds, as when you are driving in a city, the electric motor runs the car instead of the gasoline engine. When the electric motor is used, there is less pollution.

Hybrid technology is just a beginning

The gas-electric hybrid is only one of the many types of more efficient motor-powered vehicles that are being developed today. Driving this development is an interest in decreasing our use of fossil fuels for transportation. Interest in developing alternative transportation technologies will continue because they are potentially more efficient and less polluting.

In the meantime, since we all need to travel and often use gasoline-powered vehicles, how can you reduce your use a fossil fuels so that you save money and reduce pollution? Here are some options: share rides, take public transportation, and drive a medium-sized or small car that has high gas mileage.

Questions:

1. If you only need to drive two miles per day, which kind of car would be the best to use? Justify your answer.
2. Why is the efficiency of gasoline-powered cars so low?
3. Hybrid cars are better for driving in cities but not as efficient for highway driving? Why?
4. Some hybrid cars have efficiency meters—a gauge that shows your miles per gallon—so you can monitor and improve your driving habits. Make a list of driving habits that help you save gas.

Table of Contents

Chapter 14 Review

Understanding Vocabulary

Select the correct term to complete the sentences.

parallel circuit	kilowatt-hour	electrical power
horsepower	series circuit	short circuit
transformer	direct	Kirchhoff's voltage law
Kirchhoff's current law	kilowatt	voltage drop
alternating		

Section 14.1

1. A _____ contains only one path for the current.
2. According to _____, if a circuit contains a 3-volt battery, the voltage drops around the complete circuit must add to 3 volts.
3. There is a _____ across each resistor in a circuit when current is flowing.

Section 14.2

4. _____ states that all the current entering a point in a circuit must also leave that point.
5. A _____ is created when a circuit contains one branch with very little or no resistance.
6. A _____ contains multiple paths or branches for the current.

Section 14.3

7. One _____ equals 1000 watts.
8. The rate of converting electrical energy into another form of energy is called _____.
9. The _____ is a unit used by electric utility companies to measure the electrical energy your home uses each month.
10. One _____ is equal to 746 watts.
11. A battery creates _____ current.
12. Electrical appliances in your home use _____ current.
13. A _____ converts high-voltage electricity to lower voltage electricity.

Reviewing Concepts

Section 14.1

1. Draw a circuit diagram for a circuit containing a battery and two bulbs in series.
2. Is the current at every point in a series circuit the same?
3. One of the bulbs burns out in a string of lights. What happens to the current in the circuit? What happens to the other bulbs?
4. Explain how to calculate the total resistance of a series circuit.
5. As more bulbs are added to a series circuit, what happens to the resistance of the circuit? What happens to the brightness of the bulbs?
6. Explain Kirchhoff's voltage law.

Section 14.2

7. What is a parallel circuit?
8. Draw the circuit diagram for a circuit containing two bulbs in parallel.
9. What does Kirchhoff's current law say about the current entering any point in a circuit?
10. Each branch in a parallel circuit has the same _____.
11. List two advantages of parallel circuits over series circuits.
12. Does the wiring in your home connect the appliances in series or parallel? How could you prove this?
13. What happens to the total resistance of a parallel circuit as more branches are added? Why?
14. How do you calculate the total resistance of two parallel resistors?
15. What is a short circuit?
16. Why can short circuits be dangerous?

Section 14.3

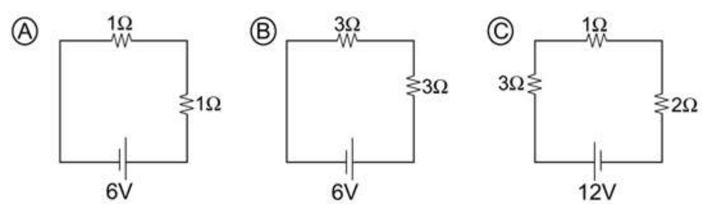
17. A light bulb has a power of 60 watts. Explain what this means in terms of energy and time.
18. Explain how to calculate the power of an electrical appliance.
19. What is the meaning of the kilowatt-hour?

20. What is the difference between direct current and alternating current?
21. How frequently does the alternating current used in the United States reverse direction?
22. Do thinner or thicker wires have more resistance?
23. Do longer or shorter wires have more resistance?
24. Why is it dangerous to connect several extension cords to make one long cord?
25. What is the purpose of the AC adapter on the end of the cord used for cell phones?

Solving Problems

Section 14.1

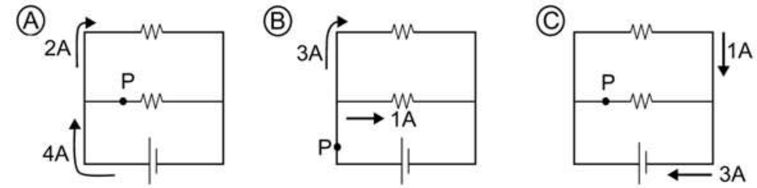
1. A circuit contains 5-ohm, 3-ohm, and 8-ohm resistors in series. What is the total resistance of the circuit?
2. A circuit contains a 9 volt battery and two identical bulbs. What is the voltage drop across each?
3. A circuit contains a 12 volt battery and two 3-ohm bulbs in series. Draw a circuit diagram and use it to find the current in the circuit and the voltage drop across each bulb.
4. A circuit contains a 12 volt battery and three 1-ohm bulbs in series. Draw the circuit diagram and find the current in the circuit.
5. Calculate the total resistance of each circuit shown below. Then calculate the current in each.



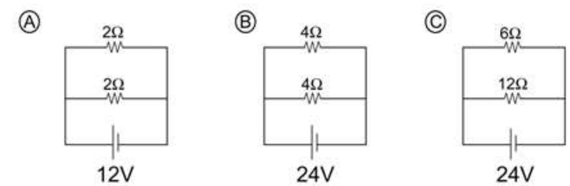
6. A circuit contains two 1-ohm bulbs in series. The current in the circuit is 1.5 amperes. What is the voltage provided by the batteries?
7. A circuit contains two identical resistors in series. The current is 3 amperes, and the batteries have a total voltage of 24 volts. What is the total resistance of the circuit? What is the resistance of each resistor?

Section 14.2

8. Find the amount and direction of the current through point P in each of the circuits shown below.



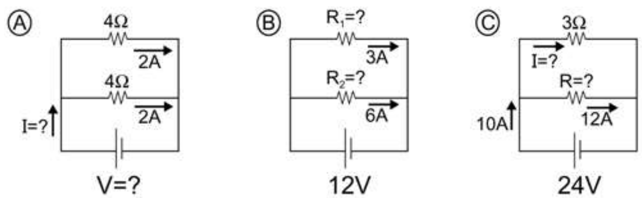
9. Do the following for each of the three circuits shown below.
   a. Find the voltage across each resistor.
   b. Use Ohm's law to find the current through each resistor.
   c. Find the total current in the circuit.
   d. Find the total resistance of the circuit.



10. A parallel circuit contains a 6-volt battery and two 6-ohm bulbs.
    a. Draw the circuit diagram for this circuit.
    b. Calculate the current through each branch.
    c. Calculate the total current.
    d. Use Ohm's law to calculate the total resistance of the circuit.
    e. Use the formula for combining parallel resistors to calculate the total resistance of the circuit.
11. A parallel circuit contains a 24 V battery, 4 Ω bulb and a 12 Ω bulb.
    a. Draw the circuit diagram for this circuit.
    b. Calculate the current through each branch.
    c. Calculate the total current in the circuit.
    d. Use Ohm's law to calculate the total resistance of the circuit.
    e. Use the formula for combining parallel resistors to calculate the total resistance of the circuit.

Table of Contents

12. Find the unknown quantity in each of the circuits below.



Section 14.3

13. Calculate the power of each of the following appliances when plugged into a 120-volt outlet.
    a. an iron that draws 10 A of current
    b. a stereo that draws 2 A of current
    c. a light bulb that draws 0.5 A of current
14. Calculate the current each of the following appliances draws when plugged into a 120-volt outlet.
    a. a 100 watt computer
    b. a 1200 watt microwave
    c. a 30 watt radio
15. A portable MP3 player requires 1.5 A of current and has a power of 15 watts. What is the voltage of the rechargeable battery it uses?
16. A flashlight contains a 6-watt bulb that draws 2 A of current. How many 1.5-volt batteries does it use?
17. Alex uses a 1000 watt heater to heat his room.
    a. What is the heater's power in kilowatts?
    b. How many kilowatt-hours of electricity does Alex use if he runs the heater for 8 hours?
    c. If the utility company charges $0.15 per kilowatt-hour, how much does it cost to run the heater for 8 hours?
18. You watch a 300-watt television for two hours while you watch a movie.
    a. What is the television's power in kilowatts?
    b. How many kilowatt-hours of electricity did you use?
    c. If the utility company charges $0.15 per kilowatt-hour, how much did it cost you to watch the movie?

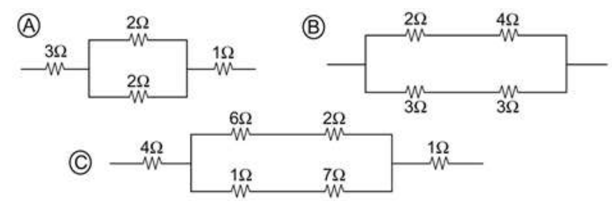
Applying Your Knowledge

Section 14.1

1. Some appliances contain components that are connected in series. For example, many microwave ovens have a light that turns on while the microwave is running. Look around your house and see how many appliances you can find that use series circuits.

Section 14.2

2. A car contains a warning bell that turns on if you open the door while the key is in the ignition. The bell also turns on if you open the door while the headlights are on. A single circuit with three switches and a a bell can be built to ring in both cases. Figure out how the circuit is designed. Draw a circuit diagram that shows your solution.
3. Many circuits contain resistors in series and in parallel. Apply what you have learned about circuits to find the total resistance of each of the sets of resistors below.



Section 14.3

4. Look at the back or underside of appliances in your home. Find the power of three appliances. Calculate the amount of current each draws when plugged into a 120-volt outlet.
5. Choose an appliance with a known power that you use frequently, such as a clock radio, stereo, or light.
    a. Calculate the power in kilowatts.
    b. Determine the amount of time you use the appliance in one day.
    c. Calculate the number of kilowatt-hours of energy the appliance uses in one day.
    d. Calculate the number of kilowatt-hours of energy it uses in one year.
    e. Find out the cost of electricity in your home.
    f. Calculate the cost of running the appliance for one year.