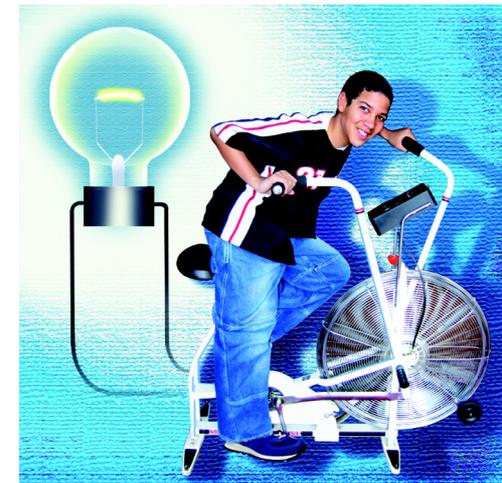


Chapter 13 Electric Circuits



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.

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.

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.

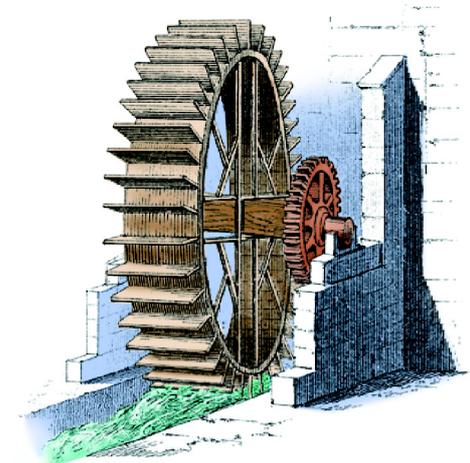


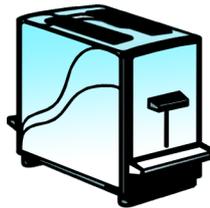
Figure 13.1: A waterwheel uses the force of flowing water to run machines.



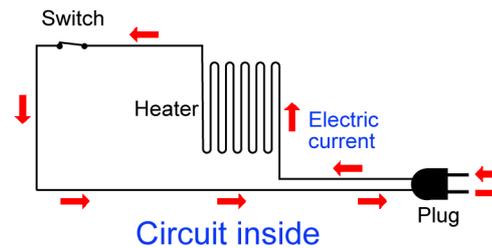
Electric circuits

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.



Electric toaster



Circuit inside

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.

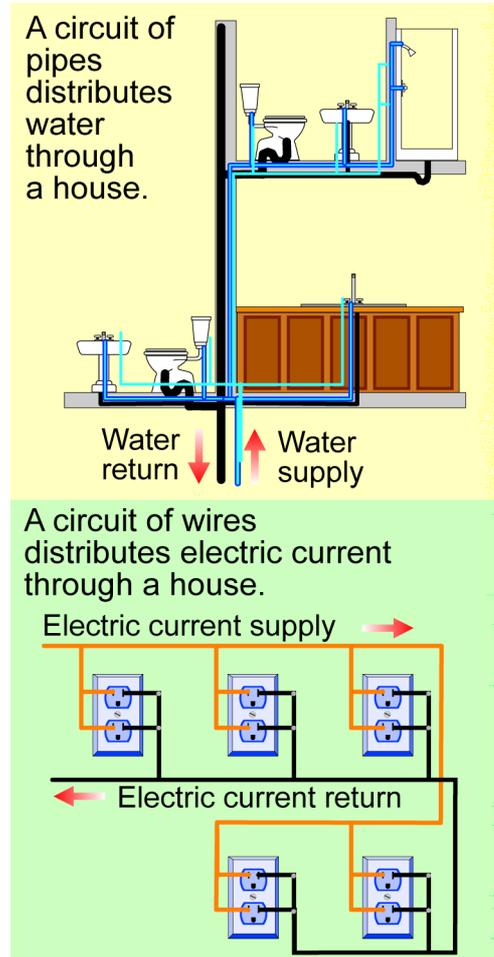
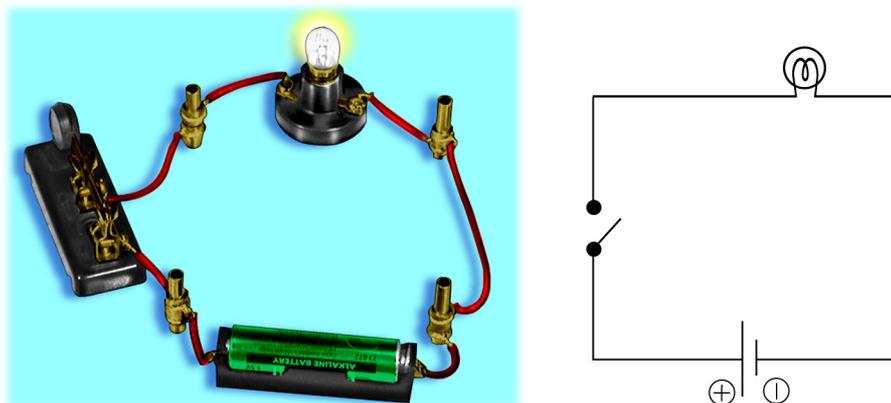


Figure 13.2: In a house or other building, we use pipes to carry water and wires to carry electric current.

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.

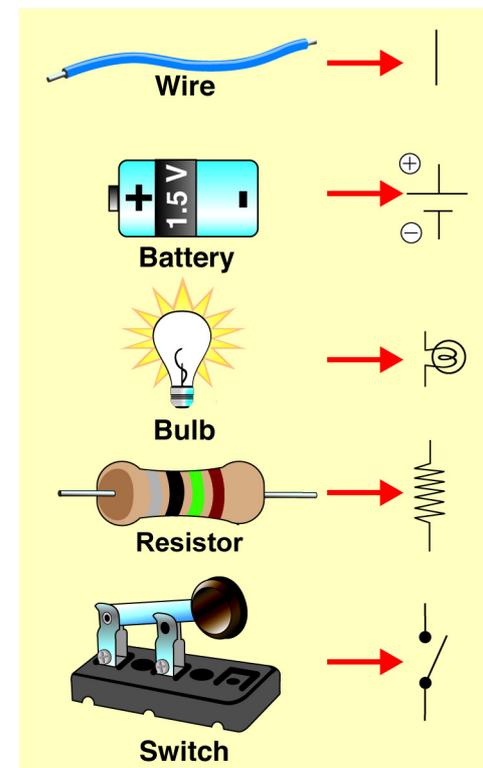


Figure 13.3: These electrical symbols are used when drawing circuit diagrams.



Open and closed circuits

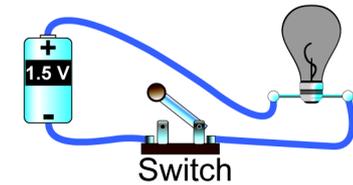
Batteries All electric circuits must have a source of energy. Circuits in your home get their energy from power plants that generate electricity. Circuits in flashlights, cell phones, and portable radios get their energy from batteries. Some calculators have solar cells that convert energy from the sun 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.

Open circuit



Closed circuit

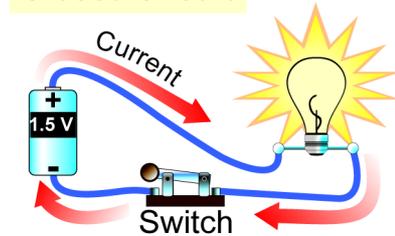


Figure 13.4: There is current in a closed circuit but not in an open circuit.

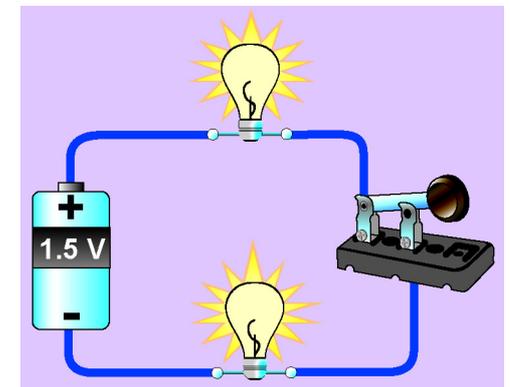


Figure 13.5: What does the circuit diagram for this circuit look like?

13.1 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?

13.2 Current and Voltage

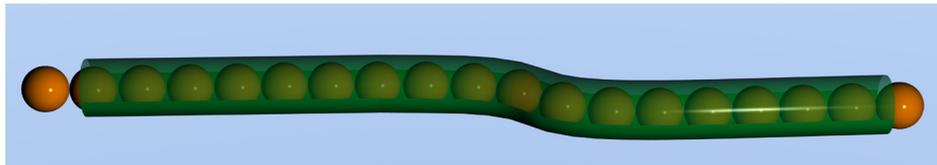
Current is what carries energy in a circuit. Like water current, electric current only flows when there is a difference in energy between two locations that are connected. Water flows downhill from high gravitational potential energy to low. Electric current flows from high electrical potential energy 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.

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.

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.

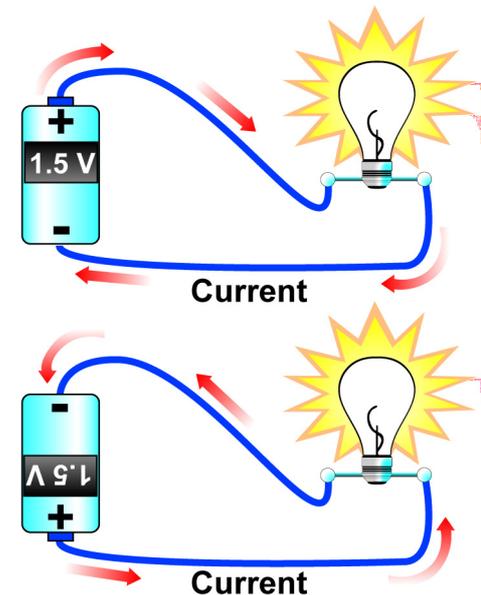


Figure 13.6: Electric current flows in a circuit from the positive end of a battery and returns toward the negative end.



Voltage

Energy and voltage

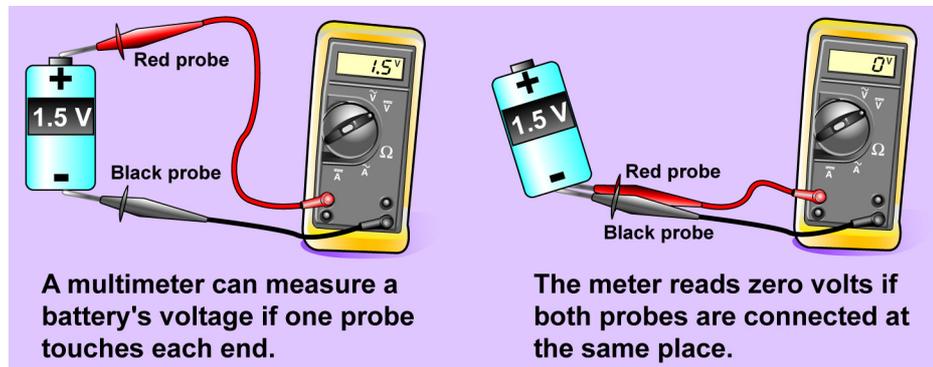
Voltage is a measure of electric potential energy, just like height is a measure of gravitational potential energy. Voltage is measured in **volts (V)**. Like other forms of potential energy, a voltage difference means there is energy that can be used to do work. With electricity, the energy becomes 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.

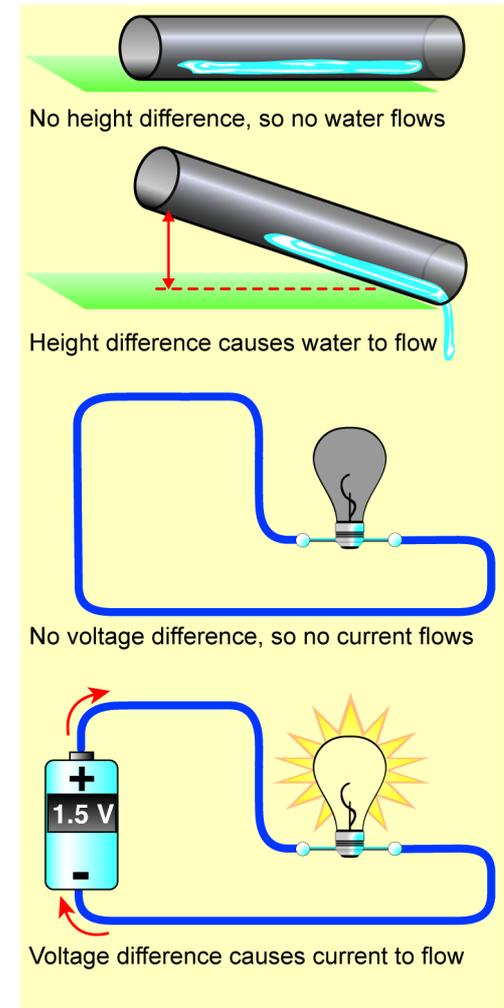
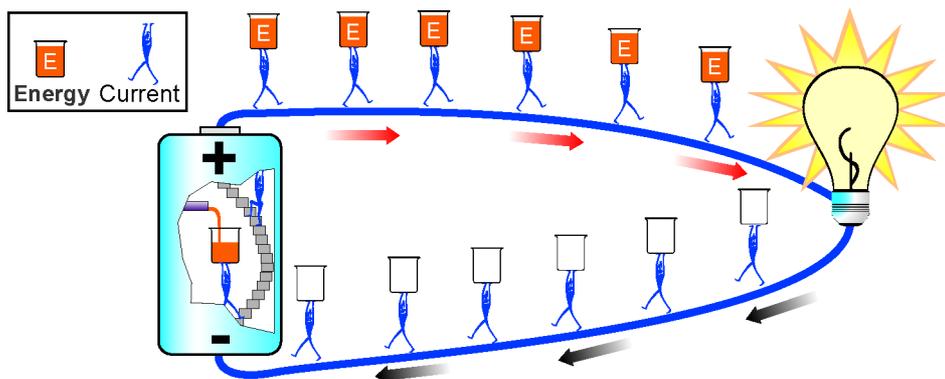


Figure 13.7: A change in height causes water to flow in a pipe. Current flows in a circuit because a battery creates a voltage difference.

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).

A pump is like a battery because it brings water from a position of low energy to high energy.

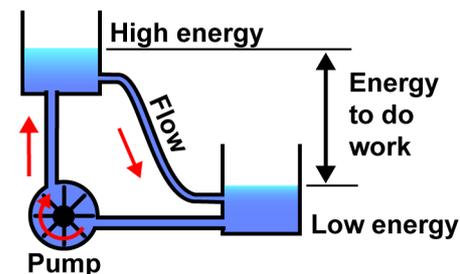


Figure 13.8: A battery acts like a pump to give energy to flowing electrical current.

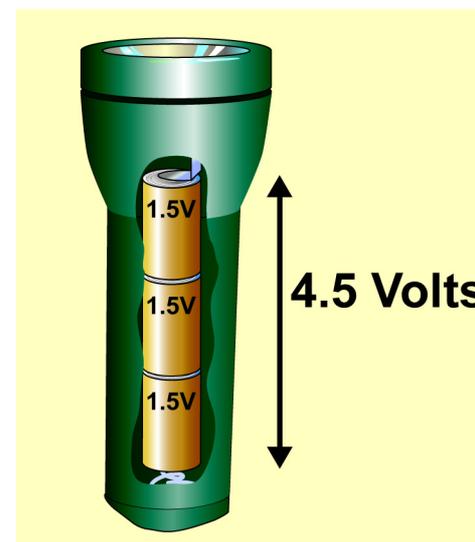


Figure 13.9: Three 1.5-volt batteries can be stacked to make a total voltage of 4.5 volts in a flashlight.



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.

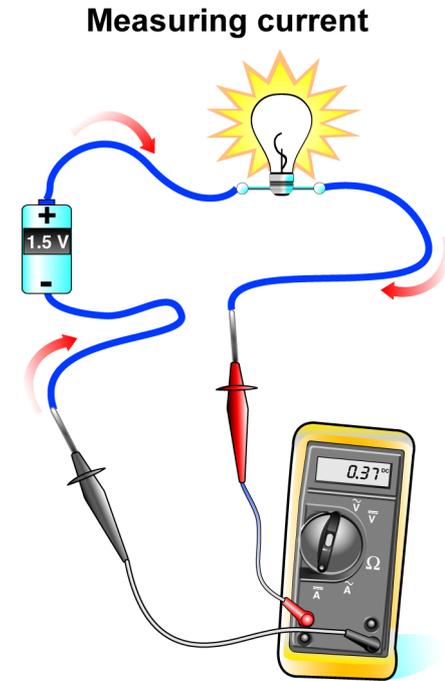


Figure 13.10: Current must pass through the meter when it is being measured.

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.

13.3 Resistance and Ohm's Law

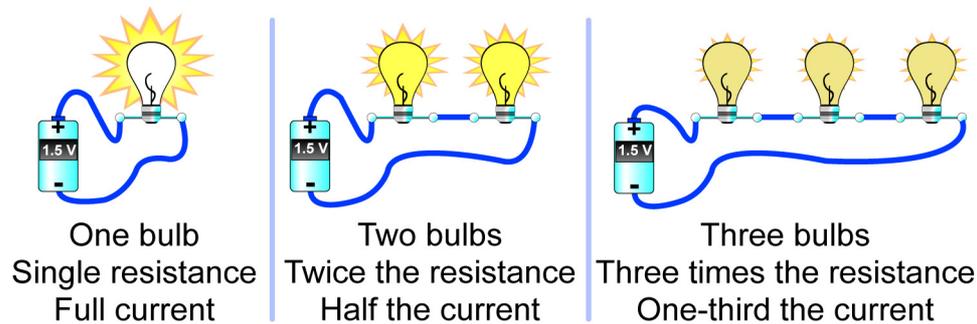
You can apply the same voltage to different circuits and different amounts of current will flow. For example, when you plug in a desk lamp, the current through it is 1 amp. If a hair dryer is plugged into the same outlet (with the same voltage) the current is 10 amps. For a given voltage, the amount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

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.



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.

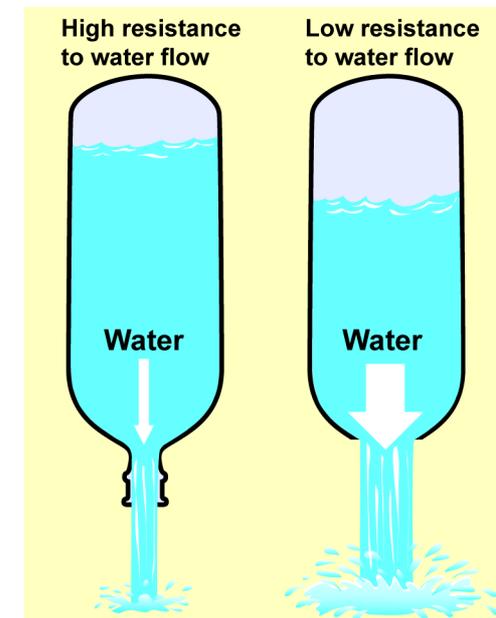
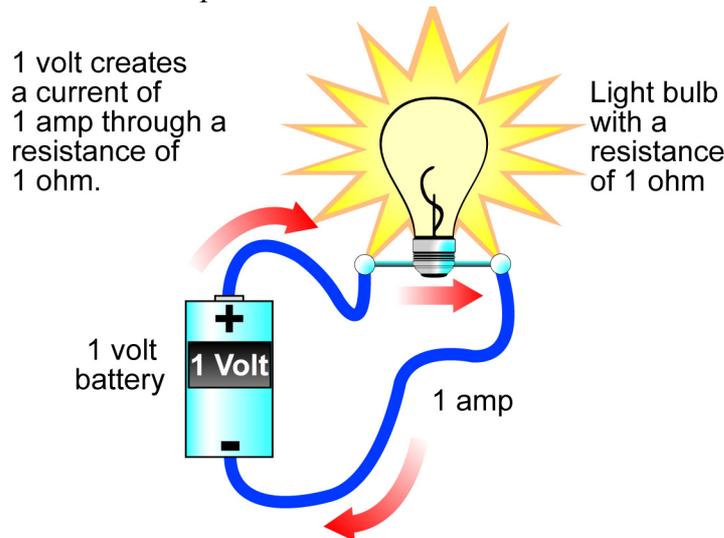


Figure 13.11: The current is less when the resistance is great.



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 ($\times 1,000 \Omega$), or mega-ohms ($\times 1,000,000 \Omega$).



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.

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

$$\text{Current (amps, A)} \rightarrow I = \frac{V}{R}$$

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 (0.001Ω) to large ($10 \times 10^6 \Omega$). 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, $9 \text{ V} \div 100,000 \Omega$ 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 ($120 \text{ V} \div 100,000 \Omega$) 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.

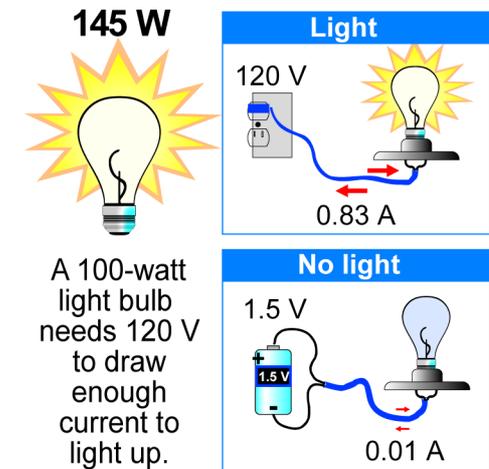


Figure 13.13: A light bulb designed for use in a 120-volt household circuit does not light when connected to a 1.5-volt battery.

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.

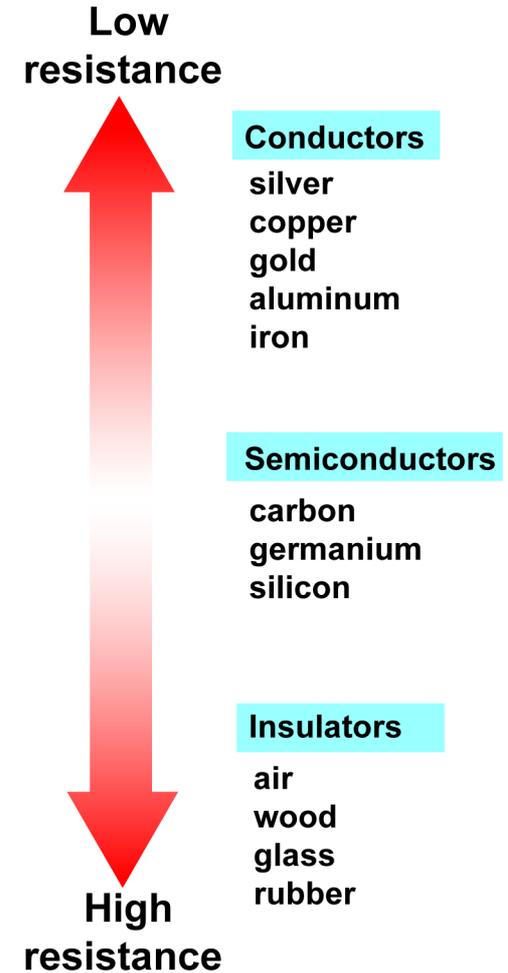
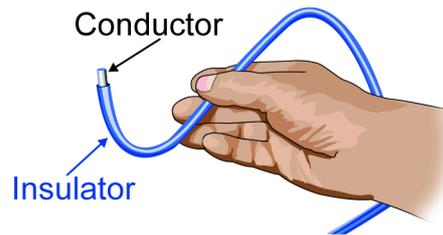


Figure 13.14: Comparing the resistances of materials.



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.

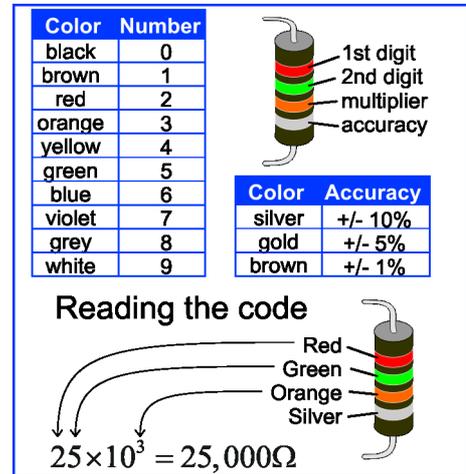


Figure 13.15: The color code for resistors.

The inside of a potentiometer

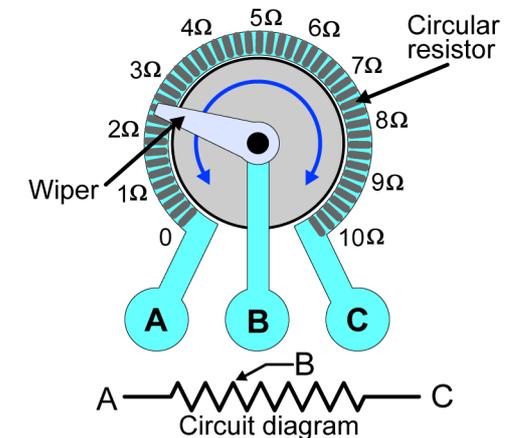


Figure 13.16: The resistance of this potentiometer can vary from 0 Ω to 10 Ω .

13.3 Section Review

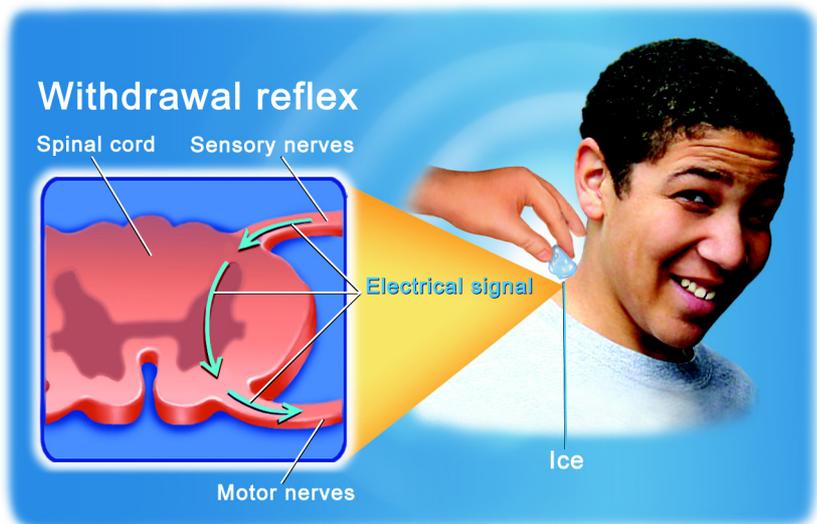
1. What happens to the current if a circuit's resistance increases? What if the voltage increases instead?
2. List the units used to measure resistance, voltage, and current. Then give the abbreviation for each unit.
3. Classify as a conductor, semiconductor, or insulator each of the following: air,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

Electric Circuits in Your Body

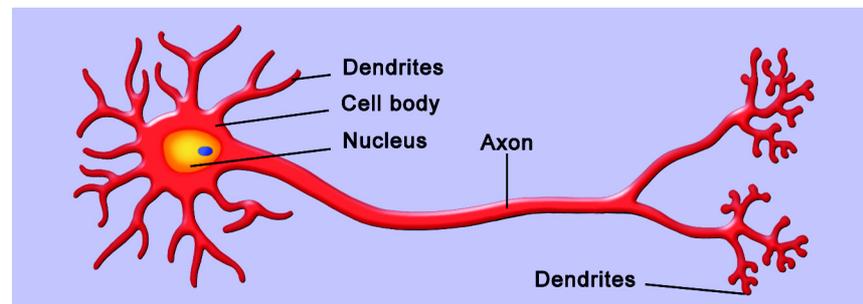
Imagine you're relaxing on the couch, watching your favorite television show. You're so absorbed in the action that you fail to notice your younger sister sneaking up behind you. Suddenly she reaches over the back of the couch and touches the back of your neck with a wet, frosty ice cube.

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.

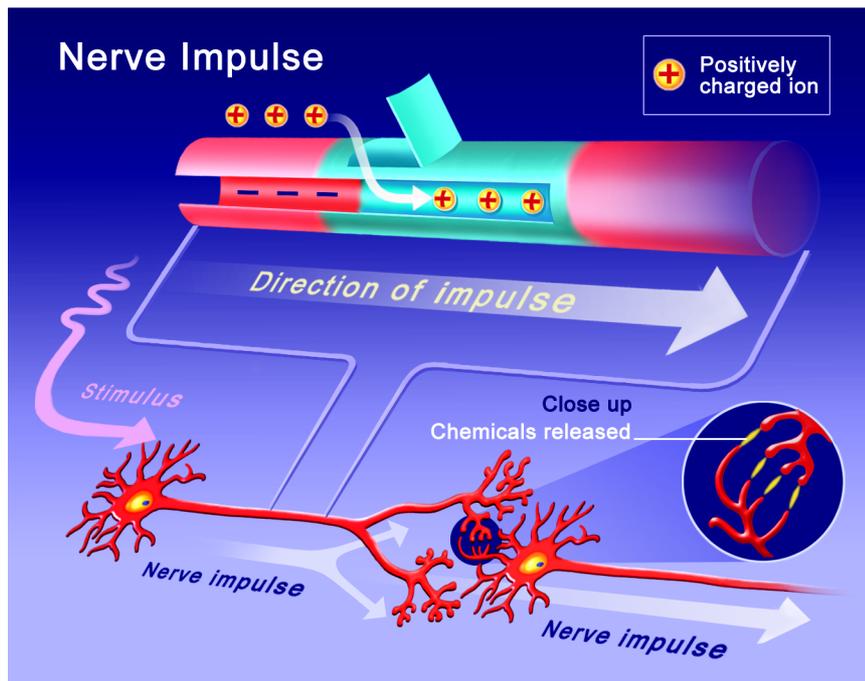
Nerve impulse: a wave of electrical changes

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.

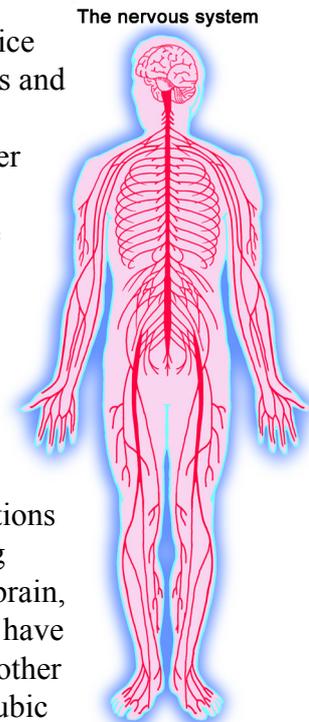
- Other channels open and let positively-charged ions out of the cell. As the ions leave, the inside the cell membrane once again becomes negatively-charged compared with the outside.
- The nerve impulse travels down the axon like dominoes falling. When the impulse reaches the end of the axon, chemicals 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:

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

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

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

Section 13.2

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

Section 13.3

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

Reviewing Concepts

Section 13.1

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

Section 13.2

- The direction of electric current in a circuit is away from the _____ end of the battery and toward the _____ end.
- How are voltage and energy related?
- A voltage of one volt means one _____ of _____ does one _____ of work in one second.
- Explain how a battery in a circuit is similar to a water pump.
- What are the differences between a multimeter, a voltmeter, and an ammeter?
- 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

- 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 it 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?

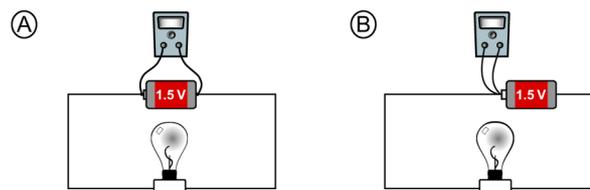
Solving Problems

Section 13.1

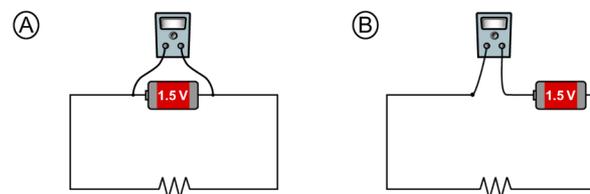
1. Draw a circuit diagram of a circuit with a battery, three wires, a light bulb, and a switch.

Section 13.2

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



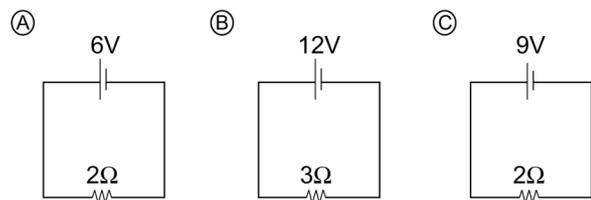
3. Which of the following diagrams shows the correct way to measure current in a circuit?



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

Section 13.3

- What happens to the current in a circuit if the resistance doubles? What if the resistance triples?
- What happens to the current in a circuit if the voltage doubles? What if it triples?
- A hair dryer draws a current of 10 A when plugged into a 120 V outlet. What is the resistance of the hair dryer?
- A television runs on 120 volts and has a resistance of 60 ohms. What current does it draw?
- 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?
- The motor in a toy car has a resistance of 3 ohms and needs 1.5 amperes of current to run properly.
 - What battery voltage is needed?
 - How many AA batteries would the car require?
- Find the current in each of the circuits shown below.



- 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?
- 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

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

Section 13.2

- 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.
- Ask an adult to show you the circuit breaker box in your home. Does it contain switches or fuses? How many?
- There are many different kinds of batteries in use today. Research to answer following questions.
 - Are all 1.5 volt household batteries the same on the inside?
 - Why can some 1.5 batteries be recharged and used over and over again?
 - Which type of batteries is used in portable electronics such as cell phones and laptop computers?
- 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

- 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.