8.2 Electric Circuits and Electrical Power

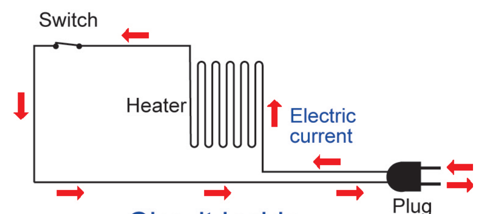
Every electrical device uses current to carry energy and voltage to push the current. How are electrical devices designed? What types of parts are used in an electrical device? Why are some devices more powerful than others, like an electric saw compared to an electric toothbrush? This section is an introduction to the technology of electricity.

Electric circuits

Electricity travels in circuits

An **electric circuit** is a complete path through which electric current travels. A good example of a circuit is the one found in an electric toaster. The circuit has a switch that turns on when the lever on the side of the toaster is pushed 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. Bread is toasted by heaters that convert electrical energy to heat.

Electric toaster



Circuit inside

Wires are like pipes for electricity

Wires act like pipes for electric current, similar to how pipes carry water (Figure 8.8). Water flows into a house through the supply pipe and out through the return (drain) pipe. Electrical current flows in the supply wire and out 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.

VOCABULARY

electric circuit - a complete path through which electric current can flow.

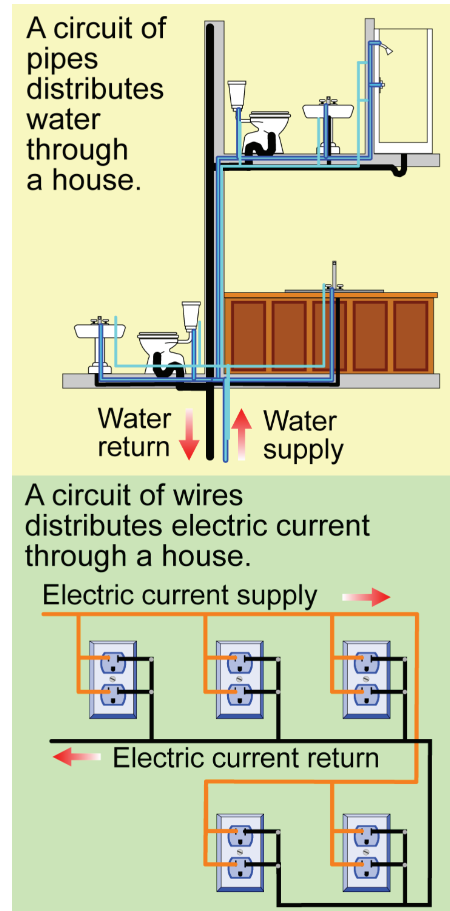


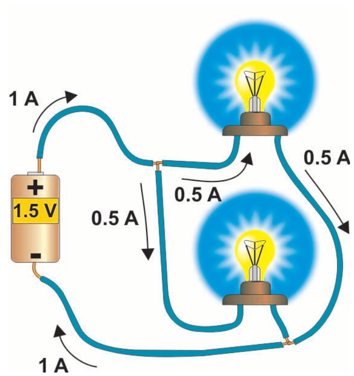
Figure 8.8: *Comparing "circuits" for water and electricity.*

Current in a circuit

Open and closed circuits Current only flows when there is a complete and unbroken path, called a *closed circuit,* from one end of a battery to the other (Figure 8.9). A light bulb will light only when it is part of a closed circuit. The opposite of a closed circuit is an *open circuit*. A circuit with a 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 other electrical device.

Current flow is always balanced



On average, the amount of electric current flowing into any part of a circuit must be the same as the amount flowing back out. Otherwise, charge would "build up" as more charge flowed in than out. This doesn't usually happen because the huge electrical forces between charges immediately attract opposite charges, cancelling any "build-up" before it can occur. It takes special devices (called *capacitors*) to build up even tiny amounts of electric charge.

Why current doesn't "leak out" of a circuit Current does not "leak out" of an open circuit because electric forces are very, very strong. As an example, imagine you could completely separate the positive and negative charges from inside the atoms in the point of a pencil. At a distance of 1 meter, the attractive force between them would be 50 thousand billion newtons. This is the weight of *three thousand million* cars, just from the charge in a pencil point (Figure 8.10)! The huge forces between charges are the reason current stops flowing the moment a circuit is broken.

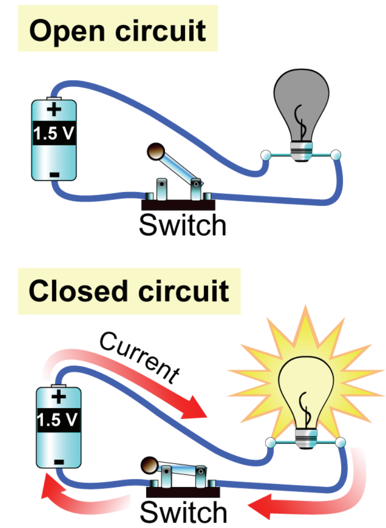


Figure 8.9: *There is current in a closed circuit but not in an open circuit.*

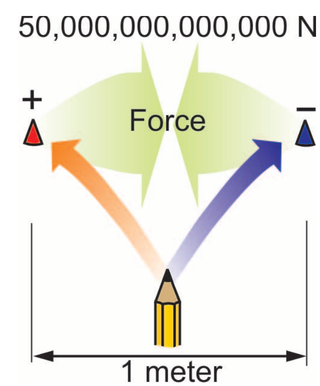


Figure 8.10: *If you could separate the positive and negative charge in a pencil point by one meter, the force between the charges would be 50 thousand billion newtons.*

Electrical power

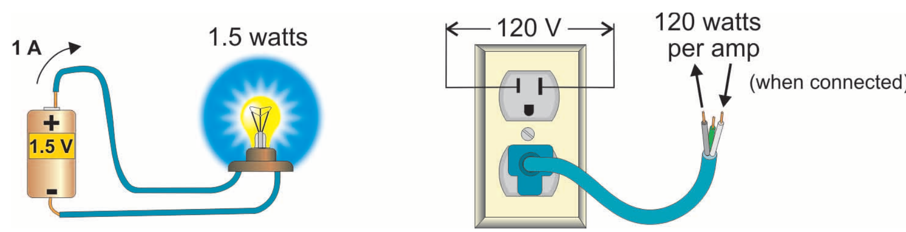
Electrical power is measured in watts

Electrical power is measured in watts, just like mechanical power (Chapter 6). Remember, power is energy per second, or energy flow. One watt is one joule per second. If you look at the top of a light bulb there is a label telling you how many watts it uses. A 100-watt electric light bulb uses 100 joules of energy *every second* (Figure 8.11).

Electrical power depends on both voltage and current

One amp of current carries one watt of electric power for each volt. The higher the voltage, the more power is carried by each amp of electric current. One amp from a 1.5-volt battery carries 1.5 watts of power. One amp from a 120-volt wall socket carries 120 watts of power.

Voltage is power (watts) per amp of current



Calculating power

Since one volt is one watt per amp, to calculate power in an electric circuit you multiply the voltage and current together. For example, suppose a 9-volt battery causes 0.5 amps to flow in a circuit. How much power does the battery provide? Well, 9 V × 0.5 A = 4.5 W. The battery supplies 4.5 watts of power.

Why electrical outlets use higher voltage

Devices that use higher power are often designed to use higher voltages. Higher voltage means the power can be carried with a smaller amount of current. For example, suppose you wanted to run a saw that needs 1,500 watts. Each amp from a 1.5 volt battery carries 1.5 watts. You would need 1,000 amps of current to get 1,500 watts. This is ten times more current than an average house uses! At 120 volts, the same power is carried by a current of only 12.5 amps. That is why your outlets are at 120 volts instead of 1.5 volts.

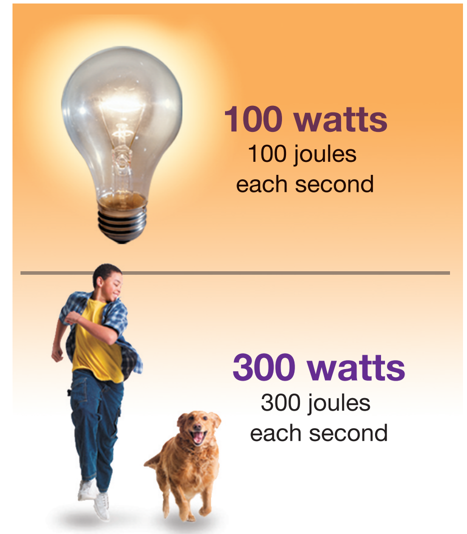


Figure 8.11: *A 100-watt electric light bulb uses 100 joules of electrical energy every second.*

POWER

Power (watts)
Current (amps)

$$P = IV$$

Voltage (volts)

Resistance

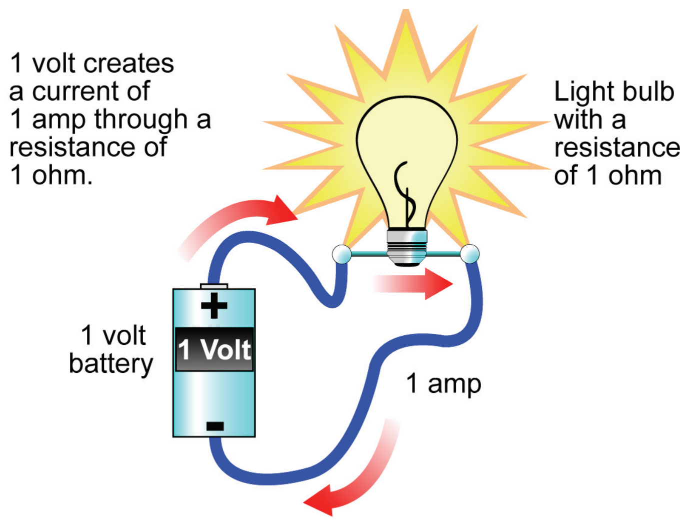
How much current flows?

You can apply the same voltage to different circuits and different amounts of current will flow. For example, when you plug a 60-watt desk lamp into a 120-volt outlet, it draws a current of 0.5 amp. If a hair dryer is plugged into the same outlet the current is 10 amps. How does each device know the right amount of current to use?

Current and resistance

Resistance (R) controls how much current flows for a given voltage. When resistance is low, current flows easily. A small voltage can cause a large current to flow. When resistance is high, it takes more voltage to make current flow. The relationship between current and resistance is like water flowing from the open end of a bottle (Figure 8.12). If the opening is large, the resistance is low and lots of water flows (high current). If the opening is small, the resistance is greater and less water flows (low current).

The ohm



Electrical resistance is measured in **ohms**. The Greek letter *omega* (Ω) is used to represent resistance in ohms. When you see Ω in a sentence, think or read "ohms." For a given voltage, the greater the resistance, the less current flows. If a circuit has a resistance of 1 ohm, then a voltage of 1 volt causes a current of 1 amp to flow.

VOCABULARY

resistance - determines how much current flows for a given voltage. Higher resistance means less current flows.

ohm - the unit of resistance. One ohm (Ω) allows 1 amp to flow when a voltage of 1 volt is applied.

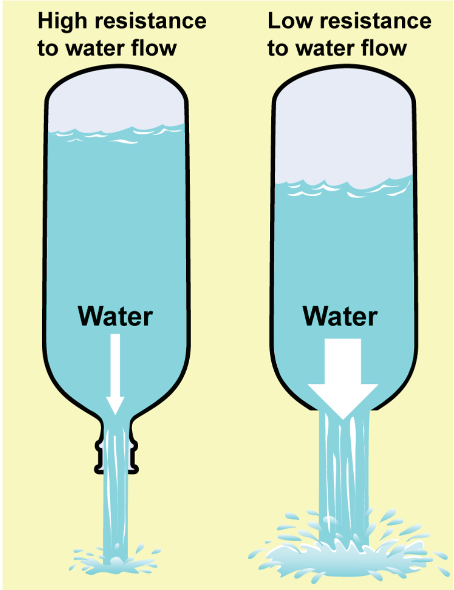


Figure 8.12: *The current is less when the resistance is greater.*

Ohm's law

Ohm's law The current in a circuit depends on voltage and resistance (Figure 8.13). 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.

Ohm's law

$$\textit{Current (amps, A)} \rightarrow I = \frac{V}{R} \quad V \leftarrow \textit{Voltage (volts, V)}, \quad R \leftarrow \textit{Resistance (ohms, } \Omega)$$

How much current flows when a 6Ω bulb is connected to 3V from batteries?

$$\textit{current} = \frac{\textit{voltage}}{\textit{resistance}} = \frac{3\text{ V}}{6\Omega} = 0.5\text{ A}$$

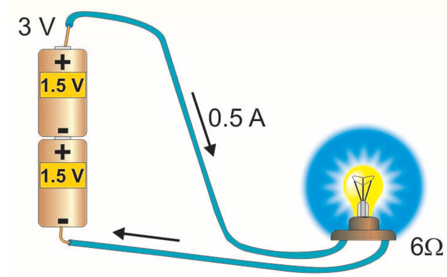


Figure 8.13: *Some examples of Ohm's law in action.*

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

Every electrical device is designed so its resistance causes the right amount of current to flow when 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 8.14). 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, only 0.00625 amp flows through 240 ohms when 1.5 volts are applied. This is not enough current to make light.

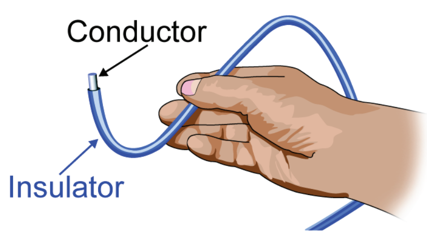
The resistance of skin

You can get a fatal shock by touching some electrical wires, so why is it safe to touch a 9-volt battery? The reason is Ohm's law. Remember, current is what flows and carries power. The 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. 120 volts from a wall socket is dangerous because it can push 0.0012 amps (120 V ÷ 100,000 Ω) through your skin, 13 times as much as the battery.

Water lowers skin resistance

Wet skin has much lower resistance than dry skin. Lower resistance allows more current to pass through your body at any voltage. The combination of water and 120-volt electricity is especially dangerous because the high voltage and lower resistance allow large (possibly fatal) currents to flow.

Conductors



A **conductor** is a material with low electrical resistance. Most metals, like copper, are good conductors. That is why the current-carrying part of a wire is copper or aluminum. **Insulators** are materials with high resistance. The outer part of a wire is an insulator, such as rubber or plastic. The insulator protects your skin by blocking the current. The outside of electrical cords and many electrical devices are insulators for safety. Wires with broken insulation (exposing bare metal) can be very dangerous.

VOCABULARY

conductor - a material with a low electrical resistance. Metals such as copper and aluminum are good conductors.

insulator - a material with a high electrical resistance. Plastic and rubber are good insulators.

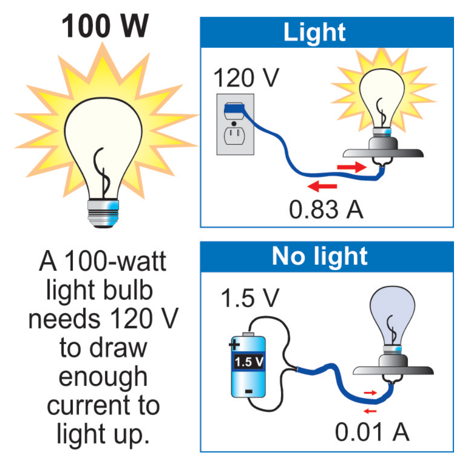
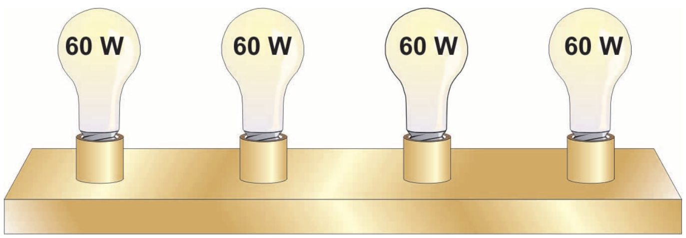


Figure 8.14: *A light bulb designed for use in a 120-volt household circuit does not light when connected to a 1.5-volt battery.*

8.2 Section Review

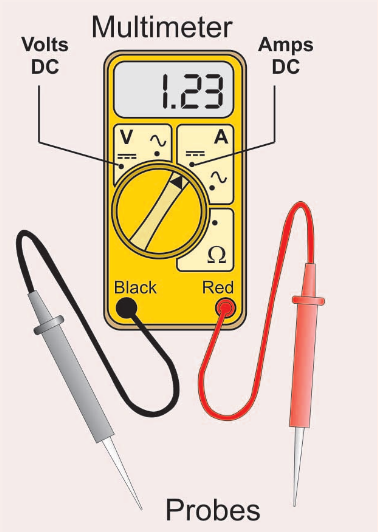
1. An electrical circuit is:
   a. a network of pipes that carry water
   b. a path for electric current to flow
   c. a source of voltage that can push current
   d. what flows and carries electrical power
2. What is a difference between water in pipes and current in wires?
   a. Water flows but electrical current does not.
   b. Water leaks out of open pipes but current does not leak out of open wires.
   c. Low resistance allows more water to flow and high resistance allows less to flow.
3. How much electrical power is carried by 2 amps of current from a 1.5-volt battery?



4. How much current must flow to carry 240 watts at 120 volts? This is the amount of electrical power used by the bathroom light fixture with four 60 W bulbs shown above.
5. Which carries more power: 100 amps at 12 volts or 10 amps at 120 volts? (Hint: Is one more, or are they equal?)
6. What happens to the current if a circuit's resistance increases? What if the voltage increases instead?
7. List the units used to measure resistance, voltage, and current. Give the abbreviation for each unit.
8. Classify each of the following as a conductor, semiconductor, or insulator: air, gold, silicon, rubber, and aluminum.

TECHNOLOGY

Measuring voltage and current



Humans cannot normally sense voltage or current. Instead, we use a multimeter to find the voltage or current in a circuit. 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. To measure current, the circuit is broken and reconnected through the meter. The current then passes through the meter where it can be measured.