Electricity Simplified

READING ASSIGNMENT

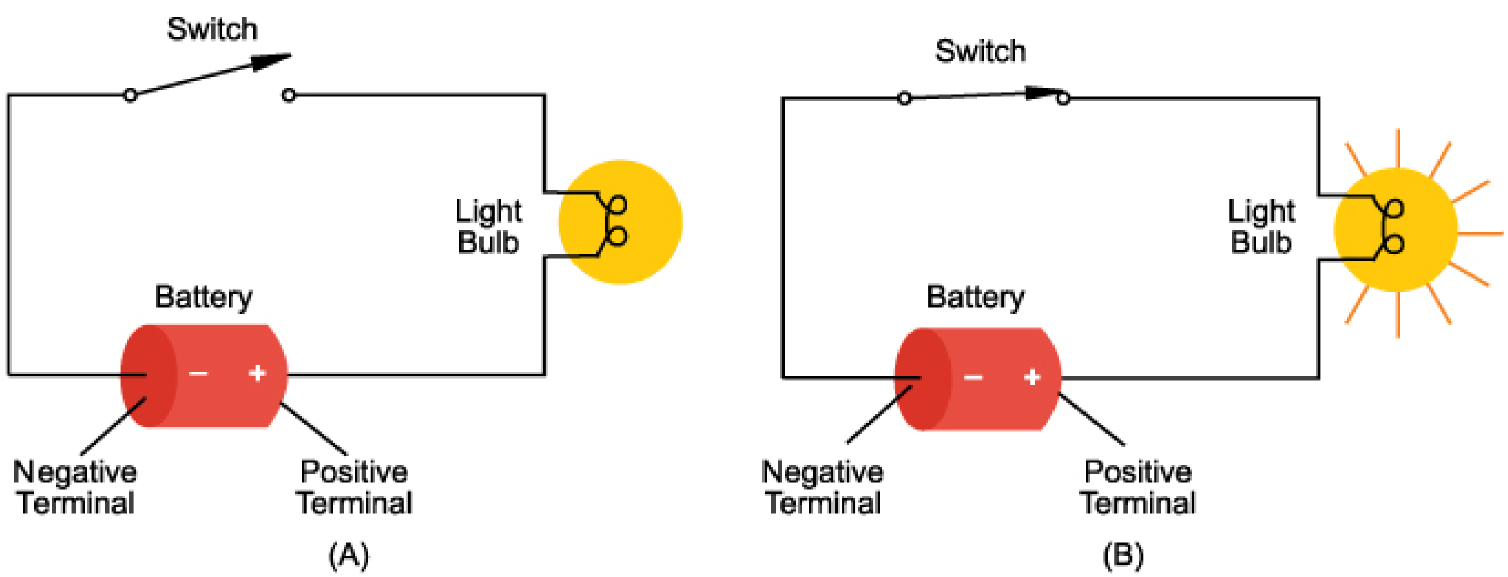
Electrical Circuits

An electrical *circuit* is defined as a complete electrical path. A typical circuit includes four components:

- The *power source* feeds power into the circuit. In homes, the power source is the service panel.
- The *conductors* are the wires that carry the electricity.
- The *load* is any device, such as a light fixture or appliance, that runs with electricity.
- The *switch* is the device used to turn the electricity flow on and off.

In a circuit, when the switch is turned on, electrical current from the power source flows through an unbroken path to the load. Then, the light turns on or the appliance runs. This is called a *closed circuit* because the circuit is complete—the current flows through the entire circuit path.

When the switch is turned off, the path of the circuit is broken, and the current can't flow to the load. The light goes out or the appliance stops running. This is called an *open circuit*.



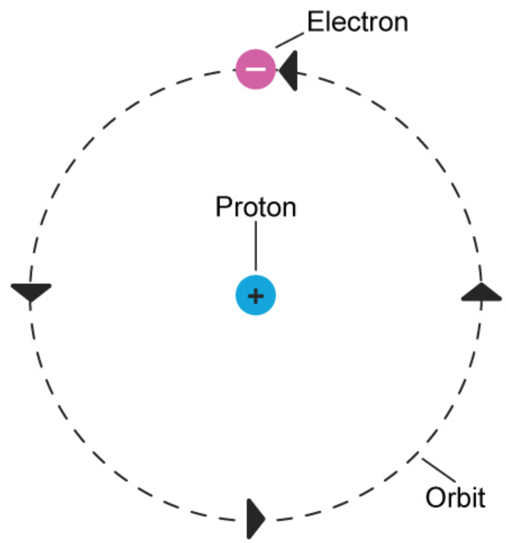
This figure illustrates a simple electrical circuit. In A, the switch is open, so electricity can't flow to the lightbulb. In B, the switch is closed, allowing electricity to reach the lightbulb.

A simple flashlight circuit is shown in the figure. The power source in this circuit is a battery. The conductors are copper wire. The load is a standard light bulb. In A the switch is open (turned off). The electrical circuit is therefore open, and current can't flow through the wires to get to the lightbulb. In B the switch is closed (turned on). The circuit is therefore complete, and current can flow through the wires to reach the lightbulb and turn it on.

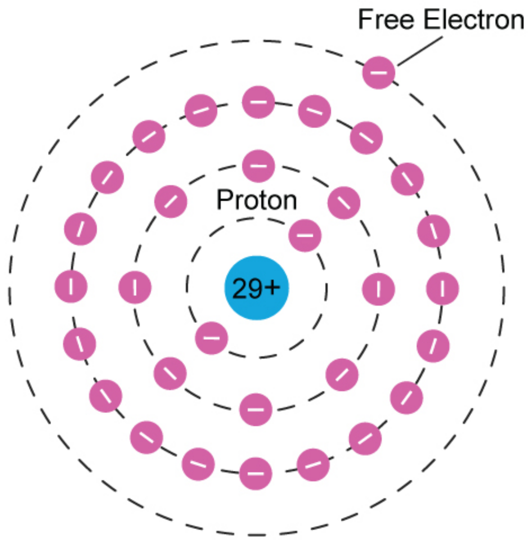
Electrons

Did you ever wonder what electricity really is? In simple terms, electricity is the movement of electrons. All matter in the universe is formed from about 100 or so different substances called *elements*. An *atom* is the smallest particle of an element that retains the properties of the element. So, each different element, such as gold, silver, or oxygen, is made up of its own unique gold, silver, or oxygen atoms.

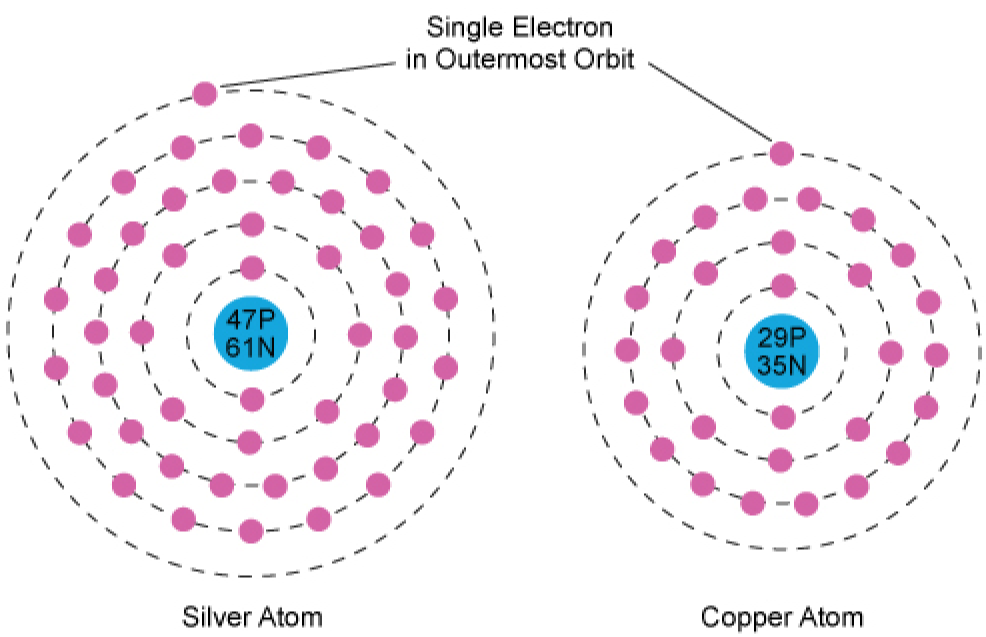
All atoms are made up of tiny atomic particles called protons, neutrons, and electrons. The *electron* is a tiny, very lightweight particle that has a negative electrical charge. *Protons* are much heavier than electrons, and they have a positive charge. *Neutrons* have no electrical charge at all—they're neutral. Electrons are the smallest type of atomic particle; they're much smaller than the atom as a whole.



A single atom of hydrogen contains one proton and one electron. The proton is represented by the circle with the plus sign (+) inside. The electron is represented by the circle with the minus sign (-) inside.



A copper atom contains a single electron in its outermost orbit. This free electron can be easily dislodged from its orbit.



Both silver and copper atoms have a free electron in their outermost orbits, and both are good electrical conductors. However, the free electron in the silver atom is farther away from the nucleus than the free electron in the copper atom. This means that the silver electron can be more easily dislodged from its orbit than the copper electron. Thus, silver is an even better electrical conductor than copper.

A hydrogen atom is the simplest atom, as it contains one electron and one proton. The proton is located in the *nucleus*, or the center, of the atom. The electron orbits around the nucleus, much as the moon orbits around the earth. All atoms are constructed in the same general way as the hydrogen atom, but the number of protons, neutrons, and electrons varies with each different substance.

The hydrogen atom is perfectly balanced electrically. The atom contains one positively charged proton and one negatively charged electron; the proton and electron balance each other out. Because of this balance, the electron in a hydrogen atom is tightly attached to the proton. The electron can't be easily removed from the atom.

Now, look at an atom of copper. The copper atom contains 29 electrons and 29 protons. The electrons orbit the nucleus of the copper atom in several layers called *shells*. The outermost shell contains only one electron called a *free electron* or *valence electron*. Since the free electron is alone and very far away from the atom's nucleus, it can be easily dislodged from its orbit.

Free electrons that can be easily dislodged from their orbits are very important in your study of electricity. You've learned that electricity (electrical current) is produced by the movement of electrons. To get the electrons moving, they have to be removed from their atoms.

The structure of an atom will determine how easily an electron can be removed from it. For example, you saw that the structure of the hydrogen atom makes it difficult to remove an electron from its orbit. Because of this, it's very difficult to get electrons moving in hydrogen atoms. However, in the copper atom, the outermost electron can be easily removed from its orbit. Therefore, it's very easy to produce a flow of electrical current in copper atoms. This is why copper is used in electrical wires and cables.

Any substance in which electrons can move freely is called a *conductor*. Atoms that are tightly bonded are very poor conductors of electricity, while atoms that contain free electrons in their outer shells (like copper) are excellent conductors of electricity.

Conductors and Insulators

When electrical current is applied to different materials (such as metals or plastics), it may or may not be carried readily. A material in which electrons can be moved easily from one atom to another is a good conductor because it conducts (carries) electricity. Metals like copper, silver, and aluminum readily allow electricity to flow through them and are, therefore, good conductors.

In contrast, a material in which electrons can't be moved easily from their atoms is a poor conductor of electricity. Some materials carry almost no electricity at all, even when a very high voltage is applied to them. These materials are called *insulators* because they're insulated against electrical flow. Examples of insulators are glass, mica, porcelain, paper, plastic, and rubber.

The properties of conductors and insulators are important because they have practical applications in home electrical systems and in electrical devices and equipment. Metals like copper and aluminum are used in electrical wiring because they carry electrical current so well. Insulating materials like plastic and rubber are used as coatings on the outside of cables to prevent the current from leaking out.

Positive and Negative Charges

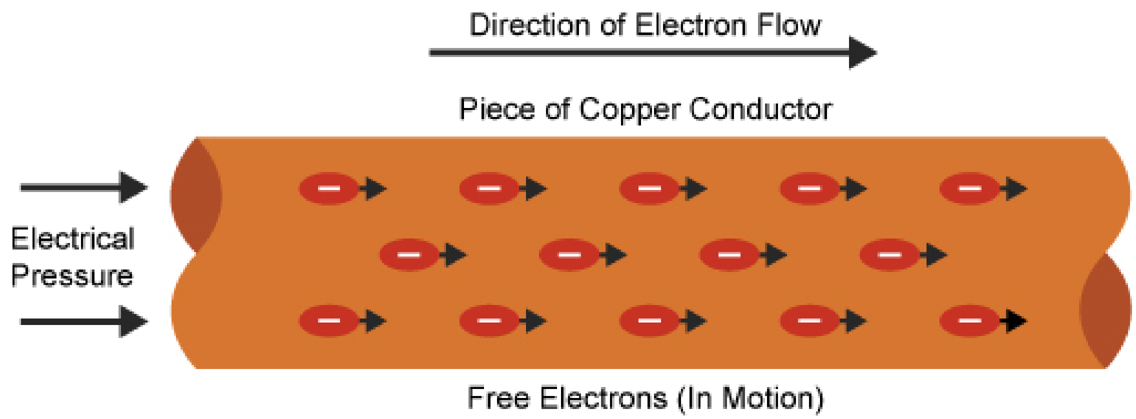
The behavior of positive and negative charges is very similar to the behavior of the two poles a magnet. You know that in magnets, the opposite poles attract each other, and the same poles repel each other. So, if you hold the opposite poles (north and south) of two magnets close together, the poles will stick together. If you hold the same poles (north and north or south and south) of two magnets close together, the poles will push each other away. The magnets create what's known as a *magnetic field*.

In the same way, atomic particles that are electrically charged will attract and repel each other. The electrical charges create what's known as an *electric field* which has similar attract and repel properties as a magnetic field. When a large number of electrons are together, all of their negative charges cause the electrons to repel each other strongly. As a result, electrons can't touch together. Only their charges interact with each other, keeping each electron away from the other electrons.

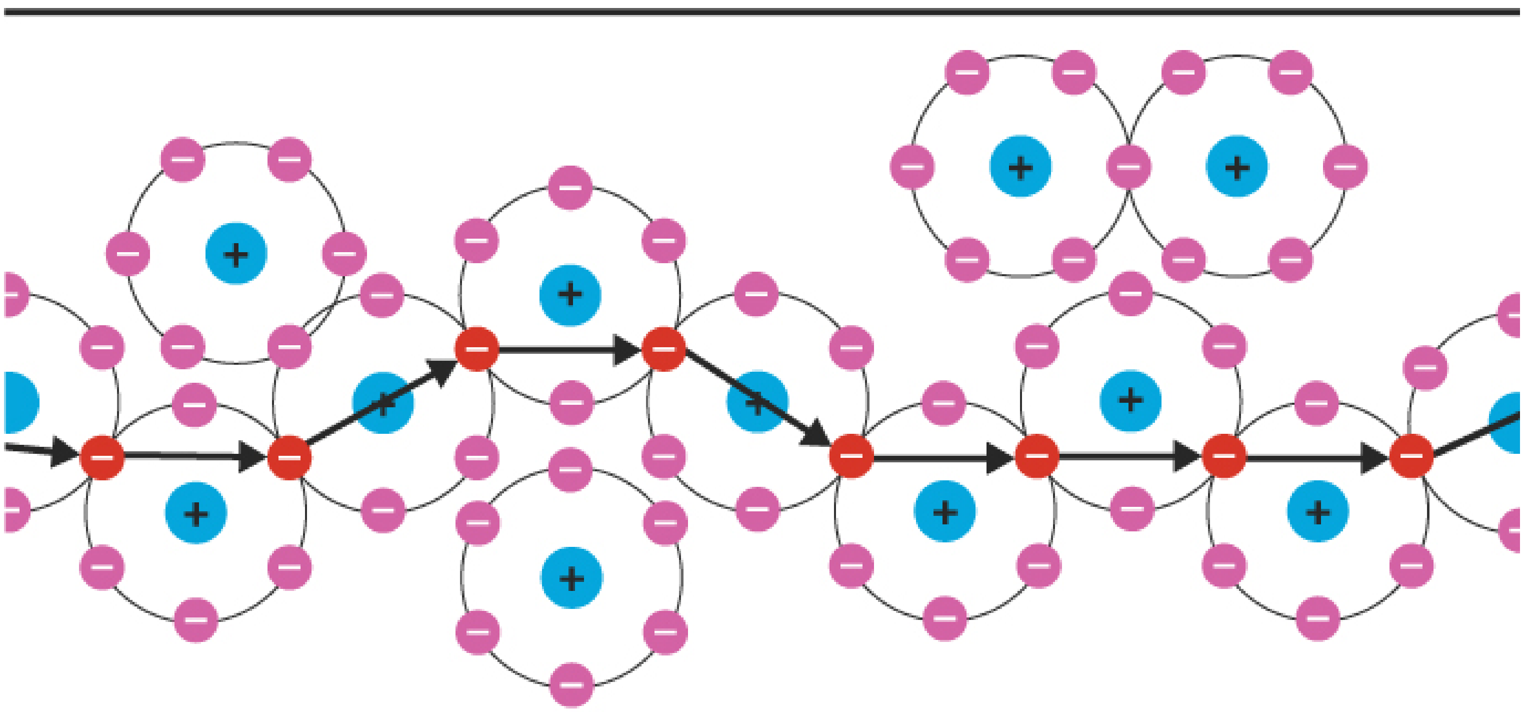
In a copper wire, there are billions of loose or free electrons, all safely in place in their orbits. They're distributed evenly throughout the wire. When a large number of electrons are together, all of their negative charges cause the electrons to strongly repel each other. As a result, the electrons can't touch together. Their charges interact with each other, pushing each electron away from the other electrons.

Electrons in Motion

If you can get one electron in a wire to move, the repulsion of the negative charges will start other electrons moving. Instantly, a chain reaction begins, with billions of electrons repelling each other and moving through the wire. The electrons all move in the same direction.



Simplified Movement of Electrons



Actual Movement of Electrons

When electrons are forced to move, they become a current flow and are able to perform work. The electrons move in a chain reaction. One electron bumps into another, and that electron bumps into another, and so on, with each electron bumping the next one in line.

As each moving electron strikes and repels the next electron in the "chain," some energy is lost. The lost energy is felt as heat in the wire. The kinetic energy associated with the electrical current can be converted to perform useful work. (In other words, the energy can be used to run lighting fixtures and appliances.) Remember, though, that to do work, electrons have to be in motion. When they stand still, they do no work. The electrons will be moved to work whenever you turn on a light switch or plug in an appliance.

Direct and Alternating Current

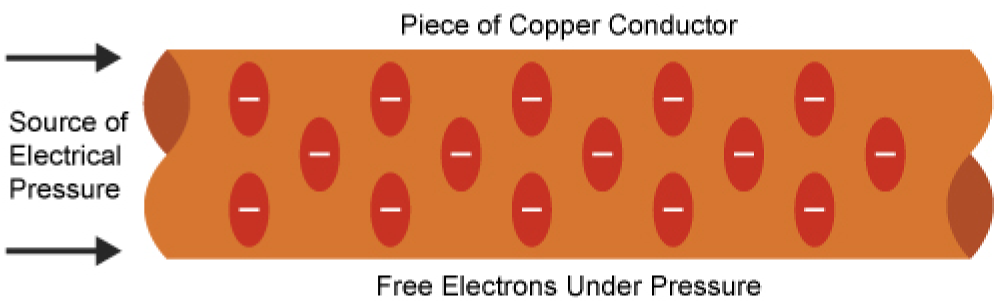
When electrons move in one direction, the resulting current flow is called *direct current,* or *DC*. Direct current is produced mainly by storage batteries and is used in battery-operated equipment and devices (such as flashlights, automobiles, and cordless tools).

When electrons move in both directions, the current flow is called *alternating current,* or *AC*. In AC, the electrons start off in one direction, stop, reverse themselves, and go back in the opposite direction. Work is performed whenever the electrons are moving, no matter which direction they move in.

In the United States, the electricity used in typical home circuits is alternating current. Alternating current changes its direction at a frequency of 60 cycles per second. This means the electrons flow first in one direction, then in the reverse direction, repeating this cycle 60 times every second. The frequency of electron movement is measured in units called *hertz;* one cycle per second is equal to one hertz, abbreviated 1Hz.

Voltage

Now that you understand how electrons move in a conductor, you may be wondering how they begin to move. Electrons can be forced to move when more electrons are pushed into the wire. The pressure required to force electrons into a wire is called *voltage* or *electromotive force.* Voltage is measured in units called *volts* (abbreviated *V*).



When voltage (electrical pressure) is applied to a wire, the loose electrons are packed under pressure.

Voltage, or electrical pressure, is always present in wall receptacles. However, work is done only when voltage moves electrons through a circuit. For this current to flow, the circuit must be complete. Remember, electrons can't flow into the wire without having a way to get out at the other end. So, suppose that you plug a lamp into a wall receptacle. Electrons from the voltage source will force their way into the lamp wire. The electrons will move through the wire, through the filament of the lightbulb, and out through the other wire.

In the United States, electricians work with several common voltages—120/240 V, 120/208 V, and 277/480 V are the most common. A typical home will work with either 120 V or 240 V. In a wall receptacle for a lamp, the typical voltage is 120 V. Most electrical devices and appliances are designed to operate with the 120/240 V that's supplied by local electric utility companies. Higher voltages are used for much larger appliances and things like machinery and industrial equipment.

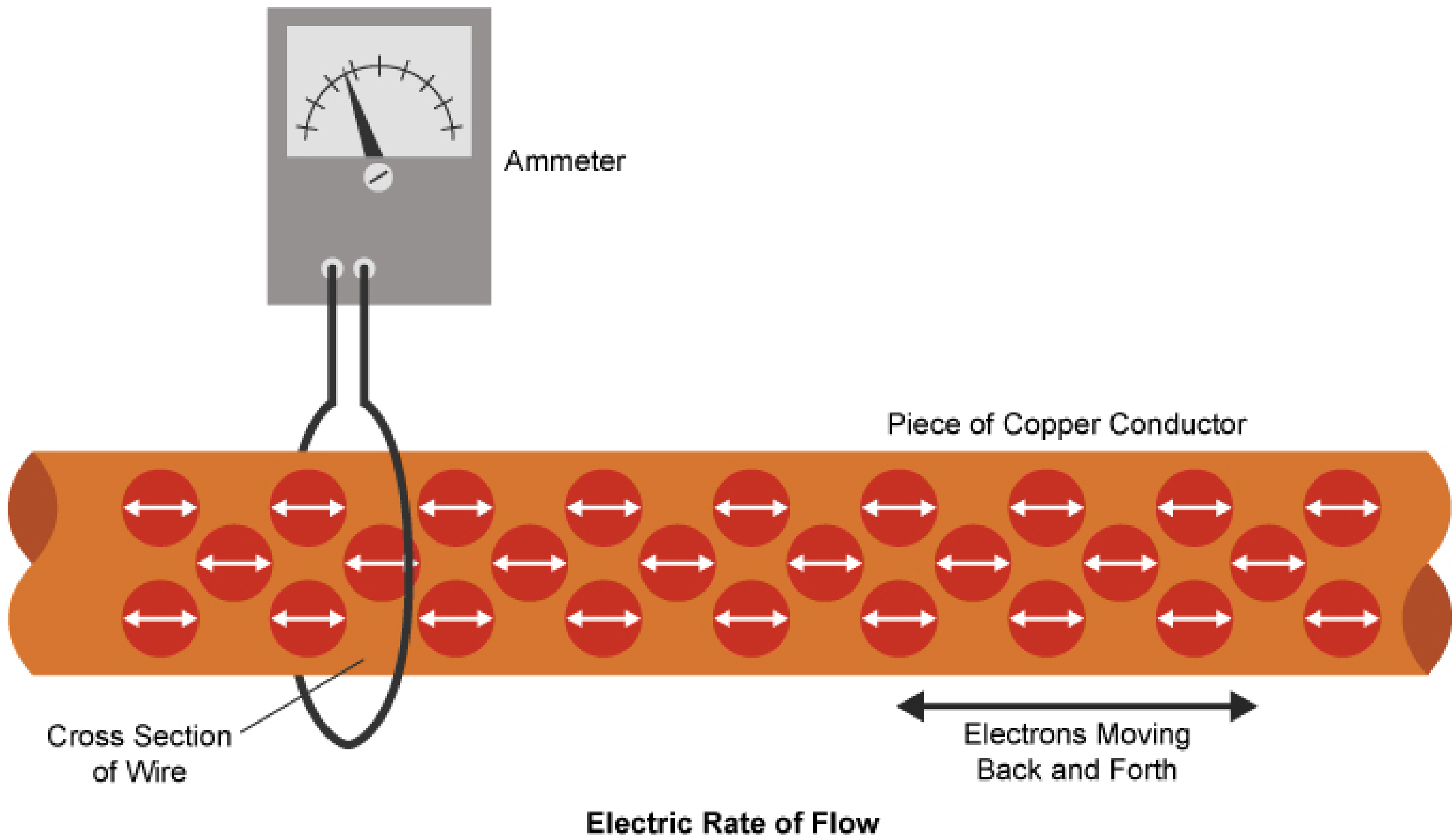
Measuring Current Flow

To form an image of current flow in your mind, take a moment to think about a water system. In order for water to flow through a piping system, it must have somewhere to go. If you try to push water into a pipe that's already filled with water and blocked on one end, no new water will be allowed to enter the pipe. If you remove the blockage by adding a drain to the pipe, the water will flow as long as the pressure remains in the system. Electricity acts similarly to a water system; it must have pressure to push it along, and a "drain" to allow it to flow continuously.

Current needs a "push" to get its flow started. This push comes from voltage. In our water system example, the water pressure can be compared to voltage. The greater the water pressure, the greater the flow of water will be through the pipes. In the same way, the greater the voltage applied to a circuit, the greater the flow of electrons in the circuit. Current flow in a circuit is maintained by a constant, or uninterrupted, voltage.

Voltage or electrical pressure forces electricity to flow. The amount of electric current flowing through a circuit is called *amperage*. The amount of current is measured in units called *amperes* or *amps* (abbreviated *A*). One ampere of current is equal to the charge of 6,240,000,000,000,000,000 electrons flowing past a given point in a circuit per second. The rate of electron flow determines the number of amperes in a circuit. You can see that it takes many millions of electrons flowing in a circuit to perform useful work!

Current flow or amperage can be measured with a device called an *ammeter.* The ammeter measures the rate of electron flow that passes through a cross section of wire.

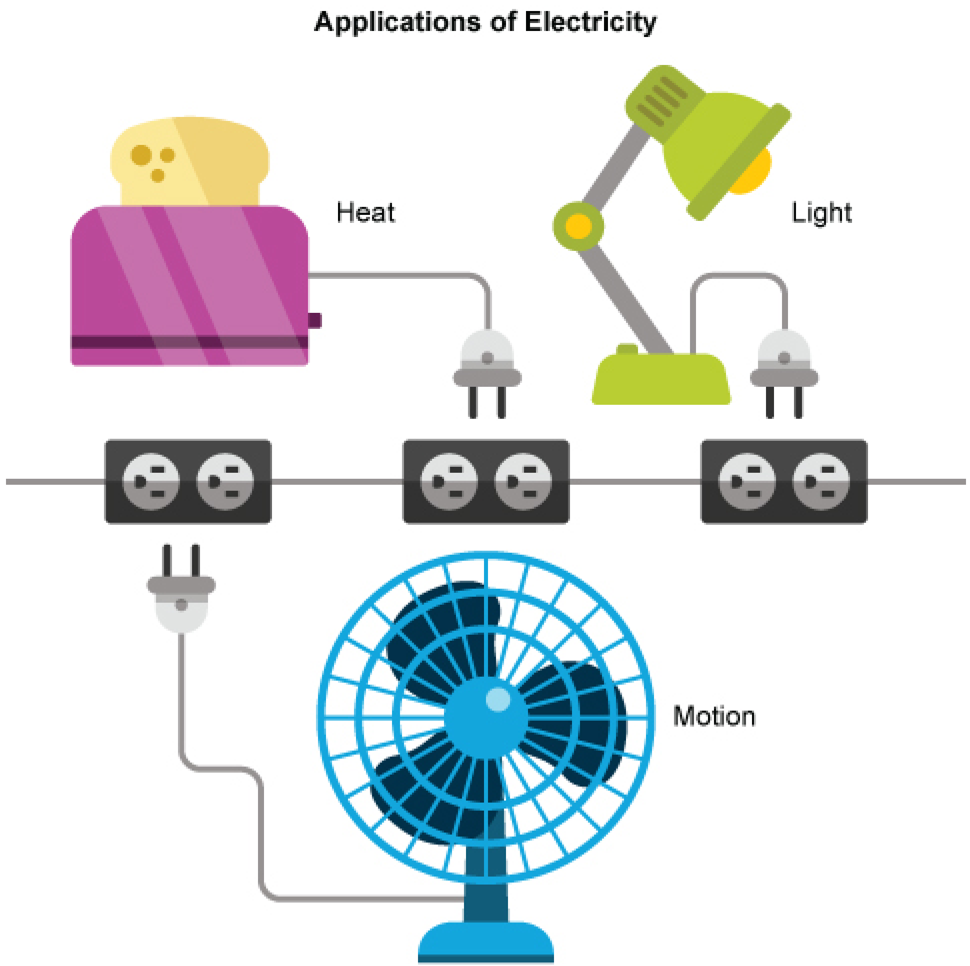


The electrical current flow or amperage that can be measured with an ammeter is the rate of electron flow that passes through a cross section of wire.

In our water system example, the current could be compared to the volume of water that's flowing through the water system in a given amount of time (for example, the number of gallons per minute that are flowing through the system). Water can flow more easily through the system if a large pipe is used instead of a small one. Similarly, in an electrical system, resistance to the current can be decreased by using thicker conducting wires.

Using Current to Perform Work

Once electrons are moving in a wire, they can be used to perform work. This is because as current flows, it possesses kinetic energy which can be converted to heat energy, light energy, or other forms of motion by devices in the home. For example, when current passes through a light bulb filament, the filament gets white-hot and emits light. When it passes through a toaster's heating element, the element gets red-hot and transmits heat to your bread. Current passing through a motor's field coils generates a magnetic field that makes the motor rotate, producing mechanical power.



Electrical energy is used to produce heat (in a toaster or space heater), to provide mechanical energy or motion (in fans and motors), and to provide light in a home.

Different devices need different amounts of electrical current to operate. Each device requires a certain number of amps. Therefore, the electrical system in a home is designed to handle your total amperage needs. If you add up all the amps you need to run your home, you'll probably find that you use less than 200 A. For example, your air conditioner may require between 15 A and 20 A, but your television may need only 1 A to 2 A.

When an electrical system is installed, the system must be designed to handle the home's total amperage needs. This total is calculated assuming that all appliances are turned on at the same time. The amount of amperage required varies depending on the type of electrical device. Since more amps often means higher costs, many of today's appliances and other electrical devices are designed to use less amperage and thus be more energy efficient.

A typical home electrical system will operate with 120/240 V. The 120/240 V voltage that a typical home uses comes from the power company and remains the same at all times. In most cases, the power company has the ability to provide you with all the power you require. The amount of current that's used varies, however, as different appliances are turned on and off. As more devices are turned on, more current flow is needed to pass through the electrical system.

Electrical Units

At this point in your studies, it will be helpful to review some of the standard units, notations, and symbols used in electrical work. In the field of electricity, a variety of terms are used to describe quantities in electrical components and circuits. Some of these units are volts, amps, coulombs, ohms, and watts.

Electrical Units		
Quantity	**Unit**	**Definition of Basic Unit**
Potential	Volt (V)	One volt is the work of one joule per coulomb.
Current	Ampere (A)	One ampere is the movement of electrical charges at a rate of 1 coulomb per second.
Charge	Coulomb (C)	One coulomb is the quantity of charge equal to 6.24×10^{18} electrons.
Resistance	Ohm (Ω)	One ohm is the resistance that allows a current of one ampere when a potential of one volt is applied to a conductor.
Power	Watt (W)	One watt is the power exerted in a circuit with a potential of 1 volt and a current of 1 ampere.

You've already learned a little bit about volts and amps. The strength of electromotive force is measured in volts. Voltage can be compared to water pressure in a water system. The stronger the voltage, the stronger the flow of electrons in an electrical circuit. *Amperage* refers to the amount of electric current flowing through a circuit and is measured in amperes, or amps.

Electrical *resistance* is the opposition that a circuit creates against the flow of electrical current. The magnitude of electrical resistance in a circuit is measured in *ohms.* One ohm is equal to the resistance of a circuit in which one volt is applied to produce one ampere of current. The abbreviation used for ohm is the symbol Ω.

Another electrical unit you should be familiar with is the *watt.* Watts are used to measure *power,* or the amount of useful work that can be done by a circuit. The abbreviation for watt is *W.*

How Electrical Units Are Related

Three of the electrical units just discussed have a special relationship to one another. These three units are the ohm, the ampere, and the volt. The connection between these units was first defined by George Ohm, and his statement of this relationship is called *Ohm's law.*

If we use the letters *V, I,* and *R* to represent voltage, current, and resistance, we can state Ohm's law with the formula

$$V = I \times R$$

in which *V* stands for voltage in volts, *I* stands for current in amperes, and *R* stands for resistance in ohms.

> Note that in Ohm's Law, the letter *I* stands for current. This is derived from the French phrase *intensité de courant*, or *current intensity* in English. "Current intensity" has since been shortened to simply "current" in modern terms. It's important to remember that *I* stands for current, but a *measurement* of current will be given in amperes, or A.

In your work with electricity, Ohm's law will have many practical applications. Using the Ohm's law formula and a little basic math, you can determine the voltage, current, or resistance in any circuit.

Watts

So far, you've learned about the flow of current in the system, which is measured in amperes. As a homeowner, you pay the electric company for the amount of current flow you use from its wires. The more current you use, the higher the electric bill. When looking at a typical bill, you may think that the rate the power company charges for electricity is based on amperes. However, it's actually based on a different measurement—kilowatts.

To understand kilowatts, think of the way light bulbs are labeled. Bulbs are typically marked with their wattages, or W—for example, 60 W or 100 W. The *watt* is the basic unit that's used to measure electrical power. So, the watt label on a lightbulb is the amount of power that's required to light that particular bulb. Unlike amperage, which is a measure of the amount of flow, *power* is a measure of how much work can be done by the flow over a period of time. Since one watt of power is a very small amount, power is commonly measured in *kilowatts (kW)*. One kilowatt is equal to 1,000 watts.

Every device in a home uses a certain amount of power when it's turned on. Electrical power is the product of the voltage and the current in a circuit. That is, voltage (in volts) multiplied by current (in amperes) equals power (in watts). This relationship is expressed by the following formula:

$$P = V \times I$$

In this formula, *V* stands for voltage in volts, *I* stands for current in amperes, and *P* stands for power in watts.

However, note that you don't pay the electric company for power; you pay for energy. *Energy* is the amount of power that's used over a period of time. The unit that's commonly used to measure electrical energy is the *kilowatt-hour* (abbreviated *kWh*). One kilowatt-hour is equal to one kilowatt of power taken continuously from the utility for a period of one hour (*h*).

Your bill from the electric company is calculated according to the number of kilowatt-hours of energy used. The amount of energy used in your home is measured by an electric meter that's called a *kilowatt-hour meter.* In previous times, an electric company employee read the kilowatt-hour reading on your electric meter to determine how much energy you had used, and thus how much you must pay the electric company. Today all new kWh meters are either connected to the utility by modem or through the power line itself using a technology known as *Power Line Communication (PLC)*.

The *wattage* of an appliance is the amount of power that's needed to enable the appliance to function properly, as observed earlier with the lightbulbs. Look at the list of appliances in the Appliance Power Ratings table. The table lists the wattage of several popular appliances. If all of these appliances were turned on at the same time, they would use a total of 3,677 W (3.677 kW) of power.

Appliance Power Ratings	
Appliance	**Power Rating**
Night light	7 W
Computer	200 W
Stereo	150 W
Ceiling light	120 W
Hair dryer	1,500 W
Refrigerator	1,000 W
Table lamp	60 W
Television	200 W
Vacuum cleaner	400 W
Shop light	40 W
Total	**3,677 W**

You and the Electric Company

As an electrician, you'll work very closely with the electric company, so it's a good idea to develop a positive working relationship with them. The electric company will deliver the voltage and power required to allow electrical installations to draw the amount of current they need.

Electricians are responsible for installing, maintaining, and repairing every single item in an electrical system. If the installation is a house, this includes all the circuits, the circuit materials, and the service entrance. The only parts of the installation that an electrician doesn't control are the kWh meter itself and the wires that come into the house from the utility pole or transformer. The electric company provides the kWh meter. An electrician will, however, have to install the meter socket for the electric company to attach the meter to.

In order for you to be able to hook up to the electric company’s system, your electric installation must be safe. For new installations or for major overhauls, the company may send an inspector to advise you and to ensure that your work is completely professional. In addition, your work may also have to be approved by the local city or county electrical inspector before the power company will hook up to it. Electric companies have developed layouts and procedures that will help you to do a good job. Their advice is valuable and should be heeded by everyone concerned.