8

# Electrical Power Systems

## Basic Concepts

- List the types of current and explain how they are produced.
- State how electrical power is measured.
- Name different types of electrical circuits and give examples of their uses.
- Identify how electricity and magnetism are related.
- Identify the types of electrical circuits used in transportation vehicles.

## Intermediate Concepts

- Describe how atoms act to produce electrical current.
- Perform electrical calculations using Ohm's law, Watt's law, and Kirchoff's law.
- Summarize applications of various switching schemes.
- Explain the purpose of common electrical components, such as fuses, breakers, wires, and batteries.
- Select wire size and other electrical components for specific applications.
- Discuss safety factors associated with live electricity.

## Advanced Concepts

- Use electrical instrumentation safely and properly.
- Troubleshoot basic electrical circuits to identify and remedy problems.
- Design simple electrical circuits to meet specified criteria.

An electrical system uses electrical energy to perform work. Electricity is the most widely used and versatile type of energy. Both simple and very complex electrical systems can be found in all aspects of modern technology. Electrical systems are used to power home appliances that make our lives easier and safer. To save and maintain lives, hospitals use electrical systems to run special machines. Manufacturing facilities rely on electrical systems to run the machines that produce needed products. See **Figure 8-1.**

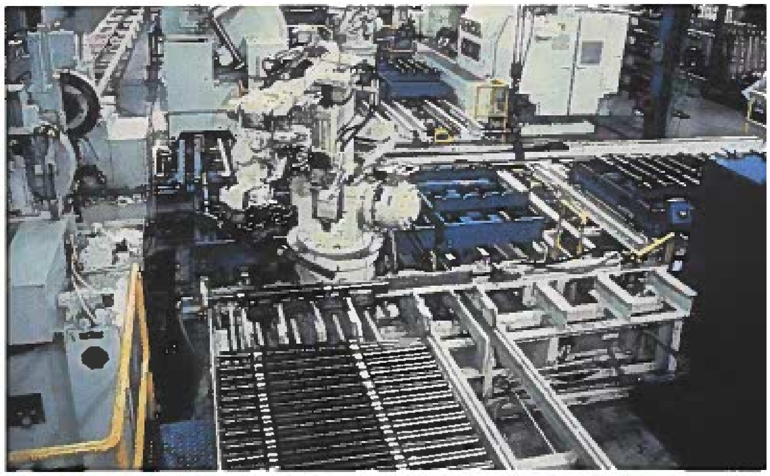


**Figure 8-1.** Electricity powers most modern machinery.

**GREEN TECH**
Hybrid vehicles use gasoline engines in combination with electric motors. The use of the electric motor is being made more efficient to help people rely less on gasoline.

*Atom:* The "building block" of everything we know of on earth. Atoms are made up of protons, neutrons, and electrons.

Electrical systems are also an essential part of most energy, power, and transportation systems. An electrical system in an automobile lets us start the engine and keep it running. Separate electrical systems operate the lights, dashboard displays, radio, and other accessories. Electrical systems can provide the source of propulsion for transportation systems such as elevators, moving sidewalks, and escalators. See **Figure 8-2.** Often, vehicles are propelled by electric motors. Auto manufacturers are beginning to develop electric automobiles as an alternative to the gasoline or diesel engine.

These systems rely on the use of atoms. An ***atom*** is the "building block" of everything we know of on earth. Rocks, trees, people, air, metal, and plastic objects are just a few examples of things made up of atoms. Since atoms are at the root of all electrical systems, this is where we will begin our study.

**Figure 8-2.** Electricity powers some forms of transportation. Electrical energy powers the people mover and the elevator system shown here. (United Airlines and Murphy/Jahn, Architects)

# Career Connection

### *Power Plant Operators*

Manufacturing

Power plants use generators to produce electricity. This electricity is then distributed across power lines to substations and ultimately to homes and buildings throughout the community. Power plant operators help monitor and maintain machines to ensure the machines are functioning correctly.

By careful monitoring of the machines, operators are able to predict and often avoid malfunctions. The workers in a power plant not only monitor the machines, but they also assist in mechanical and electrical repairs. In performing these tasks, they are involved in working with both electrical and mechanical equipment. Their jobs also include testing the machines in order to maintain safe operation.

Power plant operators must have a mechanical aptitude, and they must understand the chemical and physical properties of substances. Necessary skills for this job include engineering and mathematics. A knowledge of computer and electronic equipment is also essential. To be a worker in this field, long-term on-the-job training is required. The yearly salary may range from $38,000 to $80,000.

## Atomic Structure

*Polarity:* The type of charge an atomic particle has.

*Ring:* The path followed by electrons in an atom.

*Valence ring:* The outermost ring of electrons in an atom.

Atoms are extremely small, yet they are made up of several particles: protons, neutrons, and electrons. A proton has a positive (+) electric charge. An electron has a negative (–) electric charge. A neutron has no charge at all. Neutrons are said to be neutral. In an atom, unlike charges attract each other, and like charges repel one another. The type of charge an atomic particle has is called its ***polarity***. See **Figure 8-3.**

At the center is the nucleus, which contains the protons and neutrons. Electrons travel around the nucleus in elliptical paths. There are exactly as many electrons as there are protons in the nucleus. The number of separate paths followed by the electrons depends on their number. Each path is called a ***ring***. As the rings fill with electrons, new rings form to allow room for more electrons. Compare the two atoms illustrated in **Figure 8-4.** Notice in each atom how the number of protons equals the number of electrons. Note, too, that the atom with more electrons has more rings.

Atoms remain stable (neutral) by keeping the numbers of protons and electrons equal. Sometimes atoms need to lose electrons or gain electrons to maintain their stability. Electrons in the outermost ring, called the ***valence ring***, are the ones gained or lost. If an atom has more electrons than protons, it will lose some electrons from its valence ring. When the number of protons is greater than electrons, the valence ring will pick up electrons from nearby atoms

**Figure 8-3.** The parts of an atom. Atoms contain a nucleus of protons and neutrons, while electrons orbit around the nucleus.

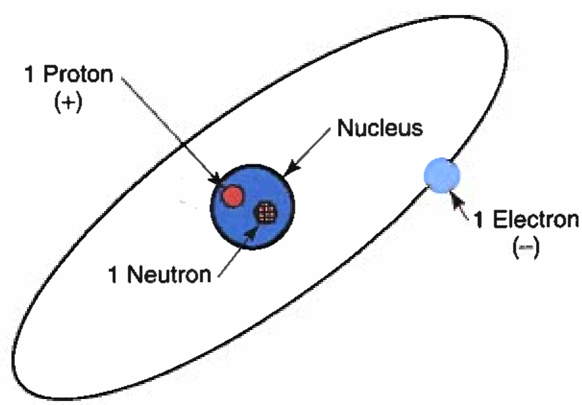
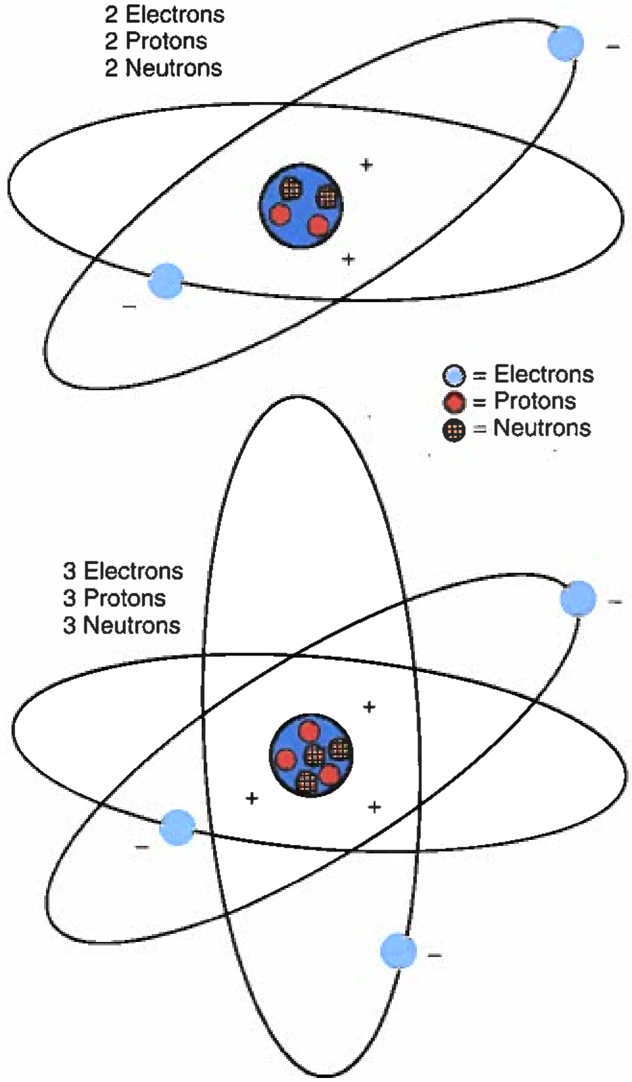


**Figure 8-4.** Atoms always try to remain stable. This means that the number of electrons will balance the number of protons.




*Conductor:* A material made of atoms that transfer electrons easily.

*Insulator:* A material made of atoms that do not transfer electrons easily.

*Semiconductor:* A material that is both a conductor and an insulator.

so the atom is stable. It is the electrons in the valence ring that lie behind the theory of electricity.

Some atoms are able to lose and gain electrons easily, while others have a difficult time. A material made of atoms that transfers electrons easily is called a ***conductor***. Wires used to carry electricity are good conductors. They are often made of copper. A material made of atoms that does not transfer electrons easily is called an ***insulator***. Insulators resist the flow of electricity. Some materials are both conductors and insulators. This type of material is called a ***semiconductor***.

Electrical systems depend on the action of electrons in relation to insulators and conductors. A semiconductor is a good example of how materials can be adapted to control movement of electrons from one atom to another. **Figure 8-5** shows one type of semiconductor (called a diode) and how it operates.

## Electron Theory and Current

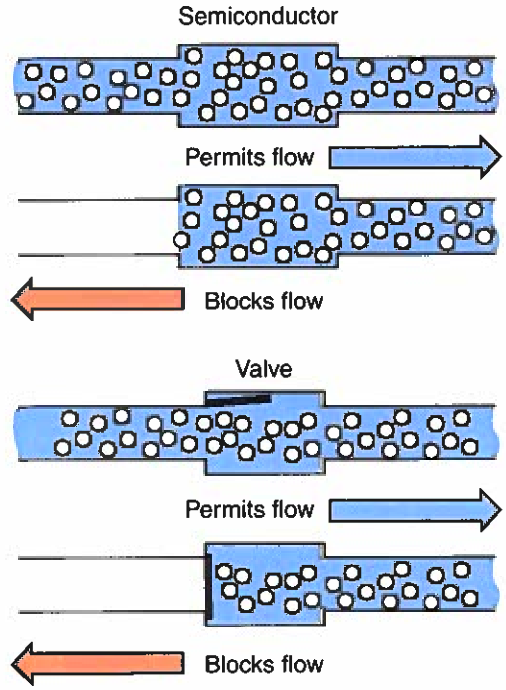
Normally, an atom is neutral (has no charge). This tells us that the number of protons equals the number of electrons. When we are able to force electrons from their valence rings, electricity is produced. **Figure 8-6** diagrams the movement of electrons through a conductor. As a negatively charged electron is forced from its valence ring, the atom becomes positively charged (there is one more proton than there are electrons). The electron forced from the valence ring is attracted to the positively charged atom to its right. Next, the atom that just lost an electron is positively charged and picks up an electron from an atom on its left.

According to the ***electron theory***, electrons flow from a negative point to a positive point. The negative point has an abundance of electrons, and the positive point has a shortage. The flow of electrons in a conductor is called ***current***.

There are two types of current: direct current (DC) and alternating current (AC). Each is based on how current moves through a conductor (wire). In ***direct current (DC)***, electrons move only in one direction. ***Batteries*** are common devices that produce DC. This type of current is used in modern automobiles, as well as in many other devices that require portable power, such as radios and flashlights. See **Figure 8-7.**

***Alternating current (AC)*** involves electrons flowing first in one direction and then reversing and flowing in the other direction. See **Figure 8-8.** AC is easier than DC to send long distances through wires. This type of current is used in houses and businesses to provide energy for lights, appliances, and machinery.

**Figure 8-5.** A diode is a type of semiconductor. It allows electrons to jump from one atom to another in one direction, but not in the opposite direction. The diode controls electron flow the same way a check valve controls the flow of water in a plumbing system.




***Electron theory:*** Electrons flow from a negative point to a positive point.

***Current:*** The flow of electrons in a conductor.

**Figure 8-6.** When electrons migrate from one atom to another in a conductor, an electric current is produced.

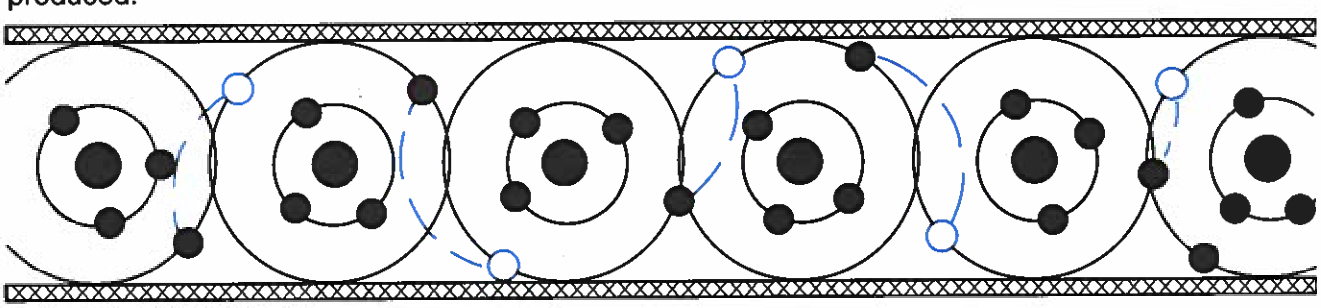


Figure 8-7. Batteries chemically store electricity and release it as direct current (DC). (Exide)


*Direct current (DC):* A type of current in which electrons move only in one direction.

*Battery:* A common device that produces direct current (DC).

*Alternating current (AC):* A type of current in which electrons flow first in one direction and then reverse and flow in the other direction.

*Current flow:* The rate at which electrons move, or amperage.

*Resistance:* Opposition to the flow of current.

## Effort, Rate, and Opposition in Electrical Systems

Like other forms of power, such as mechanical or fluid power, electricity is composed of an effort characteristic and a rate characteristic. The effort characteristic in electricity is referred to as *voltage*. Other terms used to describe electrical effort include *electromotive force*, *potential*, and even *force*. Voltage is the force behind the movement of electrons. The rate at which the electrons move is referred to as *amperage*, or *current flow*.

To try and understand the relationship between voltage and amperage, picture a garden hose with marbles flowing out of it. The pressure pushing the marbles can be thought of as the voltage. The actual marbles themselves represent the ampere flow. Now, to push the marbles through the hose, some opposition will have to be overcome. This opposition is referred to as ***resistance*** in electrical terminology, and it is often represented by the omega (Ω) symbol.

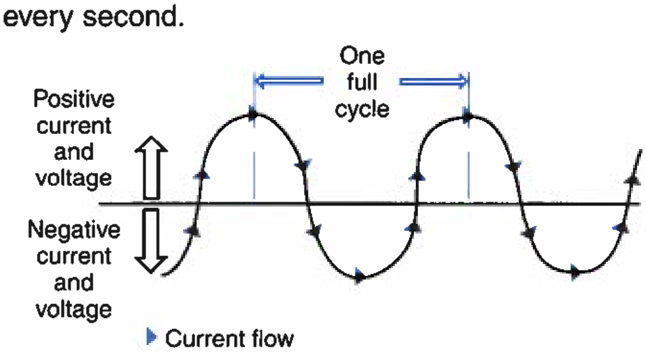
## Electrical Circuits

An ***electrical circuit*** is the heart of any electrical system. A simple electrical circuit is made of several components: a power source, a load, and conductors. The components are connected so electrical current flows in a complete path. See **Figure 8-9.**

This type of circuit must have a power source that has both negative and positive terminals (connection points). Electricity flows from the negative terminal, through the circuit, to the positive terminal. Remember, according to electron theory, electricity flows from negative to positive.

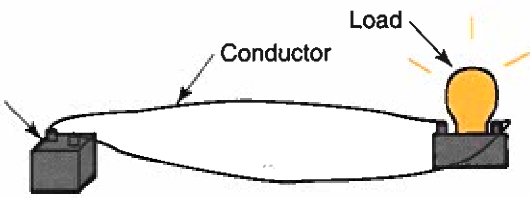
We can manipulate the electricity in the circuit by adding components, such as lightbulbs, motors, and switches, to name a few. By placing these objects in the circuit, we allow electricity to flow through them so they can

Figure 8-8. The forward and reverse flow of alternating current (AC) is represented by a sine wave, like the one shown. Household current goes through 60 full cycles every second.



operate. A component that uses electricity in a circuit is called a *load*. Conductors connect the load to the power source.

Figure 8-9. A simple circuit consists of a power source, a load, and conductors.




## Schematics

When planning and describing electrical circuits, it is easier to do it graphically than in words. ***Schematic drawings*** are used to represent an electrical circuit graphically. See **Figure 8-10.**

Schematic drawings are like road maps. Road maps show the paths taken by travelers, while schematics trace the path electron flow will take in an electrical or electronic circuit. Schematics include symbols that represent the components in the circuit. **Figure 8-11** explains some of these symbols.

*Electrical circuit:* A power source, a load, and conductors connected together so electrical current flows in a complete path.

*Schematic drawing:* A drawing that traces the path electron flow will take in an electrical or electronic circuit. Symbols are included that represent the components in the circuit.

## Open Circuits, Closed Circuits, and Short Circuits

Some terms that are helpful in describing the way a circuit is functioning are *closed circuit*, *open circuit*, and *short circuit*. A ***closed circuit*** is a properly functioning circuit in which all loads are energized. An ***open circuit*** is a circuit or part of a circuit that is not energized. Open circuits may be created intentionally, as in the case of a switch that is positioned to turn off a light. They may also occur accidentally when connections are not made properly. Such open circuits result in a loss of continuity through the circuit. ***Continuity*** is the continuous flow through a component or through an entire circuit. Accidental open circuits cause problems and can sometimes be difficult to troubleshoot.

Figure 8-10. Schematic drawings are the "road maps" of electrical and electronic circuits.

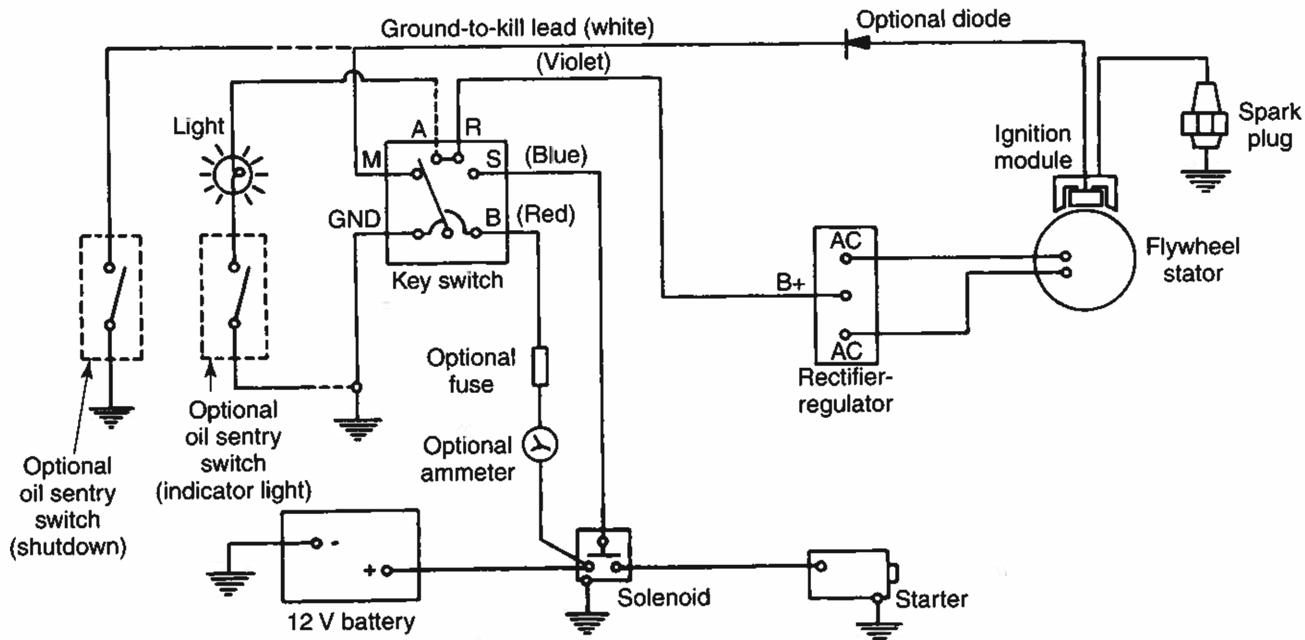
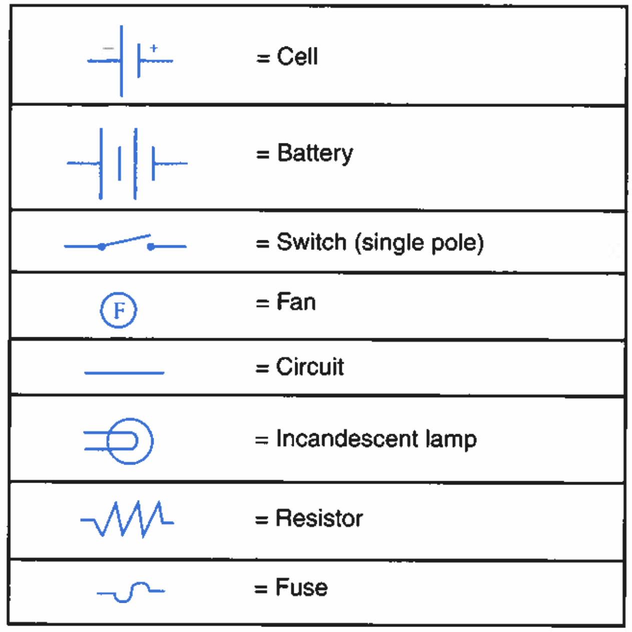


**Figure 8-11.** Some electrical and electronic symbols used in circuit schematics.




*Closed circuit:* A properly functioning circuit in which all loads are energized.

*Open circuit:* A circuit or part of a circuit that is not energized.

*Continuity:* The continuous flow through a component or an entire circuit.

Lastly, you may hear of a short circuit. A ***short circuit*** occurs when the load is bypassed and the hot wire comes directly into contact with the return leg or with something grounded. When short circuits happen, sparks may fly, and many amps (current) flow, since there is virtually no opposition to current flow. **Figure 8-12** shows all these conditions.

## Laws that Describe Electricity

There are several laws that describe the way the characteristics of electricity, such as voltage and amperage, behave within a circuit. The first law we will describe is Ohm's law. ***Ohm's law*** states that voltage (E) can be determined by multiplying current (I) by resistance (R):

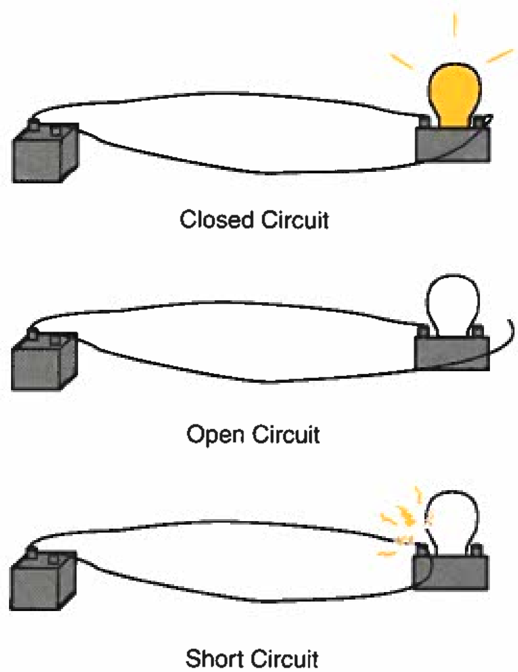
voltage = current × resistance ($E = I \times R$)

The equation can also be rewritten to calculate either current or resistance. The Ohm's law circle helps in identifying the correct equation to use. See **Figure 8-13.** To use this tool, follow these steps:

1. Cover the variable you want to find. For example, to find current, cover the *I*.
2. Review the values on the circle. In this example, you will see E/R.
3. Note the applicable equation. For example, current equals voltage divided by resistance ($I = E/R$).

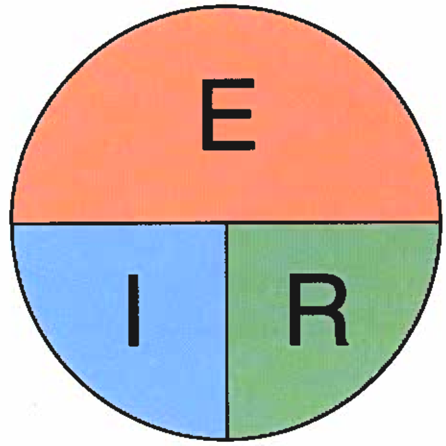
With a simple formula like Ohm's law, it is important to recognize that two out of the three quantities must be known to determine the unknown quantity. The unknown quantity can be identified in the formula through simple

**Figure 8-12.** Circuit conditions.



multiplication or division. Examples of all potential calculations are provided next to the Ohm's law circle in Figure 8-13.

**Figure 8-13.** The Ohm's law circle can be used to calculate voltage (E), current (I), or resistance (R).




$E = I \times R$

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

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

Ohm's law expresses the relationships between the characteristics of electricity. In the Ohm's law formula, $E = I \times R$, you can see that current and resistance are directly related to voltage. This means that an increase or decrease in either current or resistance will affect voltage in the same way. In other words, an increase in amperage or resistance will result in an increase in voltage. A decrease in current or resistance will result in a decrease in voltage. For example, if current flow through a load increases, the amount of voltage dropped across the load will also increase.

Looking at the formula $I = E/R$, you can see that resistance and current are indirectly related to each other. This means that a change in resistance will cause an opposite change in current. For example, if the resistance of a load increases, the amount of current flowing through the load decreases. If the resistance of the load decreases, the amount of current flowing through the load increases. Understanding the relationships found in Ohm's law could help a technician predict the outcome of a change within a circuit and help a technician troubleshoot a circuit.

*Short circuit:* A circuit in which the load is bypassed and the hot wire comes directly into contact with the return leg or with something grounded.

*Ohm's law:* Voltage (E) can be determined by multiplying current (I) by resistance (R).

Let us say a 15-amp circuit breaker that feeds your toaster and microwave keeps tripping. The microwave is rated at 120 vac (volts alternating current), 10 A. The toaster is unlabeled, but you know it plugs into a standard 120-vac receptacle and the heating element has a heat resistance of 20 Ω. You can now use Ohm's law to determine if there is something wrong with one of the appliances or the breaker, or if the circuit is simply overloaded. To do this, you need to determine the total draw on amperage. You already know that the microwave draws 10 A. The amperage for the toaster, however, is unknown. To find the amperage for the toaster, you can use the following Ohm's law equation and fill in the known values for voltage and resistance:

$I = E/R$
$I = 120\text{ vac}/20\ \Omega$
$I = 6\text{ A}$

Now, to find the total draw on amperage, add the two amperage values:

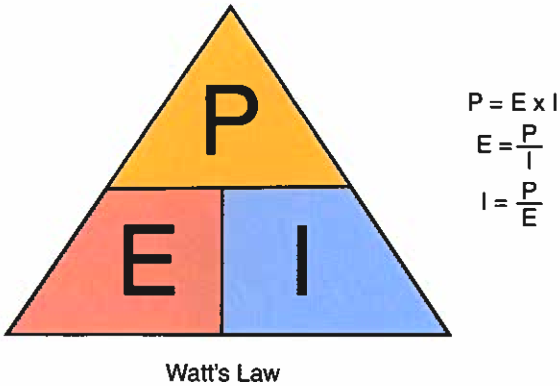
$6\text{ A} + 10\text{ A} = 16\text{ A}$

The total amperage is 16 A. Since 16 A is greater than the amperage rating of the circuit breaker (15 A), you can conclude that the circuit is simply overloaded when both appliances are turned on.

The next law that we will investigate is Watt's law. Watt's law provides an equation to measure electrical power. It is often referred to as the electrical power formula:

$P = I \times E$

**Figure 8-14.** The Watt's law triangle can be used to calculate wattage (P), voltage (E), or current (I).




In this formula, power (P) can be calculated by multiplying current (I) by voltage (E). The *P* represents power. Electrical power is measured in watts (W). A flow of 1 ampere of electrical current at a pressure of 1 volt produces 1 watt of power.

The equation can also be rewritten to calculate either current or voltage. The Watt's law triangle helps in identifying the correct equation to use. See **Figure 8-14.**

Let us say current of 20 A flows through a portable heater that is plugged into a standard 120-vac receptacle. To find the amount of power used by the heater, multiply the amount of current flowing through the heater by the voltage provided by the receptacle:

$$P = I \times E$$
$$P = 20\text{ A} \times 120\text{ vac}$$
$$P = 2400\text{ W}$$

An all-inclusive formula for electricity combines Ohm's law and Watt's law. It provides many different methods of calculating voltage, current, resistance, and wattage. See **Figure 8-15.**

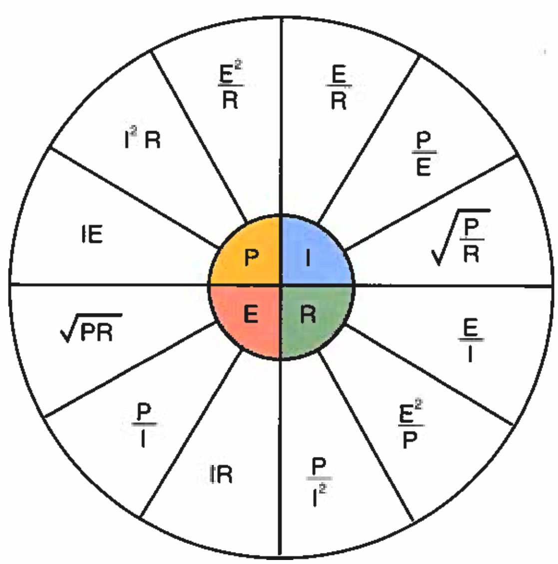
*Kilowatt-hour (kWh):* Wattage multiplied by the number of hours the wattage is used and then divided by 1000.

*Wattage:* Power being used.

## Calculating Kilowatt-Hours (kWh)

When electrical consumption is calculated for billing purposes, it is measured in ***kilowatt-hours (kWh)***. The kWh formula includes both the ***wattage***, or power being used, and the amount of time the wattage has been used. The prefix *kilo-* means "thousand." Therefore, 1 kilowatt (kW) represents 1000 watts. For the time portion of the calculation (hours), remember that 1 hour comprises 60 minutes. The following are examples of 1 kWh of electricity:

**Figure 8-15.** A helpful reference that contains both Ohm's law and Watt's law formulas.



# STEM Connection

## *Math: Ohm's Law and Watt's Law*

Through the wonders of algebraic manipulation, it is possible to combine Ohm's law and Watt's law so one or more unknowns (resistance, voltage, amperage, or wattage) may be found if any two of the other variables are known. Let us say you want to determine the wattage utilized by a baseboard heater. You know the voltage for the heater is 208 V, and the information on the heater says to replace the heater coil with a 15 Ω coil if it goes bad. Using the power formula, you can find the answer through any of the following methods:

$$P = \frac{E^2}{R} = \frac{208 \times 208\ V}{15\ \Omega} = \frac{43{,}264\ V}{15\ \Omega} = 2885\ W$$

Solve for amperage using Ohm's law, and then solve for power using Watt's law.

$$I = \frac{E}{R} = \frac{208\ V}{15\ \Omega} = 13.87\ A \qquad P = I \times E = 208\ V \times 13.87\ A = 2885\ W$$

Solve for power using a combination of Ohm's law and Watt's law.

$$P = I^2 \times R = 13.87\ A \times 13.87\ A \times 15\ \Omega = 2885\ W$$

- One 1000-watt heater running continuously for 1 hour.
- Ten 100-watt lightbulbs left on for 1 hour.
- One 2000-watt heater running continuously for 30 minutes.
- Five 200-watt lightbulbs left on for 1 hour.
- One 4000-watt central air conditioner running continuously for 15 minutes.

To determine the costs associated with using electricity, kWh must be calculated, and the cost per kWh must be known. The kWh is determined by multiplying wattage by the number of hours the wattage is used and then dividing by 1000. Next, the cost of electricity is calculated by multiplying the kWh by the cost per kWh:

kWh = (watts × hours)/1000
cost of electricity = kWh × (cost/kWh)

Let us say twelve 100-watt lightbulbs are left on in a work area for 7 1/2 hours per day, and the cost of electricity is \$.09/kWh. How much would the total cost be to light the area for a full workweek, Monday through Friday?

1200 watts × 7.5 hours × 5 days = 45,000 watt-hours
45,000 watt-hours/1000 = 45 kWh
45 kWh × \$.09/kWh = \$4.05 for the week

A dial meter, known as a *watt-hour meter*, is one type of meter typically used by electric utility companies to measure the power or wattage used within a home over a period of time. The meter readings are usually recorded by a meter reader once per month. Some meters can now simply

# Technology Link

## *Manufacturing: Peak Load Demand Billing*

Imagine a day when most of the household chores get done. The laundry gets washed, the dishwasher is run, and plenty of electricity is utilized. Now imagine receiving your electric bill. Inside the bill, it states your maximum electrical power for the month was used on that particular day. This is no surprise to you. The bill goes on to say you will be billed for having used that much power every day of the month, even though both you and the power company know that you did not use that much power every day. It does not seem fair. Fortunately, this is not the way most residential customers are billed by their electric utility providers, but it is the way most industrial consumers of electricity are billed. This method of billing for electricity is known as *peak load demand billing*.

Compare two hypothetical manufacturing firms. Company A consumes roughly the same amount of electricity over an entire 24-hour period. Company B consumes the same total amount of electricity, but almost all of it is consumed over an 8-hour period.

Even though both companies may consume the same amount of electricity to manufacture their products, the power-generating utility has much more money invested in generation, transmission ,and distribution equipment to meet the needs of Company B than Company A. The reason is simple. Since equipment used to supply Company B is only used about one-third of the day, it yields a relatively poor return on investment. Conversely, the equipment used to supply Company A is used to full potential throughout the majority of the day and, therefore, yields a much better return on investment. The cost of producing electricity to meet the peak demand brought about by companies like Company B is also considerably more substantial than the cost of generating base-load electricity that a generating utility must produce to meet its demand all the time.

The power companies could average all costs among all consumers and still yield a positive return on their investment, but this would not be fair to those consumers that use equipment most efficiently, like Company A. Therefore, most companies bill their

be scanned with a reader that automatically records a measurement. Reading a dial meter is not difficult. See **Figure 8-16.** To read a dial meter, follow these rules:

- Always read the dials on a meter from left to right.
- Interpret the first dial on the left-hand side as thousands, the second dial as hundreds, the third dial as tens, the fourth dial as ones, and the fifth dial as tenths.
- If the pointer on a dial is not positioned directly over a number, use the lower number on the dial you are reading. For example, if the pointer is positioned somewhere between three and four, use the lower number, three.

industrial customers, such as manufacturing firms, according to each customer's maximum demand for a given period. That period is usually one month, but sometimes it can be a quarter of a year. A demand meter monitors electric utility usage and records the usage. A measurement is usually taken every 15 minutes throughout the day. At the conclusion of the billing cycle, the maximum demand for any 15-minute interval is used to compute the utility bill.

It may not seem fair, but the power-generating utility's rationale is that if X amount of power was used during one period in the billing cycle, in theory, that amount of power must be made available for the entire billing cycle. After all, if a company consumes a very large amount of power for a part of one day, it certainly has the ability to consume that much power every day. The bottom line is that power companies would prefer to see a stable demand profile over a 24-hour period. This way, they would be using their generating, transmission, and distribution equipment most efficiently. Too many companies like Company B in a territory can cause a utility to have to add generating capacity, even though the utility can only sell the electricity for one-third of the day.

*Energy management* is a term that describes how utility costs are managed in a manufacturing environment. Large companies may make use of computers and software to manage the demand. For instance, if a company has four large machines and three of them are running, the energy management system might not allow the fourth machine to be started until one of the first three is shut off. This will help to keep the peak demand down to an acceptable level. In turn, this may save thousands of dollars on the monthly or quarterly utility bill. In some cases, it is even more cost effective to have a company manufacturing 24 hours per day. The power-generating utility can offer electricity at a discounted cost, as long as the electricity is not being consumed during the peak hours of 8 AM–5 PM, when it is in the greatest demand.

- If you cannot tell if the pointer is positioned over a number, check the dial to the immediate right. If the pointer on that dial is positioned between the nine and zero, use the lower number on the dial you are reading. If the pointer on the dial is positioned on or past the zero, use the higher number on the dial you are reading.

With the dial readings from the previous month, the total kWh consumption for the month and average daily kWh consumption can be calculated. The following is an example of this calculation:

current month's reading – previous month's reading = kWh consumed
kWh consumed /30-day billing period = kWh per day consumed
6453 kWh (read on May 5) – 5691 kWh (read on April 5)
= 762 kWh consumed
762 kWh / 30-day billing period
= 25.4 kWh per day (on average) consumed.

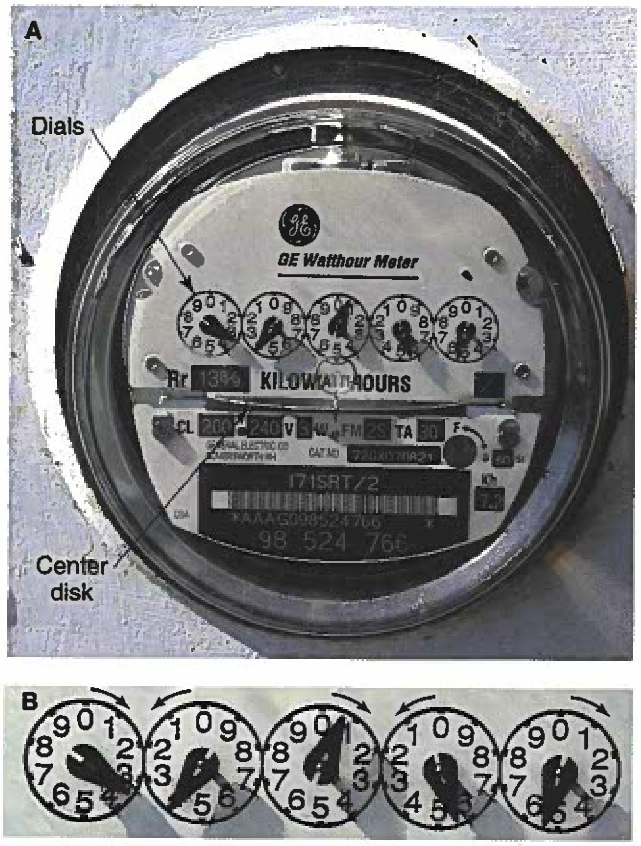
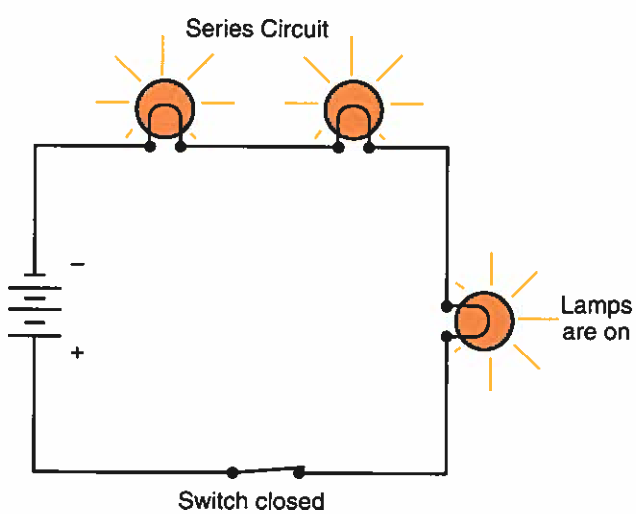



**Figure 8-16.** An electric meter records usage in kilowatt-hours (kWh). A—The center disk rotates, driving the dials that record the kWh of electricity used. B—Dials are read from left to right. This meter shows a reading of 3405.5 kWh.

**Figure 8-17.** A series circuit has only one path for electric current. When the switch is closed, the electrons flow through the circuit, and the lamps are on.




# Series, Parallel, and Series-Parallel Circuits

There are three basic types of electrical circuits: series, parallel, and series-parallel circuits. These circuits have different characteristics and can be used for many applications. Circuits can be compared by the ways they allow current to pass through them.

## Series Circuits

Series circuits have one continuous path for electrical current. If there is a break in the conductor or a bad connection, the whole circuit becomes useless. **Figure 8-17** illustrates a series circuit. Notice the single path for current between the components of the circuit. Electrical current flows from the negative terminal on the power source, through a single switch and the lightbulbs, and then to the positive terminal. One switch operates all three lightbulbs in the circuit at the same time. When it is opened, no current can pass through the circuit to power the lights. Refer to the series circuit in **Figure 8-18.**

Now let us investigate the characteristics of a series circuit. Voltage in a series circuit "drops" across each load. If you add up all the voltage drops across each load, they should equal the source voltage, as seen in **Figure 8-19.** The amount of each voltage drop varies with the resistance of each load. Opposition to electron flow, known as resistance, is easily calculated for a series circuit using a simple formula:

$$R_T = R_1 + R_2 + R_3 \ldots$$

This means that the total resistance in a series circuit can be determined by adding the resistive value of each load in the circuit to determine the total resistance. If the voltage and total resistance in a circuit are known, it is easy to calculate the current or ampere flow in a series circuit using Ohm's law. Measuring amperage in a series circuit is also easy. Since there is only one path for current flow in a series circuit, amperage can be measured anywhere in the circuit. To say it another way, amperage is the same at all points within a series circuit, regardless of where it is measured.

## Parallel Circuits

Unlike series circuits, parallel circuits allow more than one path for electrical current. Because there is more than one path, a break in the conductor or a bad connection might only shut off part of the circuit. Notice in **Figure 8-20** how the components of this circuit are arranged in branches. By adding a switch for every light, we can turn each one on or off individually, without affecting the other lights. See **Figure 8-21.**

Examining the characteristics of a parallel circuit is slightly more complicated than examining a series circuit, since there are multiple paths for current flow. The easiest characteristic to understand in a parallel circuit is voltage, since the potential difference between the hot, or feed, leg and the return leg remains constant. This concept is explained by Kirchoff's voltage law for parallel circuits, which states that the voltages across each branch of a parallel circuit are equal. See **Figure 8-22.** The concept is important because it allows for standardization. For instance, most appliances in the United States run on standard 120 vac, which is available at convenience receptacles located throughout residential and commercial structures. If these receptacles were wired in series, the voltage available at each receptacle would vary based on the loads in the circuit. Also, if any load in the circuit were switched off, all the loads in the circuit would switch off.

Neither of these scenarios is very practical. Both scenarios are, however, avoided in a parallel circuit. This is because the voltage or potential difference remains constant between the feed and the return leg and because various branches of the parallel circuit can be energized and de-energized without affecting one another.

Kirchoff's law states that current in a parallel circuit is the sum of current flowing in each of the circuit's branch circuits. A load such as a lightbulb can be turned off on one branch of the circuit without affecting bulbs that are turned on across other branches of the parallel circuit. Look again at Figure 8-22. It shows the amperage that would be expected to be measured at various points in a parallel circuit with several loads, based on the calculations provided.

**Figure 8-18.** This is the same circuit as in Figure 8-17. When the switch is opened, the lamps will not light.

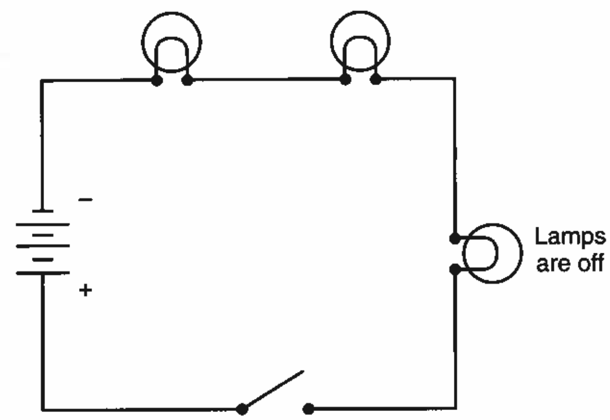



**Figure 8-19.** Voltage, amperage, and resistance in a series circuit.

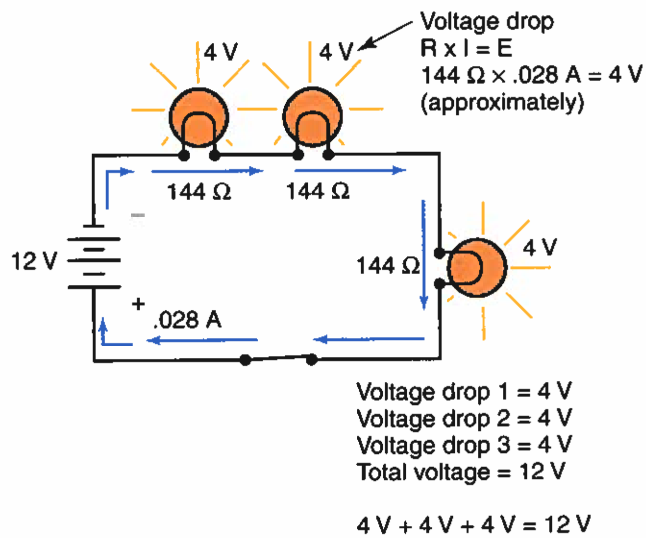
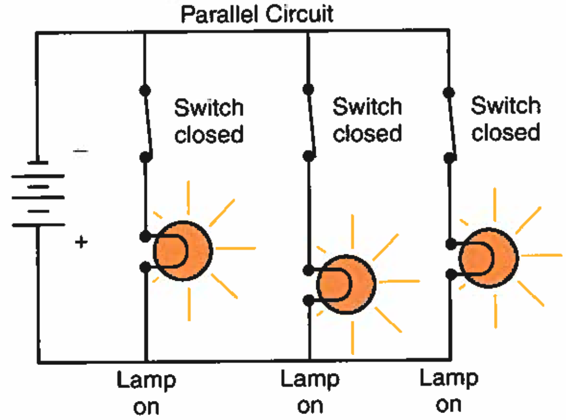



**Figure 8-20.** An example of a parallel circuit. Even if one of the switches is opened, the other lamps will remain lit.



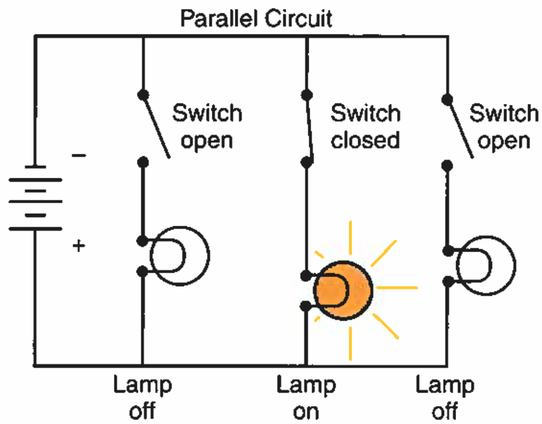



**Figure 8-21.** This is the same circuit shown in Figure 8-20 with two switches open. Can you trace the current in this illustration?

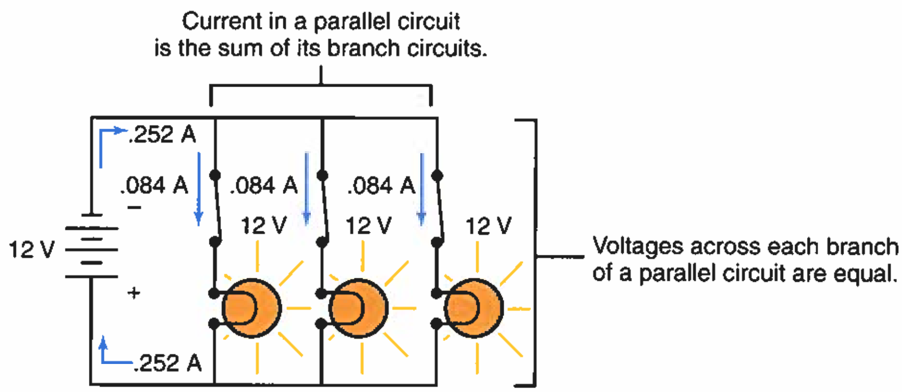
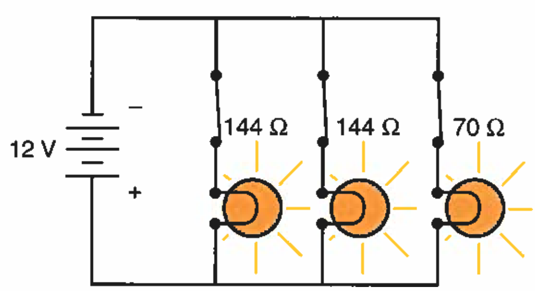



**Figure 8-22.** This circuit illustrates Kirchoff's voltage and current laws for parallel circuits. Notice that the voltages across each branch are equal and that the total current is equal to the sum of current flowing through each branch.

Resistance in a parallel circuit is perhaps the least intuitive characteristic to understand. This is because, as the load in a parallel circuit increases, resistance actually decreases! Every time a load is added to a parallel circuit, another path is created that allows the current to flow from the positive to the return leg. Thus, more opportunity for electrons to flow between the positive and negative legs is created, decreasing total resistance. The formula for calculating resistance in a parallel circuit is as follows:

$$\frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \ldots}$$

The reciprocals within the formula ensure that the value of the total resistance in a parallel circuit is always less than the value of any individual resistance within the circuit. This includes the resistive value of the smallest load. See **Figure 8-23.**




$$\frac{1}{\frac{1}{144} + \frac{1}{144} + \frac{1}{70}} = 35.7\ \Omega$$

**Figure 8-23.** Calculating resistance in a parallel circuit. Notice that total circuit resistance is smaller than the resistance of any single component.

## Series-Parallel Circuits

See **Figure 8-24** for an example of a series-parallel circuit. You should be able to recognize that it is a combination of the two circuits discussed earlier. In the circuit illustrated, the first lightbulb after the negative terminal is in series with everything else in the circuit. The other two lightbulbs in the circuit are arranged in parallel with each other. This means that a break at the first lightbulb would shut off the whole circuit. A break at any other lightbulb would still allow current to flow through some parts of the circuit. Follow the path of current to see how this can work.

The means by which resistance is calculated in a series-parallel circuit is as follows. First, calculate the parallel portions of the circuit, and then add that value to the value of the resistance in series within the circuit. If the resistance is calculated and the source voltage is known, the current can also be calculated using Ohm's or Kirchoff's law. An example is provided in **Figure 8-25.**

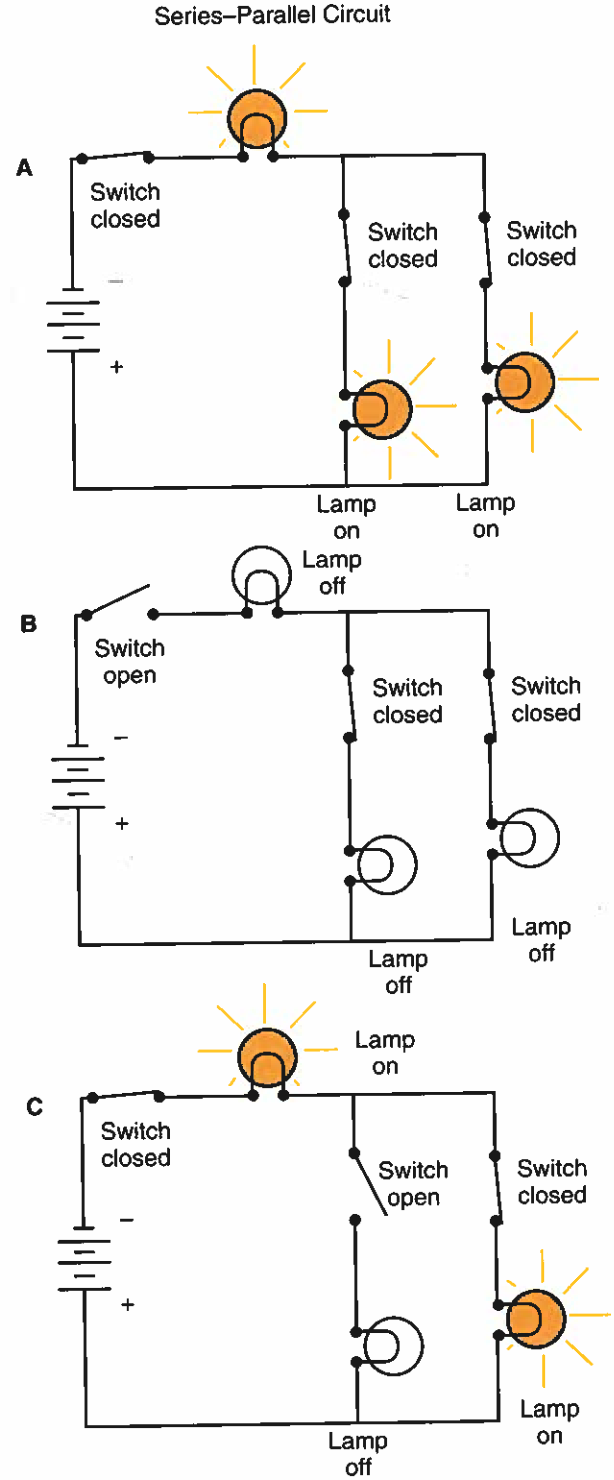
## Magnetism

Magnetism, or the property, quality, or condition of being magnetic, is important in the study of electricity because the two can affect each other. Electrical current produces magnetism. Magnets can induce, or cause, electrical current in conductors.

A ***magnet*** is a material attracted to any metal containing iron. It has an invisible force field that makes it stick to these metals. Magnets usually contain two poles: north and south. These poles are on opposite ends of the magnet. ***Lines of force*** run between the poles on the outside of the magnet. These lines are also called ***flux***. You cannot actually see the flux, unless you place the magnet on a piece of paper and then sprinkle iron filings on the paper. See **Figure 8-26.** The iron filings form arcs between the north poles and south poles of the magnet and represent the lines of force.

When two magnets are brought together, their magnetic poles influence each other. Like poles repel each other, and unlike poles attract each other. In other words, a north pole and a

**Figure 8-24.** In a series-parallel circuit, part of the circuit is in series, and part is in parallel. A—All parts of the circuit are working. B—No current is found in the circuit. Do you know why? C—By looking at this circuit, can you tell which parts of it are parallel?



*Magnet:* A material attracted to any metal containing iron.

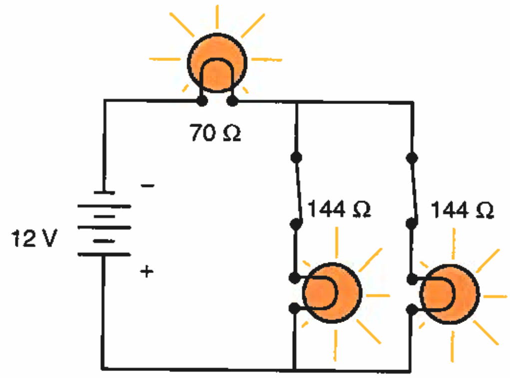
*Line of force:* A theoretical line running between the poles on the outside of a magnet.

*Flux:* The lines of force on a magnet.

*Electromagnet:* A conductor wrapped around an iron core. The two ends of the conductor are attached to a power source. When current passes through the conductor, the iron core becomes magnetized.

*Electromagnetic induction:* The production of electricity in conductors with the use of magnets.

**Figure 8-25.** Calculating unknown values in a series-parallel circuit.




**Calculating Total Resistance**

First calculate total resistance of the parallel portion of the circuit:

$$\frac{1}{\frac{1}{144}+\frac{1}{144}} = 72\ \Omega$$

Then add the total resistance of the parallel circuit to the resistance in series:

$$72\ \Omega + 70\ \Omega = 142\ \Omega$$

**Calculating Total Current**

Use Ohm's Law to calculate total current:

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

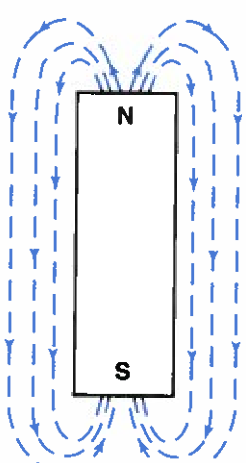
$$\frac{12\ V}{142\ \Omega} = .085\ A$$

south pole are attracted to each other. Two north poles or two south poles force themselves away from each other.

## Electromagnets

More than 150 years ago, Hans Oersted, a Dutch scientist, found that electricity produces a magnetic field. This discovery brought about the electromagnet. An ***electromagnet*** consists of a conductor wrapped around an iron core. The two ends of the conductor are attached to a power source. When current passes through the conductor, the iron core becomes magnetized. When this happens, the iron core is attracted to anything that has iron in it. **Figure 8-27** shows one application of an electromagnet.

**Figure 8-26.** Lines of flux, indicated by the dotted lines, run between the poles of a magnet.




## Electromagnetic Induction

As mentioned earlier, we can produce electricity in conductors with the use of magnets. This process is called ***electromagnetic induction***. Most of our electricity is produced this way. Remember that electricity is made when we are able to force electrons from their valence rings. When we pass a magnetic field through a conductor or a conductor through a magnetic field, the flux causes electrons to be forced from their atoms, producing electricity. See **Figure 8-28** for a description of electromagnetic induction.

# Electrical Power Sources

We have seen that an important part of an electrical system is a power source. In fact, we could not have a working system without one. The electrical power source provides a method for producing electrical current in a circuit. Some examples of electrical power sources are cells, batteries, AC generators, and DC generators.

Figure 8-27. Scrap iron and steel can be picked up by an electromagnet.

## Cells and Batteries

You have probably had to put cells inside many devices, like watches, calculators, smoke detectors, and radios. A *cell*, often mistakenly called a *battery*, is a common device for storing electrical power. There are many different types of cells and batteries. You may already recognize the cells used in flashlights. The same cell may be used in some clocks and smoke detectors. Batteries are used in transportation vehicles. These are tougher and more powerful than flashlight cells. All cells and batteries produce DC.

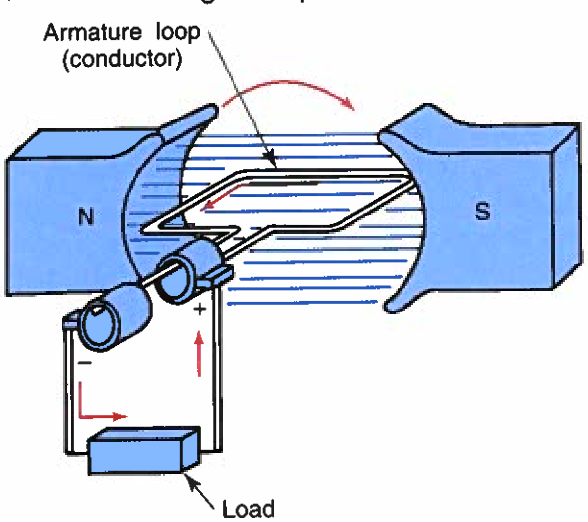
A battery is made of one or more cells. Cells and batteries are devices that change chemical energy to electrical energy. They consist of two different materials called electrodes and electrolytes. The terminals on each end of a battery are actually the ***electrodes***. Remember that one electrode has a positive charge, and the other has a negative charge. The ***electrolyte*** is usually a liquid or paste that surrounds and touches both electrodes. The chemical reaction between the electrodes and electrolyte produces electrical current. See **Figure 8-29.**

*Cell:* A common device for storing electrical power. A cell changes chemical energy to electrical energy.

*Electrode:* A terminal on a cell or battery.

*Electrolyte:* A liquid or paste that surrounds and touches electrodes, causing a chemical reaction between the electrodes and electrolyte, which produces an electrical current.

Figure 8-28. A simple electrical generator demonstrates the principle of electromagnetic induction. The armature loop (conductor) of the generator rotates through lines of force from a magnet to produce an electric current.



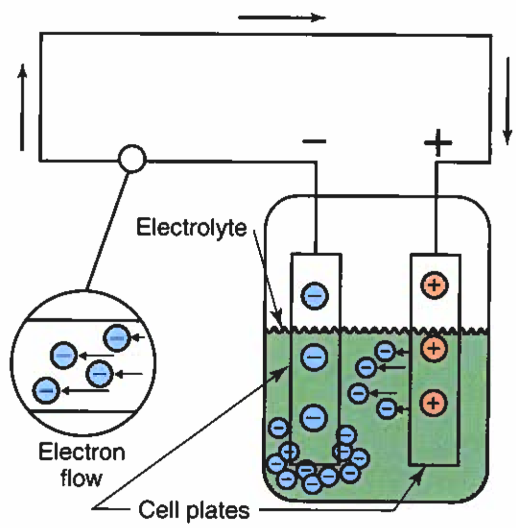



**Figure 8-29.** A simple battery illustrates how a difference in electrical potential can cause electrons to flow in a circuit. In a chemical reaction between battery terminals and the electrolyte, electrons migrate from the positive to the negative terminal. If the other ends of the electrodes are connected, the electron flow causes a current through the circuit. (Kohler Company)

*Primary cell:* A type of cell that cannot be recharged.

*Carbon-zinc battery:* A type of primary cell in which the carbon is the positive electrode and the zinc is the negative electrode.

*Secondary cell:* A type of cell that can be discharged and recharged many times.

*Lead-acid battery:* A common secondary cell used in automobiles. It is a combination of several cells. This type of battery includes a series of positive and negative metal plates in a weak sulfuric acid electrolyte.

There are two kinds of cells: primary and secondary. A ***primary cell*** cannot be recharged. These cells can produce electrical current only while the chemicals in the electrolyte are reacting with each other. When the reaction stops, the cells are discharged and must be replaced. It is this type of cell that powers toys and flashlights.

A ***carbon-zinc battery*** is the most common primary cell used in these applications. In this type of cell, the carbon is the positive electrode, and the zinc is the negative electrode. Other types of primary cells are alkaline, lithium, silver-oxide, zinc-air, and zinc-chloride cells. Alkaline batteries are the typical batteries found in almost any convenience store. They are cheap and dependable, but they do not offer longevity or recharging capability. The very small batteries used in watches and some calculators are lithium cells. Silver-oxide batteries are typically used for watches and calculators, although some bigger ones can have other applications. Zinc-air batteries are tiny batteries typically used for applications such as hearing aids. Zinc-chloride batteries come in many varieties, including a 1.5 V AA-sized battery that is ideal for portable games, hand-held radios, and calculators.

A ***secondary cell*** can be discharged (used up) and recharged many times. To recharge a secondary cell, electrical current is sent through the cell in a reverse direction from normal electron flow. The number of times a secondary cell can be recharged depends on its size, type, and the conditions under which it operates.

**Figure 8-30** shows a common secondary cell used in automobiles. This cell is known as a ***lead-acid battery***. It is a combination of several cells. This type of battery includes a series of positive and negative metal (lead) plates in a weak sulfuric acid electrolyte. Other types of secondary cells are lithium-ion (Li-ion), nickel-cadmium (NiCd), nickel-iron (NiFe), nickel-metal hydride (NiMH), and rechargeable alkaline cells. Li-ion, NiCd, and NiMH batteries are among the most popular of the rechargeable batteries commonly found in cell phones and cordless power tools. They are even used as reusable replacements for conventional alkaline batteries of the common A, AA, AAA, C, and D sizes in countless

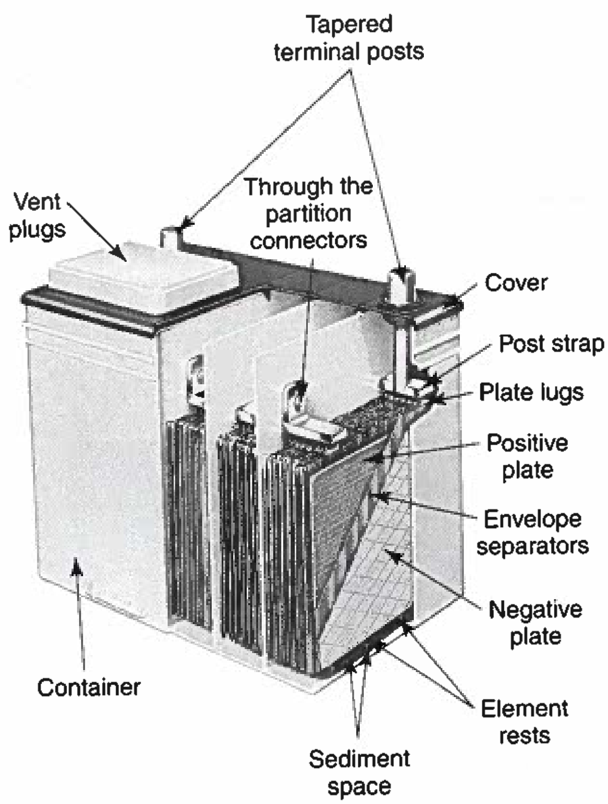



**Figure 8-30.** A lead-acid battery is made up of a number of cells. Each cell consists of positive and negative plates, or electrodes. They are held apart by a separator and surrounded by conductive fluid called electrolyte. This cutaway shows three of the six cells used in a 12-volt automotive battery. (Battery Council International)

**GREEN TECH**
The method of disposal of a battery is important because of the chemicals in the battery. These chemicals can leak into the soil. Because of this, most batteries can now be recycled.

applications. These batteries offer the advantage of having the ability to be charged and discharged many times over the life of the battery, when compared to a typical battery that is used until it is drained and then disposed.

## AC Generators

An ***AC generator*** is a device that converts mechanical energy into electrical energy. This device is also called an ***alternator***. It converts mechanical energy into electrical energy by using electromagnetic induction. In a simple AC generator, an armature loop (conductor) passes through a magnetic field. See **Figure 8-31.** As the conductor rotates through the magnetic field, current flows through the conductor to the

*AC generator:* A device that converts mechanical energy into electrical energy by using electromagnetic induction.

*Alternator:* See *AC generator*.

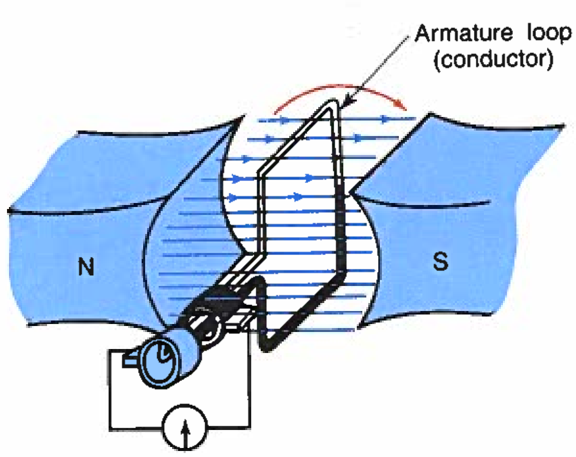


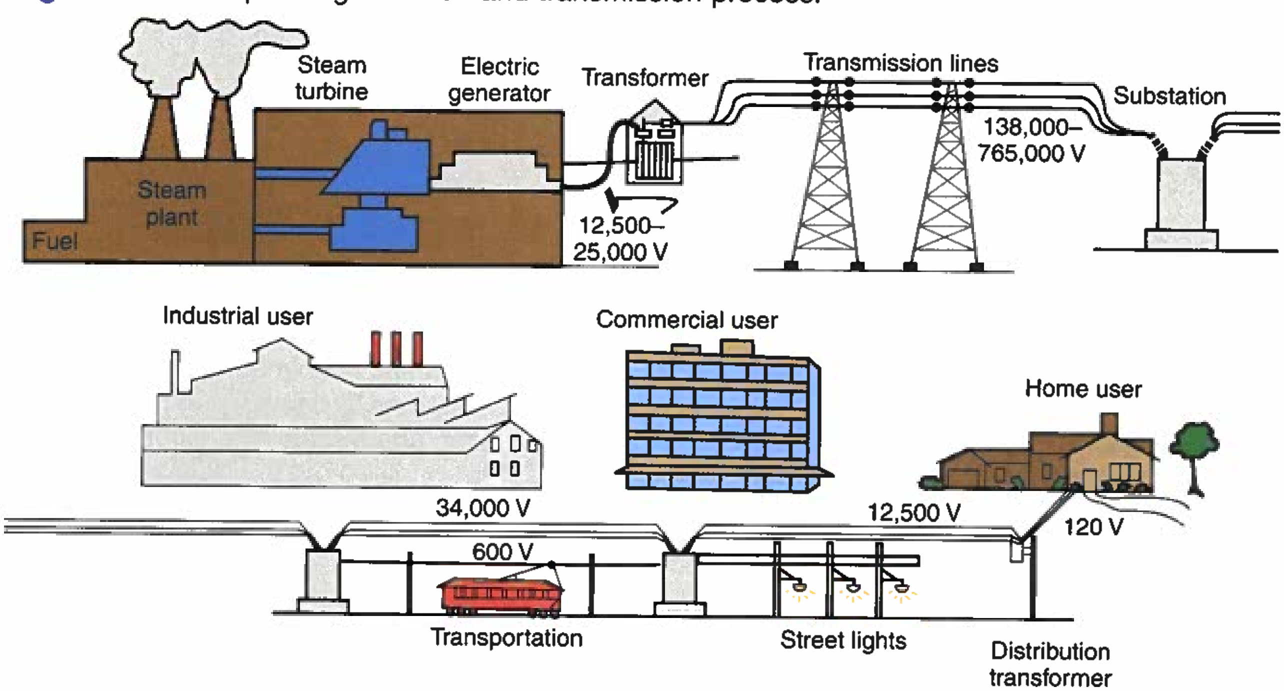

**Figure 8-31.** A diagram of a simple alternator. As the armature loop (conductor) cuts through the the magnetic field, magnetism causes electrons to flow in the armature loop and through the external circuit.

circuit. Current flows through the circuit in one direction for one half of a revolution and in the opposite direction for the second half of a revolution. This action produces AC.

Power plants produce electricity with the aid of AC generators. See **Figure 8-32.** Mechanical energy is supplied to the generator through water or steam channeled to a turbine. See **Figure 8-33.** The turbine is connected by a shaft to the generator. As the turbine spins, it rotates the generator. The blades of the turbine spin the magnets inside the generator. The rotating magnetic field has the same effect as does a rotating armature loop in a fixed magnetic field.

**Figure 8-32.** The generators at the Hoover Dam hydroelectric plant. The huge generators are powered by turbines, which are situated beneath the generators and are driven by the force of moving water. (U.S. Bureau of Reclamation)

**Figure 8-33.** The power generation and transmission process.



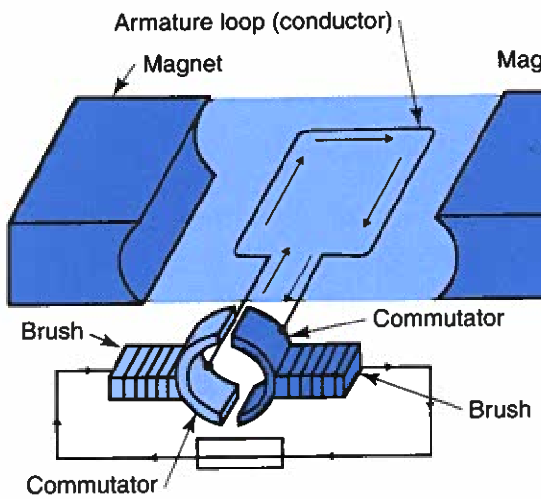
## DC Generators

Like an AC generator, a ***DC generator*** relies on the principle of electromagnetic induction to create DC. See **Figure 8-34.** A DC generator consists of an armature loop (conductor) mounted on a shaft that rotates. On two sides of the armature loop are magnets. A north pole and a south pole are directed toward the armature loop. As the armature loop rotates between the magnetic fields, a current is produced.

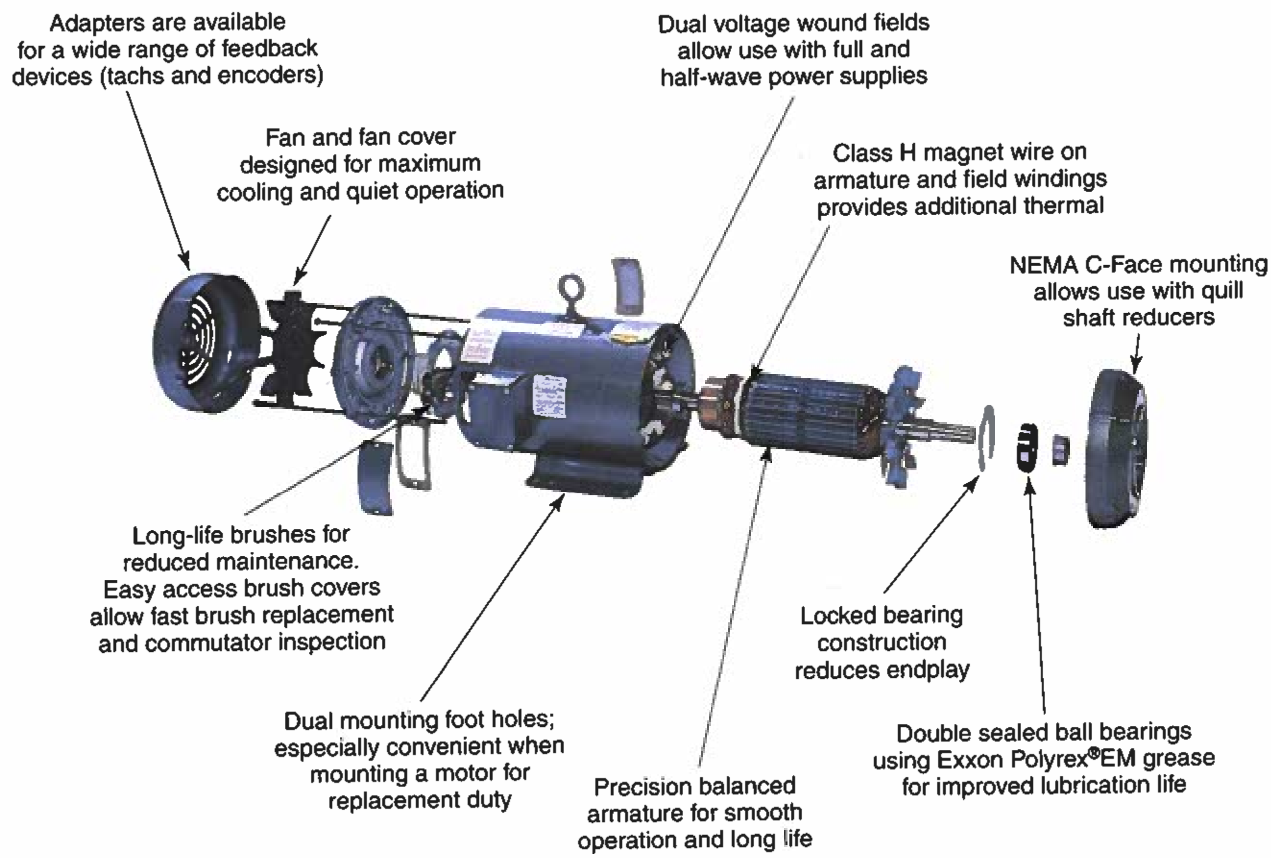
*DC generator:* A device that relies on the principle of electromagnetic induction to create direct current (DC). It consists of an armature loop mounted on a shaft that rotates. On two sides of the armature loop are magnets. A north pole and a south pole are directed toward the armature loop. As the armature loop rotates between the magnetic fields, a current is produced.

**Figure 8-34.** A direct current (DC) generator. A—A simplified drawing of a DC generator, with parts labeled. B—A cutaway view of a DC generator. Can you recognize the different parts? (Baldor Electric)

A




B



Remember that different magnetic poles produce different directions of current flow. To solve this problem and produce DC, DC generators make use of a commutator and brushes. Look again at Figure 8-34.

As the armature loop rotates through the magnetic field, it turns the commutator. Brushes that touch on each side of the commutator carry the electric current away from the armature loop. Notice that the commutator is split so the armature loop is not a complete circuit. The two parts of the commutator touch the brushes at different times. This way, the current produced by the north magnetic polarity will always be carried by one brush. The same is true for the opposite magnetic field. Its induced current will always be carried by the opposite brush. Can you see how this makes one brush negative and the other positive, thus producing a DC output?

***Single-pole, single-throw (SPST) switch:*** A switch that makes or breaks one set of contacts to turn a load on and off.

***Single-pole, double-throw (SPDT) switch:*** A switch used to control a load from two different locations.

***Double-pole, double-throw (DPDT) switch:*** A switch used in conjunction with two single-pole, double-throw (SPDT) switches, allowing one or more loads to be controlled from three or more locations.

***Momentary contact switch:*** A switch that makes or breaks a circuit based on the input or touch of the switch. When the switch is not depressed, the switch returns to its default status.

***Push-button make/break (PBMB) switch:*** A switch that retains its status until pressed again.

# Basic Control Elements for Electricity

There are many basic control elements that allow us to effectively use electricity to do useful work. Perhaps the most fundamental control elements are switches, since they are routinely used to turn loads on and off. Other types of control elements are diodes and transformers.

## Switches

The simplest of all switches is the ***single-pole, single-throw (SPST) switch***. This switch makes (closes) or breaks (opens) one set of contacts to turn a load on and off. A slightly more complex switching scheme makes use of a pair of ***single-pole, double-throw (SPDT) switches*** to control a load from two different locations. This type of switching is typically used to turn lights on and off from either end of a staircase. It is commonly referred to as a *three-way switch*.

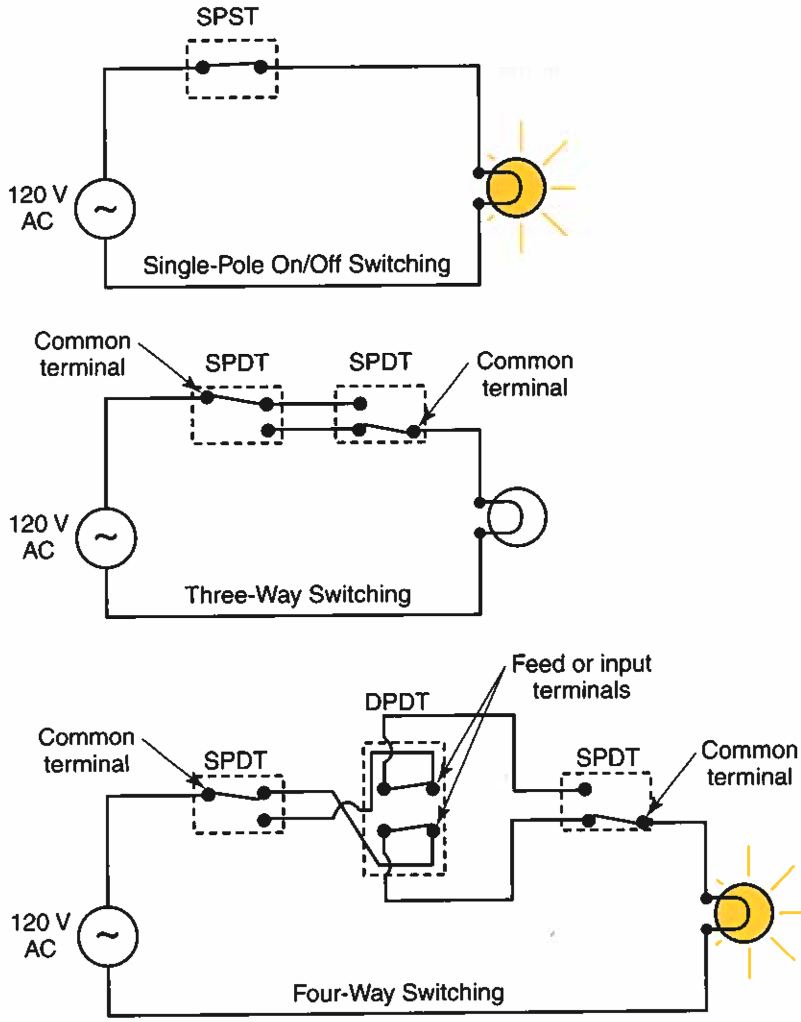
Now let us suppose that the lights needed to be controlled from three or more locations, such as in a large room or garage. This is an application for a ***double-pole, double-throw (DPDT) switch***, often referred to as a *four-way switch*. When a DPDT switch is used in conjunction with two SPDT switches, one or more loads can be controlled from three or more locations. All these switching schemes are diagrammed in **Figure 8-35.**

There are many other types of common switches used in everyday life. Some are known as ***momentary contact switches***. These switches make or break a circuit based on the input or touch of the switch. When the switch is not depressed, the switch returns to its default status. The two most common momentary contact switches are known as the push-button normally opened (PBNO) and the push-button normally closed (PBNC). See **Figure 8-36.**

A further extension of this type of switch is the ***push-button make/break (PBMB) switch***. This switch retains its status until pressed again. In this sense, it is said to have memory. Some examples may be the button on a lamp or on the front of your stereo. If a PBMB switch is pushed in once, the appliance stays on. If it is pushed again, the appliance goes off and stays off.

Sometimes, more complex on/off control capability is required. For example, let us say you have a table saw that has a start and stop button on the front of the saw. Did you ever wonder why there are two separate

**Figure 8-35.** Basic switching schemes. Look at the various switching schemes and imagine what would happen if any one of the switch positions changed. Would the light turn on or off?

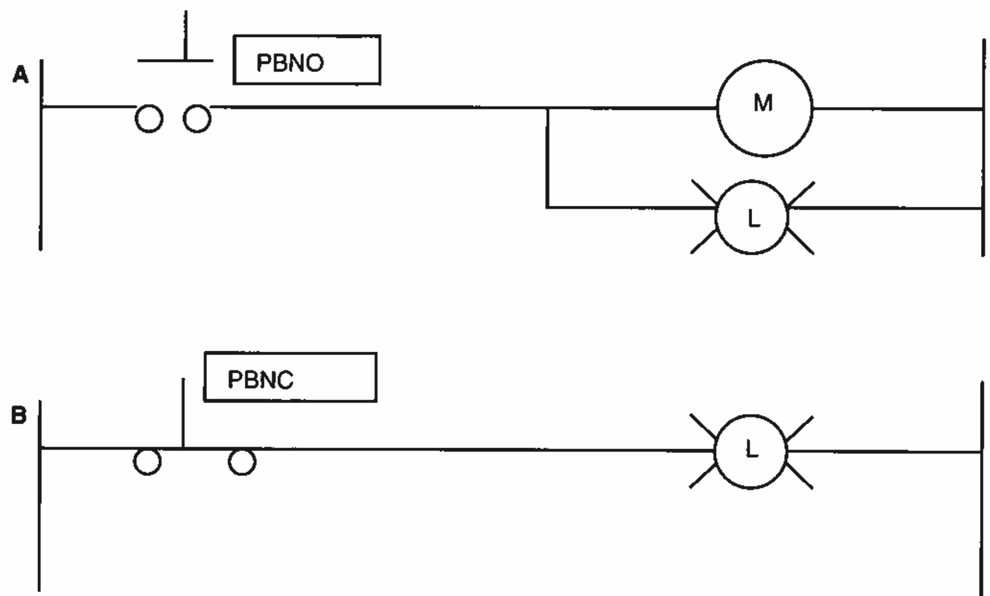



buttons, instead of a simple SPST switch to turn the machine on and off? The answer has to do with safety. If an SPST were used and the power went off, the saw could inadvertently come back on when power is restored to the machine. Using momentary contact switches and a magnetic motor starter to start the saw ensures that, if the power to the saw goes off during operation, it cannot turn on at an inopportune time. The only way to start the saw is to push the start button again. The start button triggers a magnetic contactor that closes and remains latched until the stop button is depressed or the power is interrupted. The entire process is known as a ***latching relay***, and it forms the heart of a magnetic motor starter.

Additionally, most motor starters provide overload protection for the motors they feed. If the motor draws excessive amperage, the motor starter can automatically open the magnetic contactor that allows power to flow to the saw. The result is that the saw stops and cannot be started again until the start button is pushed. See **Figure 8-37.**

***Latching relay:*** The process of using momentary contact switches and a magnetic motor starter to start a device. This ensures that, if the power goes off during operation, the device cannot turn back on at an inopportune time. The only way to start the device is to push the start button again. The start button triggers a magnetic contactor that closes and remains latched until the stop button is depressed or the power is interrupted.

**Figure 8-36.** A momentary contact switch operation. The normal state is the state the switch is in if it is left alone and nothing is pushing on it. A—A push-button normally opened (PBNO) switch is used to feed a motor that quickly mixes two parts of a plastic resin together so the liquid plastic will harden. When the button is depressed, the motor spins, and the indicator light goes on. When the operator takes his finger off the button, the motor stops spinning, and the light goes off. B—A push-button normally closed (PBNC) switch is used to keep a light on. This is the type of switch that can be found inside your refrigerator door. When the door is opened, the switch pops out to its normal, or closed, state, and electricity flows to the bulb. When the door is closed, the PBNC switch is held in its alternate state (opened), and the bulb goes off.



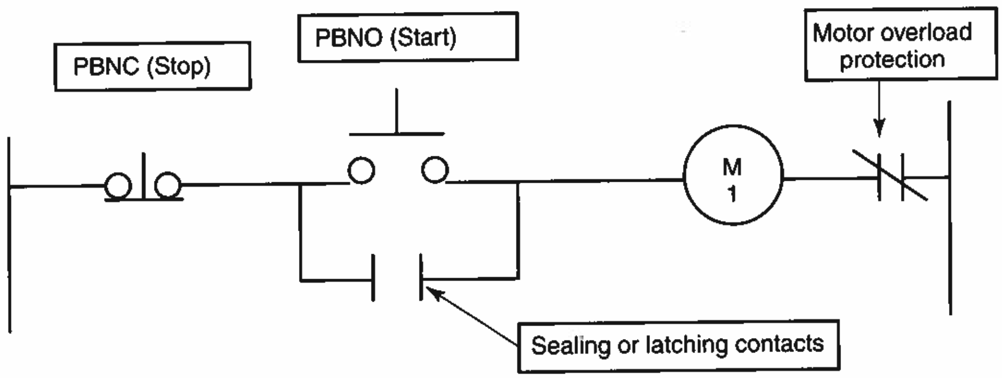

So far, all the switches described are examples of on/off control devices, in the sense that they only have the ability to turn loads on or off at full power. An example of a switch that can provide variable motion control is a dimmer switch, more appropriately referred to as a rheostat, or ***potentiometer***. See **Figure 8-38.** The potentiometer can vary the resistance within the switch, which in turn affects both the current and voltage flowing out of the switch. Potentiometers can also be used to control the speed of certain types of motors.

*Potentiometer:* A switch that can provide variable motion control. It can vary the resistance within the switch, which affects both the current and voltage flowing out of the switch.

## Diodes

A control element that only allows electricity to flow in one direction is known as a diode. Diodes have a multitude of applications in electricity and electronics. Let us say you have to charge a battery, so you plug the charger into the wall and attach it to the battery. Several hours later, the battery is fully charged. The battery did not discharge through the charger and into the power source because a diode ensures that the electricity used to charge the battery can only flow through it in one direction. Diodes are also used in power supplies to convert AC to DC.

**Figure 8-37.** A start/stop motor control operation. A push of the push-button normally opened (PBNO) button closes the motor starter and causes the motor to turn on. Once the motor starter closes, the sealing contacts labeled "M1" remain held magnetically in place to keep the motor starter closed and the motor starter running. The machine is stopped by pushing the push-button normally closed (PBNC) button at the beginning of the circuit. This stops feeding electricity to the magnetic contacts. Without being fed by the control circuit, the contacts spring open, stopping the flow of power to the motor. The only way to start the motor again is to press the PBNO (start) button and reenergize the coil to make the sealing contacts latch again. Note that if the motor is overloaded, the overload protection can also cause the control circuit to shut the motor down.




*Transformer:* A device used to increase or decrease voltage supplied to a circuit.

*Step-down transformer:* A transformer used to decrease voltage supplied to a circuit.

*Step-up transformer:* A transformer used to increase voltage supplied to a circuit.

## Transformers

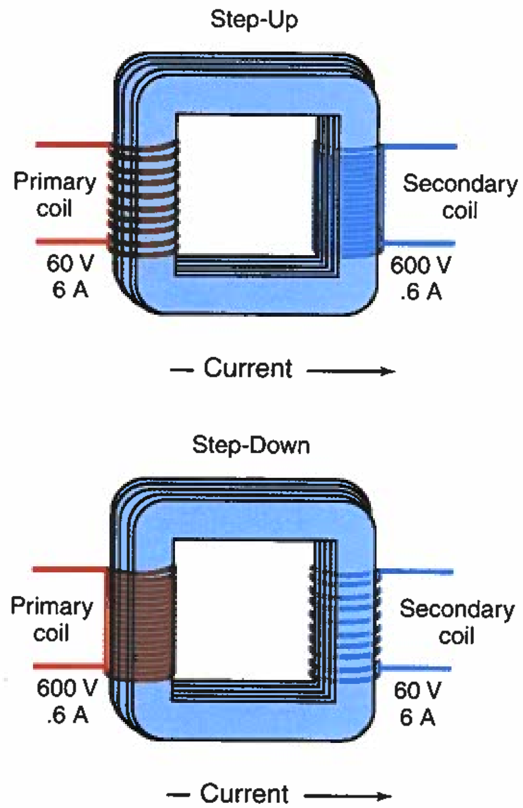
Many times, the electrical voltage supplied to a circuit is either too much or too little. If there is a need to increase or decrease voltage or current, we use a ***transformer***. When we need to reduce the amount of voltage, we use a ***step-down transformer***. One common household application for a step-down transformer is to power a doorbell system. When we have too little voltage and need more, we can use a ***step-up transformer***, which boosts the amount of voltage available. The utility company uses step-up transformers when it is necessary to transport electricity over long distances to reach communities. This is because transporting electricity at a high amperage would require wires massive in diameter.

Transformers work on the principle of electromagnetic induction. See **Figure 8-39**. Both transformers are made of an iron core with separate coils wrapped around each side of the core. The coil attached to the input side is called the ***primary coil***. The coil attached to the output side is called the ***secondary coil***.

Notice that the primary coil is smaller than the secondary coil on the step-up transformer.

**Figure 8-38.** A dimmer switch.

**Figure 8-39.** A transformer is made of an iron core with wrappings of wire to increase the voltage. The two coils of wire are not electrically connected. Electromagnetic induction caused by a current in one of the coils causes a current in the other coil.




As the current in the primary coil induces a magnetic field, the magnetic field is carried to the secondary coil. The extra wraps on the secondary coil allow the magnetic field to induce more voltage. This causes the transformer to exude more electrical voltage than it was given.

Now, notice that the primary coil is larger than the secondary coil on the step-down transformer. Again, the induced magnetic field travels from the primary coil to the secondary coil. This time, the smaller secondary coil is not able to induce as much voltage as the larger primary coil supplied. It is important to recognize that transformers cannot produce any more power than what is put into them. They can only modify the characteristics of the power to achieve a goal, such as stepping up the voltage for long-distance transmission.

Wattage into a transformer must equal wattage out. This is assuming 100% efficiency. In the examples provided in Figure 8-39, notice how voltage may be increased or decreased on the output side of the transformer, but amperage is affected accordingly. In this sense, the electrical transformer is an advantage-gaining device, similar to a gear set that has the ability to increase effort, while decreasing rate. In this case, the effort is voltage, and the rate is amperage.

*Primary coil:* The coil attached to the input side of the iron core of a transformer.

*Secondary coil:* The coil attached to the output side of the iron core of a transformer.

*Fuse:* A filament that breaks the circuit if too much electrical current passes through it. It prevents damage to the rest of the circuit in the event of an overload.

In reality, transformers are not 100% efficient. To calculate the efficiency of a transformer, you must be able to determine its theoretical maximum potential and compare that to its actual measured output. For instance, if a transformer receives 660 volts at 200 amps on the input side, the maximum power it could possibly produce on the output side is 660 V × 220 A, which equals 132,000 W, or 1.23 kW. A step-up transformer can produce more voltage, but at a lower amperage. A step-down transformer can produce more amperage, but at a lower voltage. There is no transformer that can produce more than 1.32 kW. This is the maximum potential output of the transformer. Note that the maximum output of the transformer can only be determined if the transformer is under load. The efficiency of a transformer can be calculated with the following formula:

$$\text{efficiency} = \frac{\text{output power}}{\text{input power}} \times 100$$

## Protecting Electrical Circuitry

Fuses or circuit breakers are an essential part of any electrical circuit, no matter what the circuit's purpose is. A *fuse* is made of a filament that breaks the circuit if too much electrical current passes through it. It prevents damage to the rest of the circuit, should there be an overload. Placing the fuse between the energy source and the rest of the circuit is important. Fuses are made with different ratings. This means that some fuses allow more current to pass than others before they break the circuit. **Figure 8-40** shows various types of fuses used in vehicles, homes, industries, and many other electrical applications.

Figure 8-40. A variety of fuses used to protect electrical circuitry in machines, automobiles, and homes.

A ***circuit breaker*** performs the same function as a fuse, except a circuit breaker is restorable. Circuit breakers are also designed to withstand the initial surge of current associated with starting a motor when it is at rest. Only a special fuse known as a ***slow-blow fuse*** can be used for this function. Unlike fuses, circuit breakers do not need to be replaced when they break the circuit. They simply need to be reset. Circuit breakers can, however, go bad.

*Circuit breaker:* A restorable device that breaks the circuit if too much electrical current passes through it.

*Slow-blow fuse:* A fuse designed to withstand the initial surge of current associated with starting a motor when it is at rest.

One easy way to check if a circuit breaker or fuse is in working order is with a ***continuity checker***. This checker is powered from a battery within the meter, so power should not be applied to a fuse or breaker being checked. The continuity checker simply checks for continuous flow through a device or circuit and indicates continuous flow with a steady beep from the meter. Since fuse elements are destroyed when they fail, a beep will not occur when the meter probes are placed at opposite ends of a fuse.

Sometimes the fuse element in a fuse is visible, but with some fuses, the element is not visible. Either way, the continuity check will provide positive proof as to whether the fuse is good or bad. If the meter is used to check a circuit breaker, be sure the circuit breaker is turned to the on position. Since circuit breakers are designed to be fail-safe, you will not receive a beep if the circuit breaker has failed internally, even when its position is indicated as on. The continuity checker can be used to determine the status of many other components, including switches and diodes. See **Figure 8-41.**

Figure 8-41. Using a continuity checker to see if a fuse is good or bad. A light or a beep indicates continuity (a good fuse).

A ***Ground Fault Circuit Interrupter (GFCI)*** can trip to open a circuit in much the same way as a circuit breaker or fuse can open a circuit in the case of an overload. This is, however, where the similarities end. Unlike circuit breakers or fuses designed to protect equipment, the GFCI is designed to protect people. To do so, it must be more sensitive than a circuit breaker or fuse and provide a quick reaction time.

***Continuity checker:*** A device used to check if a circuit breaker or fuse is in working order.

***Ground Fault Circuit Interrupter (GFCI):*** A device that can trip to open a circuit in case of an overload. It is designed to protect people and so is more sensitive than a circuit breaker or fuse and provides a quick reaction time.

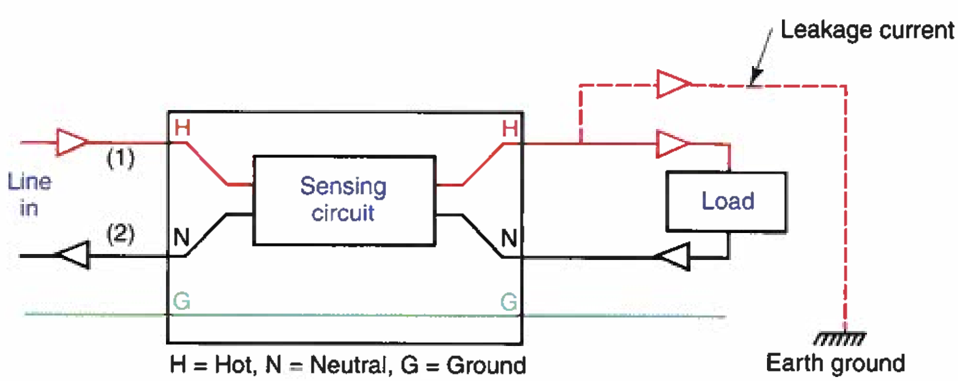
To accomplish this goal, the GFCI uses a sensing coil, which monitors the ampere flow going to the load on the hot leg and returning to the load on the return or neutral leg. Since amperes flow in a complete loop, incoming and outgoing amperage should be identical. See **Figure 8-42.**

In the event that these values differ, it is evident that a leak or fault has occurred. Such a situation could be extremely dangerous. A person could be in contact with the electricity and providing a return path or causing the fault current to flow to the ground. Therefore, the sensor on the GFCI is designed to sense ampere flow imbalances between the hot and neutral legs. If an imbalance of greater than 6 milliamperes (mA) occurs, the GFCI will trip, thereby disconnecting power from the source to the load. Since a shock of 6 mA or less is not regarded as life threatening, the GFCI is an ideal personnel protective device for many applications.

**Figure 8-42.** Ground Fault Circuit Interrupters (GFCI) are designed to protect people from electrical shock. A—A typical GFCI used in a bathroom or other location within 6′ of a sink or other water source. B—The GFCI uses a sensing circuit to detect an imbalance between current flowing in the hot and neutral sides of the circuit.

**A**

**B**



## Sizing Wire and Components According to Load

Wire and other permanently installed electrical components must be sized in accordance with the load they are intended to power. If these components are undersized, they will generate excessive heat, possibly tripping a circuit breaker or blowing a fuse. On the other hand, if the components are oversized, they may not be able to appropriately connect to the components they are intended to feed. Oversizing also results in the inefficient use of materials and may create unsafe conditions.

For instance, using the table in **Figure 8-43,** let us say a heater is designed to draw 22 amps at full operation. If it is wired with wire that can feed 40 amps and the wire is protected with a 40-amp circuit breaker, the heater could overheat and cause a fire without the circuit breaker ever tripping. These are some of the reasons that correctly sizing wire and other components in accordance with the anticipated load is so vitally important. **Figure 8-44** provides the maximum amperage for common wire gauges used for residential, commercial, and industrial applications.

## Electrical Safety

Every year, thousands of people are injured, and many are even killed, working with voltages as low as 120 vac. The National Safety Council reports that approximately 20% of electricity-related deaths each year are the result of faulty household wiring. Many of the remaining deaths occur from exposure to voltages as low as 120 vac. These figures do not include deaths caused as a result of fires started by improper electrical installations. When studying electricity, no topic is more important than that of electrical safety. Here is some practical advice on how to work with and use electricity safely and efficiently:

- Use the appropriate size fuse or circuit breaker for the given application.
- Do *not* assume that a circuit breaker or fuse will protect your body from excessive amperage flow.

**Figure 8-43.** Wire gauges and typical high-voltage applications.

| Wire Gauge | Typical Application |
|---|---|
| 24–20 Cu | Phones and communications |
| 18 Cu | Doorbells and thermostats |
| 16 Cu | Light extension cord wire |
| 14 Cu | Convenience circuits throughout most areas of the home |
| 12 Cu | Heavier branch circuits for the kitchen, the garage, and dedicated circuits for appliances such as refrigerators and room air conditioners |
| 4–10 Cu | Dedicated circuits that power a specific appliance, such as a hot water heater, electric range, or air conditioner |
| 2–0000 Al* | Service entrance cable for feeding electricity into the home |
| *Note that aluminum (Al) service entrance cable is typically used to feed homes in most parts of the country. All other wire is typically copper (Cu). | |

**Figure 8-44.** Amperage ratings of common wire gauges.

| Wire Gauge | Maximum Ampacity |
|---|---|
| 14 | 15 |
| 12 | 20 |
| 10 | 30 |

- Troubleshoot circuits in a de-energized state.
- When troubleshooting a de-energized circuit, be sure to identify and properly drain all capacitors.
- Do *not* ground yourself while working on an electrical system.
- Ensure that GFCI protection is installed in outdoor electrical receptacles and receptacles near water sources.

Always use the appropriate size fuse or circuit breaker for the given application. Fuses and circuit breakers are designed to perform one specific function: they will break the energized (hot) leg of a circuit when an overload or short circuit occurs. They perform their task extremely well if properly sized in accordance with the wire and other components they are designed to protect. If a fuse or breaker is oversized in relation to the components it is supposed to protect, the protective function of the fuse or breaker is significantly diminished.

Do *not* assume that a circuit breaker or fuse will protect your body from excessive amperage flow. Circuit breakers and fuses are designed to protect permanently installed wire and components, such as switches and receptacles, against heat buildup from excessive ampere flow. They are not designed to protect people. Circuit breakers and fuses are essentially single-purpose devices and cannot sense what load is drawing the electricity that flows through them. In other words, a 20-amp circuit breaker has no idea if a person is being electrocuted. The circuit breaker or fuse only knows to shut the circuit off if more than 20 amps flow through it for a period of time. This is important, since many applications require amperage well in excess of that which is required to cause physical harm to humans. See **Figure 8-45** for the effects of electrical current on the human body.

**Figure 8-45.** Physical effects of different levels of electrical current on the human body.

| Effects of Electrical Current on the Human Body | |
|---|---|
| **Current Value** | **Physical Effects** |
| 1 milliampere (mA) | Threshold of feeling. Only mild sensation. |
| 1mA –5mA | Sensation of shock and surprise. Not painful. Person can let go of contact point. |
| 5mA–10mA | Painful shock and reflex action. Person can still let go of contact point. |
| 20mA–50mA | Severe, painful shock and muscular contraction. Breathing is difficult. |
| 50mA–100mA | Possible ventricular fibrillation and breathing difficulty. |
| 100mA–200mA | Almost certain heart stoppage and death. |
| Above 200mA | Severe muscular contractions and burns. Heart stops as long as current flows through body. Breathing stops. |

Remember that circuit breakers are designed to protect only permanently installed components and not all components. This is why many plug-in appliances may include their own replaceable fuses or restorable circuit breakers and why most motors come with their own form of protective devices. In these instances, severe damage could occur without ever tripping a circuit breaker or blowing a fuse.

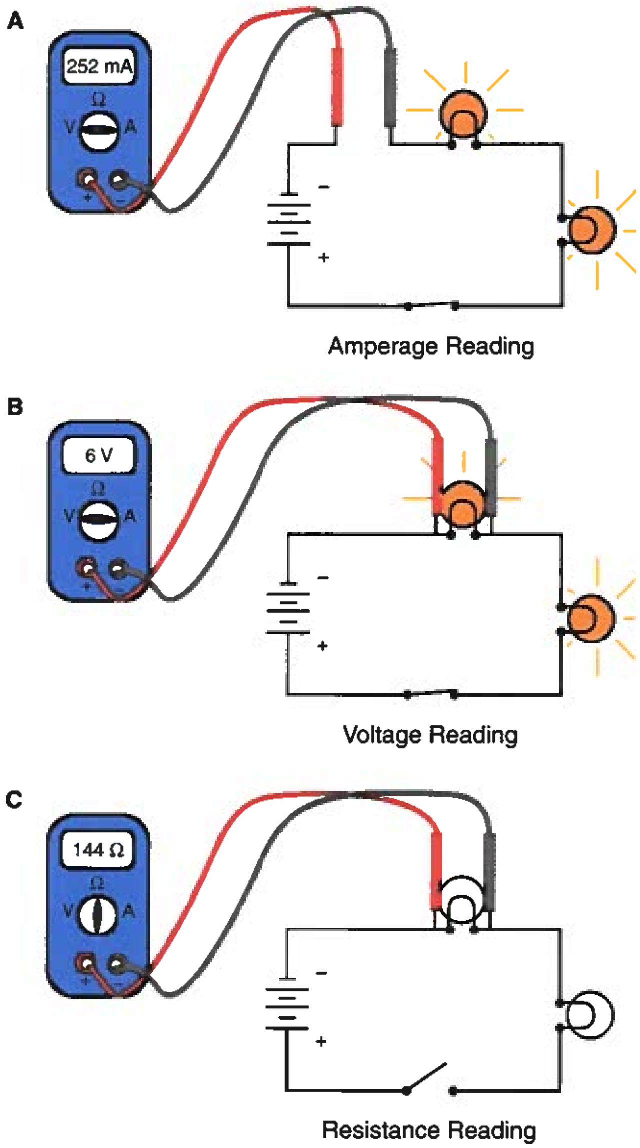
You should always troubleshoot circuits in a de-energized state. Although troubleshooting live circuitry has certain analytical advantages, troubleshooting a de-energized circuit is much safer. Troubleshooting an energized electronic circuit that operates at low voltages and amperages is often desirable. Most electrical circuitry and components can, however, be analyzed in a de-energized state. With an ohmmeter and a continuity tester, it is often just as easy to troubleshoot a de-energized circuit as it is to troubleshoot an energized circuit with a voltmeter. Remember, only well-qualified individuals should troubleshoot energized, high-voltage circuits and only when there is no other alternative.

Be aware that a de-energized circuit can still cause harm. Some electrical or electronic circuitry includes capacitors. Since capacitors are designed to store current even after a circuit is de-energized, they have the potential to deliver a severe shock. From a safety standpoint, learning how to identify and drain capacitors is extremely important. Capacitors are frequently used in electronic circuitry, but their use in high-voltage electricity is often limited to machines that use capacitors to help start motors spinning.

Do *not* ground yourself while working on an electrical system. When you connect an electrical conductor to the earth, it is said to be grounded. Since the earth offers a potential of zero volts, connecting the metal frame or housing of any device that uses electricity to the ground is often done for safety. You do not have to run your own wire to the ground to ground your load. Any device that has a three-terminal plug should make the connection to the ground for you. The third, rounded connector on a three-terminal plug does this. Grounding loads is important because if a hot wire came off of a terminal and touched the grounded part of the device, the electricity would immediately be passed on to the ground. To avoid the possibility of an electrical shock, it is important to ground your loads. When devices are not properly grounded, the electricity can flow through a person to the ground, causing possible injury or even death. Electricians that have to work with live electricity, such as utility workers, go to great lengths through the clothing they wear and the equipment they use to ensure they are *not* grounded while working around live electricity. If an accident were to occur, the severity of the shock would be based in large part on how much a person was grounded.

The National Electrical Code (NEC) requires GFCI protection for many locations, including outdoor electrical receptacles and those near water sources, such as the kitchen and bathrooms. You should therefore ensure that GFCI protection is installed in outdoor electrical receptacles and receptacles near water sources. GFCI protection should also be used in the laboratory when working with electricity.

Figure 8-46. Meter placement. A—Amperage is measured in series. B—Voltage is measured in parallel. C—Resistance is measured in parallel with the circuit de-energized.




## Using Instrumentation Safely and Properly

Several types of instruments can be used when measuring electricity. The primary instrument is the multimeter, which is a meter that can measure voltage, resistance, and sometimes amperage. Other meters sometimes used include voltmeters, ammeters, amp clamps, ohmmeters, wattmeters, and watt-hour meters.

A few general rules apply to the use of all instrumentation. Observing these rules will help ensure accurate measurements and protection of the instrumentation and of the person doing the measuring. Failure to observe these rules could damage an expensive piece of equipment and possibly cause bodily injury.

- Determine the proper instrument for measuring the desired quantity. It is important to be sure the meter you choose has the capability to measure the quantity (voltage or amperage) you desire to measure.
- Determine whether the instrument should be inserted into the circuit in series or in parallel. Amperage is always measured in series, and voltage is always measured in parallel. Both measurements require the circuit to be energized. Observe the placement of the meters in the diagram in **Figure 8-46.**

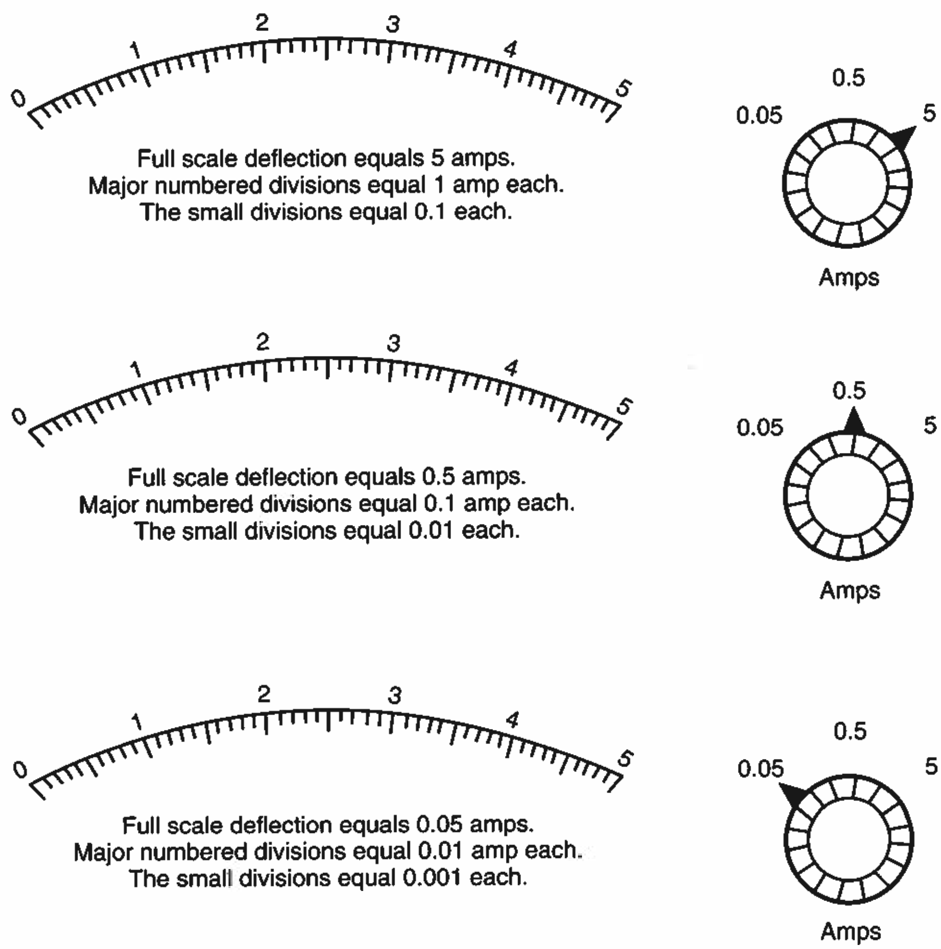
**Safety Note**

**Working with live electricity can be very dangerous. Be certain you are not grounded when working around live electricity. Always wear rubber-soled shoes when working with live electricity known to be above 24 volts, and always use the proper instrumentation and equipment.**

- Resistance is always measured with the circuit de-energized and the meter in parallel with the load. See Figure 8-46.
- Always start on the highest range when measuring unknown quantities with a multirange instrument. Many of the contemporary digital meters automatically switch ranges. Even with these types of meters, however, you may need to switch ranges for an accurate reading.

- If using an analog meter, determine whether the scale you will be reading is divided into even increments or whether it is skewed. It is common for one scale to be used to represent several ranges with a multirange instrument. You may need to add or subtract decimal places to obtain the correct reading on such instruments. See **Figure 8-47.**
- Use surge suppressors to protect delicate equipment, such as computers and stereo systems, from excessive voltages. Remember, circuit breakers protect electrical circuits only from excessive amperage. They are not voltage protection devices. It is possible to protect a circuit from voltage fluctuations and excessive voltage, using devices other than circuit breakers or fuses. For instance, when a constant voltage is critical, a constant voltage transformer may be used. This device has the ability to take in voltages higher or lower than the desired voltage and produce a consistently desired voltage on the output side of the transformer. One application for constant voltage transformers would be to protect delicate hospital equipment. These transformers can receive anywhere from 90 vac to 140 vac and produce a consistent 120 vac.

**Figure 8-47.** Reading an analog meter scale.



# Summary

Most communication, transportation, and manufacturing systems rely heavily on one or more electrical systems for proper operation. Electricity provides lights for night-time operation. It powers electric motors that operate various components in a vehicle. Electricity is necessary for the operation of most heat engines. Onboard computers need a reliable source of electricity to perform their many functions. Likewise, radios and other accessories depend on a reliable source of electricity.

Electricity is produced when atoms trade electrons between their valence rings. Conductors are materials that carry electrical current easily. Devices like bells, lights, motors, switches, and fuses are connected with a conductor and then attached to a power source to form a circuit. These circuits are the heart of an electrical power system when they do work, create light, or create heat.

Magnetism is important in the study of electricity. Magnets are used to create electrical current by a process called electromagnetic induction. Iron can be magnetized by passing an electrical current around it. When iron is magnetized in this way, it is called an electromagnet. Electricity-producing generators, alternators, and electric motors, use the principles of electricity and magnetism to operate.

Batteries convert chemical energy to electrical energy. Both types of energy may be used for transportation vehicles. Some batteries are also able to store electricity for later use. Transformers are used to increase or decrease the amount of electrical current or voltage supplied to a circuit.

# Key Words

*All the following words have been used in this chapter. Do you know their meanings?*

AC generator
alternating current (AC)
alternator
atom
battery
carbon-zinc battery
cell
circuit breaker
closed circuit
conductor
continuity
continuity checker
current
current flow
DC generator
direct current (DC)
double-pole, double-throw (DPDT) switch
electrical circuit
electrode
electrolyte
electromagnet
electromagnetic induction
electron theory
flux
fuse
Ground Fault Circuit Interrupter (GFCI)
insulator
kilowatt-hour (kWh)
latching relay
lead-acid battery
line of force
magnet
momentary contact switch
Ohm's law
open circuit
polarity
potentiometer
primary cell
primary coil
push-button make/break (PBMB) switch
resistance
ring
schematic drawing
secondary cell
secondary coil
semiconductor
short circuit
single-pole, double-throw (SPDT) switch
single-pole, single-throw (SPST) switch
slow-blow fuse
step-down transformer
step-up transformer
transformer
valence ring
wattage

# Test Your Knowledge

*Write your answers on a separate sheet of paper. Do not write in this book.*

1. Recall three types of electrical circuits found in vehicles.
2. What are three parts of an atom?
3. _____ are materials that transfer electrons easily and are used to connect the parts of an electrical circuit.
4. According to electron theory, electricity moves from a(n) _____ point to a(n)_____ point.
5. DC stands for _____.
6. AC stands for _____.
7. _____ is a measurement of electrical power.
8. What type of drawing is used to represent electrical circuits on paper?
9. A switch can create which type of circuit when electricity does not flow through it?
10. What law would you use to calculate voltage, if current and resistance are known?
11. A current of 47 A flows through an electric welder with a resistance of 10 Ω. What power is dissipated in the circuit?
12. A heating element requires 220 volts. Its heat resistance is 6 Ω. What power does the heater require?
13. _____ is the unit by which we are billed for electricity.
14. How much will it cost to run 14 75-watt lightbulbs for 5 days at 10 hours per day, assuming the cost of electricity is $.09 per kilowatt-hour (kWh)?
15. Calculate the total resistance of a series circuit that contains the following three resistors: 10 Ω, 100 Ω, and 1000 Ω.
16. What is the difference between series and parallel circuits?
17. Calculate the total resistance of a parallel circuit that has three lightbulbs that offer the following resistances: 17 Ω, 42 Ω, and 90 Ω.
18. _____ use an electrical current to produce a magnetic field in a piece of iron.
19. The process of using magnetic fields to create electrical current in a wire is called _____.
20. Make a sketch showing how moving water causes a turbine to create electricity.
21. What electrical component will only allow electricity to flow through it in one direction?
22. Sketch a simple DC generator and describe how it works.

23. Identify the type of switch used to turn a load on or off from two different locations.

24. A(n) _____ switch used in conjunction with two single-pole, double-throw (SPDT) switches can control a load from three or more locations.

25. Diagram a pair of three-way switches that control two lights in parallel.

26. If you want to make an indicator light come on only when a button is depressed and go off after the button is released, use a(n) _____ switch.

*Matching questions: For Questions 27 through 32, match the phrases on the left with the correct term on the right.*

27. _____ Converts chemical energy to electrical energy.
28. _____ Surrounds electrodes in a battery to help produce current.
29. _____ Can be discharged (used up) and recharged many times.
30. _____ Produces alternating current (AC) using mechanical energy.
31. _____ Produces direct current.
32. _____ Reduces or increases electrical current in a circuit.

A. Electrolyte.
B. Battery.
C. Transformer.
D. Alternator.
E. DC generator.
F. Secondary cell.

33. Calculate the efficiency of a transformer, given the following characteristics: input voltage = 120 vac, input amperage = 2 A, output voltage = 24 vac, and output amperage = 6.5 A.

34. Which devices will protect an electrical circuit from excessive ampere flow?

35. What type of tester can be used to check if a switch, diode, fuse, or breaker is functioning properly?

36. Identify the primary factor to consider when sizing wire and other electrical components.

37. Is 120 vac a safe voltage with which to work?

38. Almost certain death or heart stoppage can occur from a current as little as _____ mA.

39. _____ is always measured with the meter in series with the load.

40. _____ is always measured with the meter in parallel with the load and with the circuit energized.

41. _____ is always measured with the circuit de-energized.

# STEM Activities

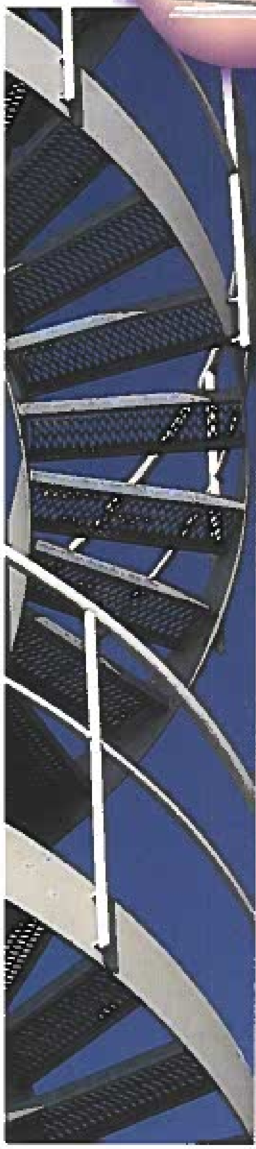
1. Connect two flashlight cells (batteries) in series (positive poles to negative poles). Ask your instructor to help you use a voltmeter or volt-ohmmeter (VOM) to measure voltage. Be sure the function switch on the voltmeter is turned to the direct current (DC) voltage position. Use rubber bands to hold meter leads to the cell's terminals. After measuring the voltage of the two cells, measure each cell individually. Report the voltage readings to the class. Research circuit theory in an electricity reference book and explain why the measured voltage is different from the individual voltage of either battery.
2. Study and set up a simple parallel circuit using a suitable power source (battery or cell), switches, conductors, and lights.

**Safety Note**

**Wear eye protection for Activity 3. Automobile batteries contain acid that could cause blindness. Even a film of battery acid on the case could cause serious injury if it comes in contact with the skin or an eye.**

3. Check an automotive battery for leakage across its top. Set a voltmeter at its lowest setting. Attach the probe with the black conductor to the negative terminal of the battery. Touch the positive probe to the battery case on the opposite side near the positive battery terminal. If the voltmeter registers voltage, there is an electrical leak because of a dirty top. Using a brush, clean the top of the battery case with a solution of warm water and baking soda. Retest as before. Is there any leakage now?

# Career Skills



## *Communication Skills*

Communicating effectively with others is important for job success. Being a good communicator means that you can share information well with others. It also means you are a good listener.

Good communication is central to a smooth operation of any business. Communication is the process of exchanging ideas, thoughts, or information. Poor communication is costly to an employer, as when time is lost because an order was entered incorrectly. Poor communication can result in lost customers, too.

The primary forms of communications are verbal and nonverbal. Verbal communication involves speaking, listening, and writing. Nonverbal communication is the sending and receiving of messages without the use of words. It involves body language, which includes the expression on your face and your body posture.

Listening is an important part of communication. If you do not understand, be sure to ask questions. Also give feedback to let others know you understand them and are interested in what they have to say. Leaning forward while a person is talking signals interest and keen listening. Slouching back in a chair and yawning give the opposite signal—that you are bored and uninterested.

The message you convey in telephone communication involves your promptness, tone of voice, and attitude. Answering the phone quickly with a pleasant voice conveys a positive image for the company. Learning to obtain accurate information from the caller without interrupting that person's message is important.

Communication tools have advanced with the development of new technologies. To be an effective employee, you need to know how to communicate well with the common tools of your workplace. For example, when sending e-mail communications, remember to think through each message as you would before sending a postal letter. Often messages are sent quickly without thought of how the recipient may interpret them. The same is true of voicemail.

The development of good communication skills is an ongoing process. Attending communication workshops and practicing often can keep your skills sharp. You should periodically give yourself a communications checkup by asking your supervisor to suggest areas that need improvement.