UNIT

2

Electrical Quantities and Ohm's Law

Delmar Online Training Simulation | Electricity

Why You Need to Know

Anyone working in the electrical field must know and understand the basic units used to measure electric power. To accomplish this, it is important to understand how electricity works and is evaluated. In order to work with electric components and control devices in the field, you must know the electrical measuring terms and how to apply these terms. This unit presents

- the difference between voltage and current. You will discover, for example, that voltage is actually the force that pushes the electrons through a conductor. Voltage cannot flow, but it can cause current to flow.
- current. This is a quantity of electrons moving through a conductor within a certain length of time. Current, or amperes, is the actual amount of electricity that flows through the circuit. If it were possible to cut a wire and catch electricity in a container, you would have a container full of electrons.
- watts. This is a measure of power. It is basically the rate at which electrical energy is being converted into some other form. It is also the measurement used by the power company to charge its customers for the amount of energy consumed.
- Ohm's law. This is the basis for all electrical calculations. Ohm's law is a method of mathematically determining electrical quantities when other quantities are known. It is possible, for example, to determine the amount of current that will flow in a circuit if the resistance in the circuit and the voltage applied to it are known.
- a discussion of the similarity of electricity and water systems.

Key Terms

Ampere (A)
British thermal unit (BTU)
Complete path
Conventional current flow theory
Coulomb (C)
Electromotive force (EMF)
Electron flow theory
Grounding conductor
Horsepower (hp)
Impedance
Joule
Neutral conductor

Outline

Objectives

After studying this unit, you should be able to

- define a coulomb.
- define an ampere.
- define a volt.
- define an ohm.
- define a watt.
- calculate different electrical values using Ohm's law.
- discuss different types of electric circuits.
- select the proper Ohm's law formula from a chart.

Key Terms Continued...

Ohm (Ω)
Ohm's law
Potential difference
Power
Resistance
Volt (V)
Watt (W)

Preview

Electricity has a standard set of values. Before one can work with electricity, one must know these values and how to use them. Because the values of electrical measurement have been standardized, they are understood by everyone who uses them. For instance, carpenters use a standard system for measuring length, such as the inch, foot, meter, or centimeter. Imagine what a house would look like that was constructed by two carpenters who used different lengths of measure for an inch or foot. The same holds true for people who work with electricity. The standards of measurement must be the same for everyone. Meters should be calibrated to indicate the same quantity of current flow or voltage or resistance. A volt, an ampere, or an ohm is the same everywhere in the world. ■

2–1 The Coulomb

The **coulomb** is a measure of charge. The letter C is used to represent the coulomb. An electron, designated as q_e, has a charge of 1.6×10^{-19} C. To produce a charge of 1 C would require 6.25×10^{18} or 6,250,000,000,000,000,000 electrons. To better understand the number of electrons contained in one coulomb, think of comparing 1 second to 200 billion years. The coulomb can be thought of as a quantity measure of electrons similar to a quart, gallon, or liter. It requires a certain amount of liquid to equal a liter, just as it requires a certain amount of electrons to equal a coulomb.

The coulomb is named for a French scientist who lived in the 1700s named Charles Augustin de Coulomb. Coulomb experimented with electrostatic charges and developed a law dealing with the attraction and repulsion of these forces. The law, known as ***Coulomb's law of electrostatic charges, states that the force of electrostatic attraction or repulsion is directly proportional to the product of the two charges and inversely proportional to the square of the distance between them.*** It is the System Internationale (SI) unit of electric charge. A coulomb is defined as the charge transferred by a current of 1 ampere in one second.

2–2 The Ampere

The **ampere** is named for André Ampère, a scientist who lived from the late 1700s to the early 1800s. Ampère is most famous for his work dealing with electromagnetism, which is discussed in a later unit. The ampere (A) is equal to 1 coulomb per second. Notice that the definition of an ampere involves a quantity measurement, the coulomb, and a time

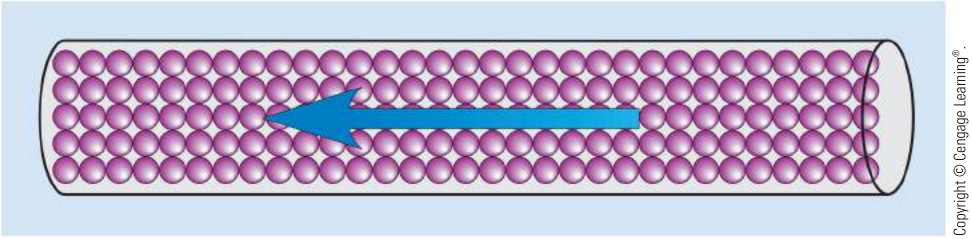

FIGURE 2–1 One ampere equals one coulomb per second.

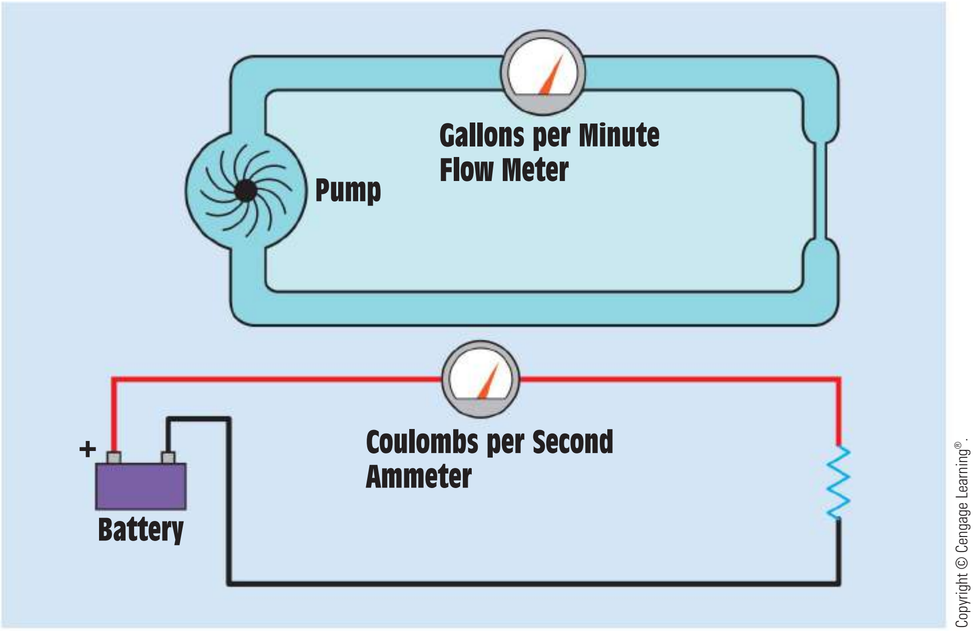

FIGURE 2–2 Current in an electric circuit can be compared to flow rate in a water system.

measurement, the second (I = q/t). One ampere of current flows through a wire when 1 coulomb flows past a point in one second *(Figure 2–1)*. The ampere is a measurement of the amount of electricity that is flowing through a circuit. In a water system, it would be comparable to gallons per minute or gallons per second *(Figure 2–2)*. The letter *I*, which stands for intensity of current, and the letter *A*, which stands for ampere, are both used to represent current flow in algebraic formulas. This text uses the letter *I* in formulas to represent current.

2–3 The Electron Flow Theory

There are actually two theories concerning current flow. One theory is known as the **electron flow theory** and states that because electrons are negative particles, current flows from the most negative point in the circuit to the most positive. The electron flow theory is the more widely accepted as being correct and is used throughout this text.

2–4 The Conventional Current Flow Theory

The second theory, known as the **conventional current flow theory,** was defined by Benjamin Franklin and is older than the electron flow theory and states that current flows from the most positive point to the most negative. Although it has been established almost

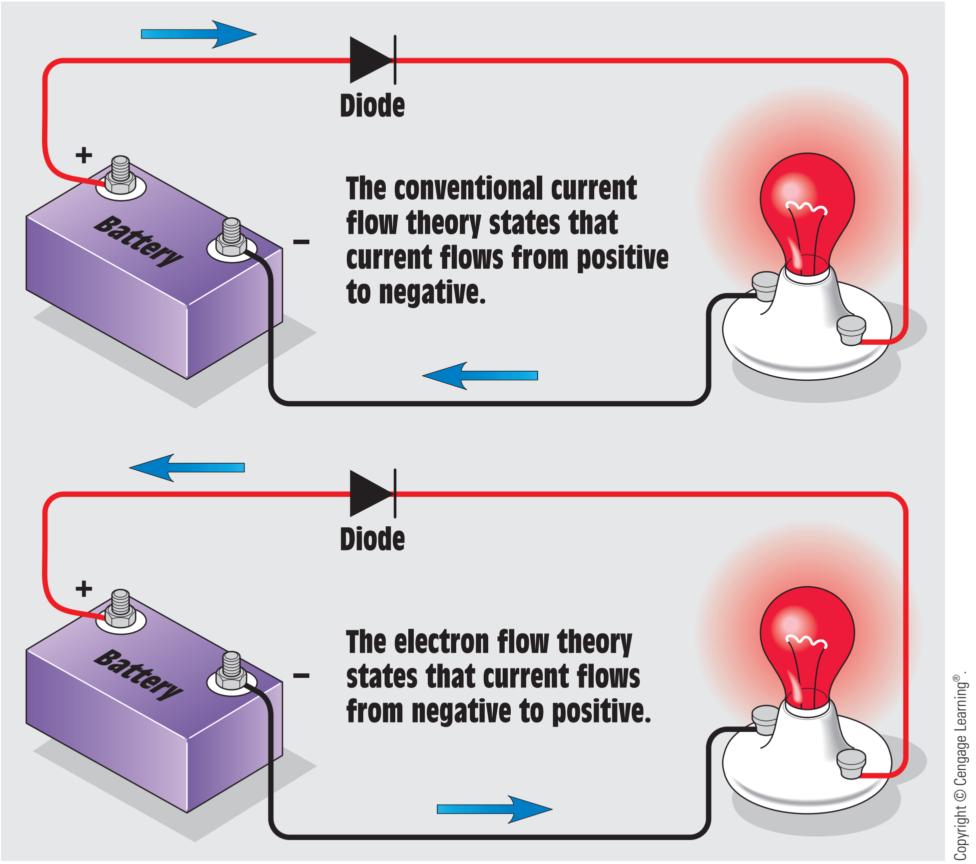

FIGURE 2–3 Conventional current flow theory and electron flow theory.

to a certainty that the electron flow theory is correct, the conventional current flow theory is still widely used for several reasons. Most electronic circuits use the negative terminal as ground or common. When the negative terminal is used as ground, the positive terminal is considered to be above ground, or hot. It is easier for most people to think of something flowing down rather than up, or from a point above ground to ground. An automobile electric system is a good example of this type of circuit. Most people consider the positive battery terminal to be the hot terminal.

Many people who work in the electronics field prefer the conventional current flow theory because all the arrows on the semiconductor symbols point in the direction of conventional current flow. If the electron flow theory is used, it must be assumed that current flows against the arrow (*Figure 2–3*). Another reason that many people prefer using the conventional current flow theory is that most electronic schematics are drawn in a manner that assumes that current flows from the more positive to the more negative source. In *Figure 2–4*, the positive voltage point is shown at the top of the schematic and the negative (ground) is shown at the bottom. When tracing the flow of current through a circuit, most people find it easier to go from top to bottom than from bottom to top.

2–5 Speed of Current

To determine the speed of current flow through a wire, one must first establish exactly what is being measured. As stated previously, current is a flow of electrons through a conductive substance. Assume for a moment that it is possible to remove a single electron from a wire and identify it by painting it red. If it were possible to observe the progress of the

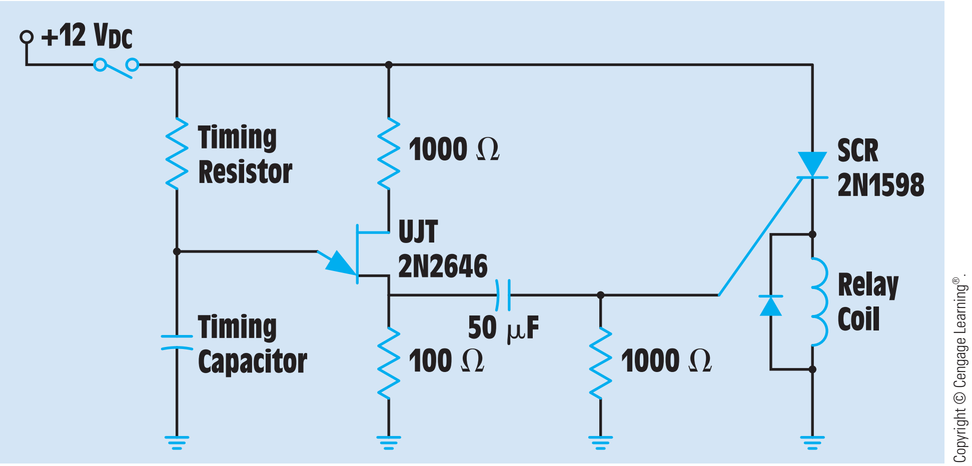

FIGURE 2–4 On-delay timer.

identified electron as it moved from atom to atom, it would be seen that a single electron moves rather slowly *(Figure 2–5)*. It is estimated that a single electron moves at a rate of about 3 inches per hour at 1 ampere of current flow.

Another factor that must be considered is whether the circuit is DC, AC, or radio waves. Radio waves move at approximately the speed of light, which is 186,000 miles per second or 300,000,000 meters per second. The velocity of AC through a conductor is less than the speed of light because magnetic fields travel more slowly in material dielectrics than they do through free air. The formula shown can be used to calculate the wavelength of a signal traveling through a conductor. Wavelength is the distance that current travels during one AC cycle. Wavelength is discussed more fully in Unit 15.

$$L = \frac{984\ V}{f}$$

where

$$\begin{aligned} L &= \text{length in feet} \\ V &= \text{velocity factor} \\ f &= \text{frequency in megahertz (MHz)} \end{aligned}$$

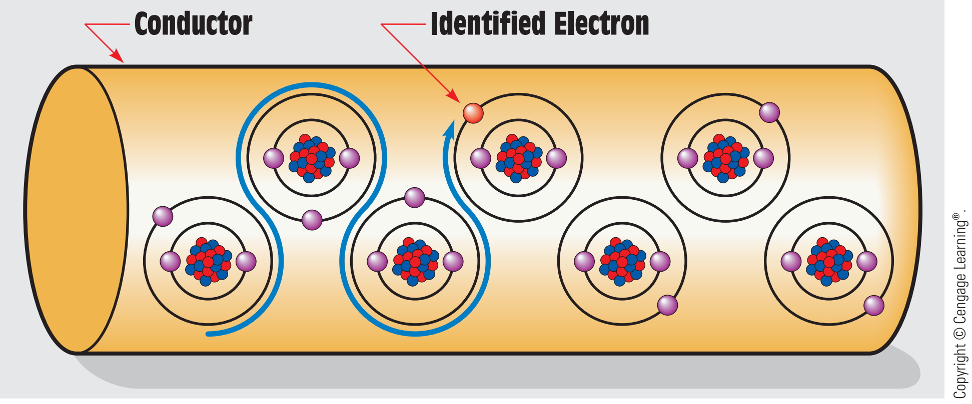

FIGURE 2–5 Electrons moving from atom to atom.

Description or Type Number	Velocity Factor	Characteristic Impedance	Capacitance per Foot
Coaxial Cable			
RG–8A/U	0.66	53	29.5 pF
RG–58A/U	0.66	53	28.5 pF
RG–17A/U	0.66	50	30 pF
RG–11A/U	0.66	75	20.5 pF
RG59A/U	0.66	73	21 pF
Parallel Conductors			
Air Insulated	0.975	200–600	—
214–023	0.71	75	20 pF
214–056	0.82	300	5.8 pF
214–076	0.84	300	3.9 pF
214–022	0.85	300	3 pF

TABLE 2–1 Data for Different Types of Transmission Lines

The velocity factor is determined by the type of conductor. *Table 2–1* gives the velocity factor for several different types of coaxial cables and parallel conductors.

How many feet would a 5-MHz signal travel through a conductor with a velocity factor of 0.66 during one AC cycle?

$$L = \frac{984 \times 0.66}{5}$$

$$L = 129.888 \text{ feet}$$

In a DC circuit, the impulse of electricity can appear to be faster than the speed of light. Assume for a moment that a pipe has been filled with table-tennis balls (*Figure 2–6*). If a ball is forced into the end of the pipe, the ball at the other end will be forced out. Each time a ball enters one end of the pipe, another ball is forced out the other end. This principle is also true for electrons in a wire. There are billions of electrons in a wire. If an electron enters one end of a wire, another electron is forced out the other end. Assume that a wire is long enough to be wound around the earth 10 times. If a power source and a switch were connected at one end of the wire and a light at the other end (*Figure 2–7*), the light would turn on the moment the switch was closed. It would take light approximately 1.3 seconds to travel around the earth 10 times.

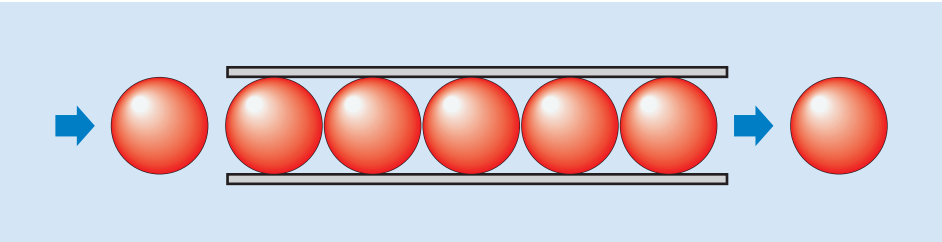

FIGURE 2–6 When a ball is pushed into one end, another ball is forced out the other end. This basic principle causes the instantaneous effect of electric impulses.

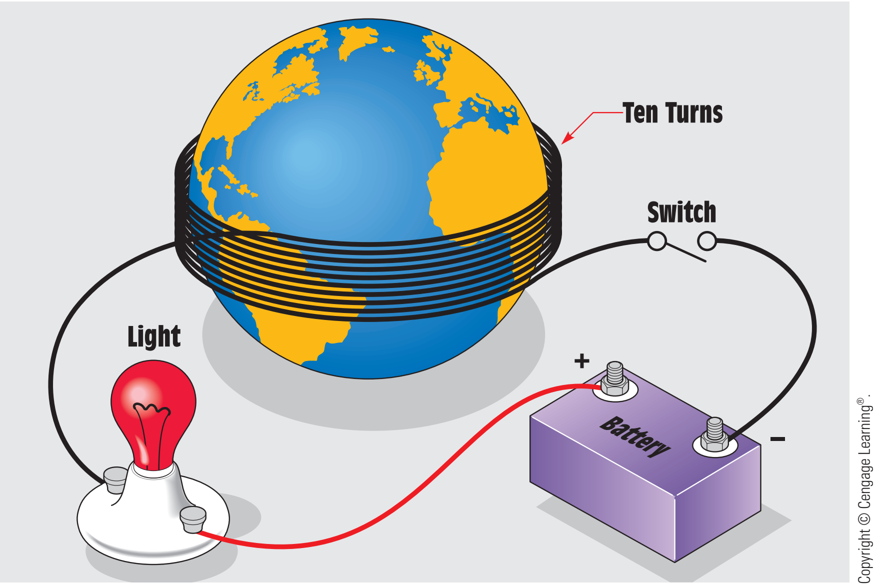

FIGURE 2–7 The impulse of electricity can appear to travel faster than light.

2–6 Basic Electric Circuits

A **complete path** must exist before current can flow through a circuit (*Figure 2–8*). A complete circuit is often referred to as a *closed circuit*, because the power source, conductors, and load form a closed loop. In *Figure 2–8*, a lamp is used as the load. The load offers resistance to the

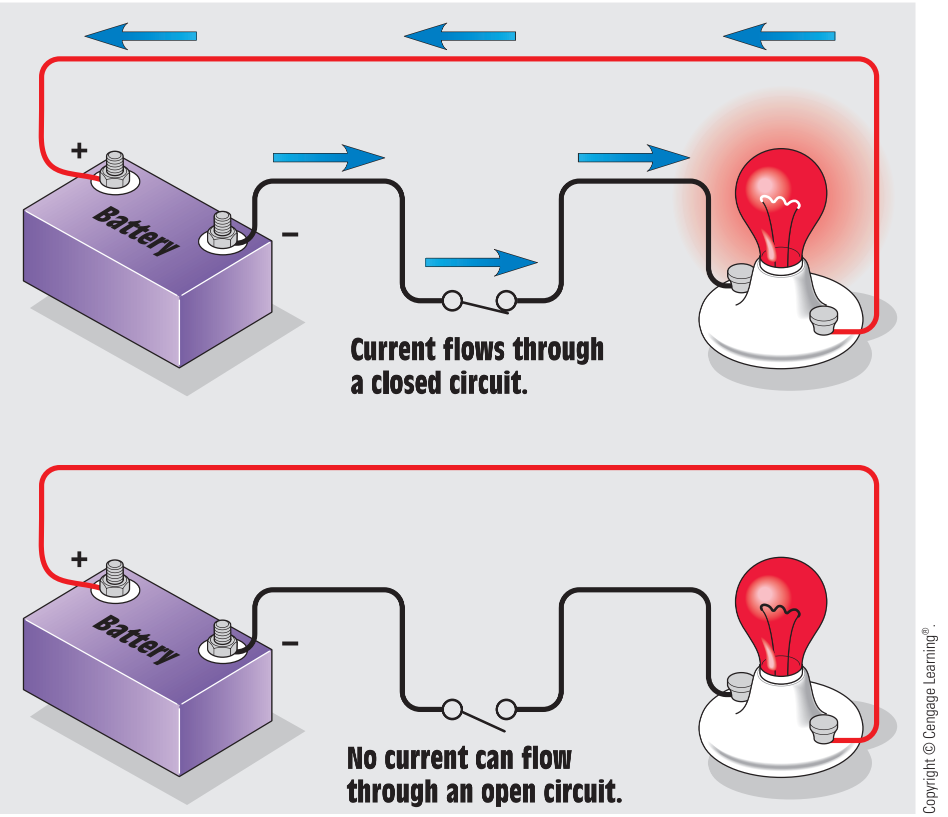

FIGURE 2–8 Current flows only through a closed circuit.

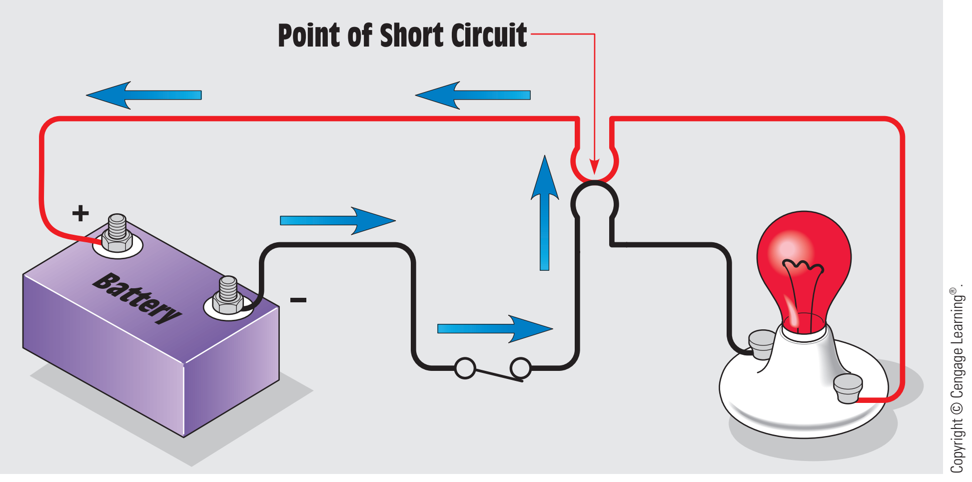

FIGURE 2–9 A short circuit bypasses the load and permits too much current to flow.

circuit and limits the amount of current that can flow. If the switch is opened, there is no longer a closed loop and no current can flow. This is often referred to as an incomplete, or open, circuit.

Another type of circuit is the short circuit, which has very little or no resistance. It generally occurs when the conductors leading from and back to the power source become connected (*Figure 2–9*). In this example, a separate current path has been established that bypasses the load. Because the load is the device that limits the flow of current, when it is bypassed, an excessive amount of current can flow. Short circuits generally cause a fuse to blow or a circuit breaker to open. If the circuit has not been protected by a fuse or circuit breaker, a short circuit can damage equipment, melt wires, and start fires.

Another type of circuit, one that is often confused with a short circuit, is a grounded circuit. Grounded circuits can also cause an excessive amount of current flow. They occur when a path other than the one intended is established to ground. Many circuits contain an extra conductor called the **grounding conductor.** A typical 120-volt appliance circuit is shown in *Figure 2–10*. In this circuit, the ungrounded, or hot, conductor is connected to the fuse or circuit breaker. The hot conductor supplies power to the load. The grounded conductor, or **neutral conductor,** provides the return path and completes the circuit back to the power source. The grounding conductor is generally connected to the case of the appliance to provide a low-resistance path to ground. Although both the neutral and grounding conductors are

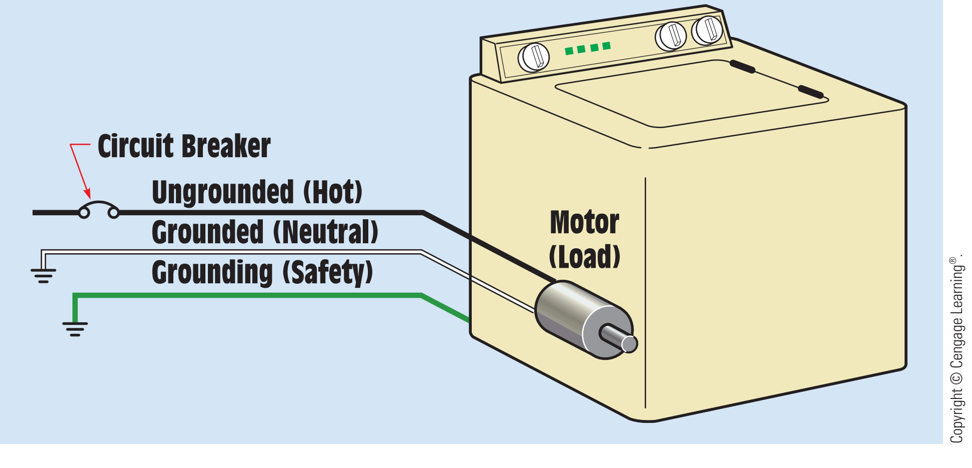

FIGURE 2–10 120-V appliance circuit.

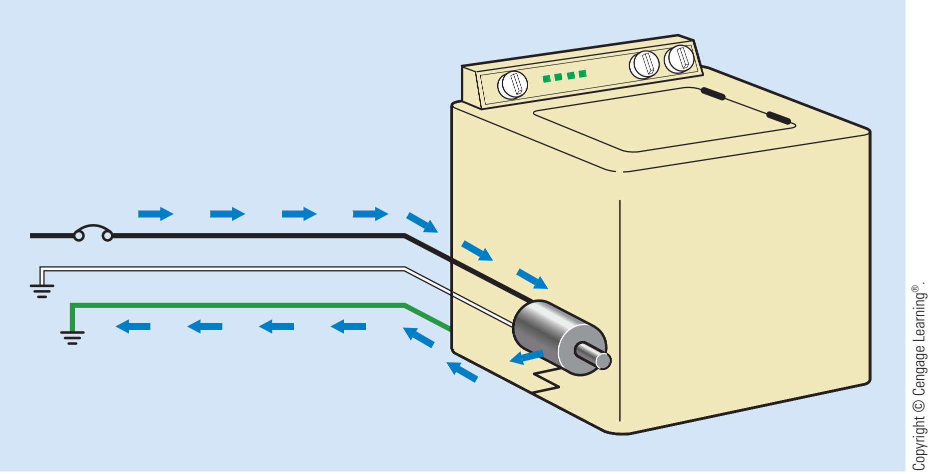

FIGURE 2–11 The grounding conductor provides a low-resistance path to ground.

grounded at the power source, the grounding conductor is not considered to be a circuit conductor, because current will flow through the grounding conductor only when a circuit fault develops. In normal operation, current flows through the hot and neutral conductors only.

The grounding conductor is used to help prevent a shock hazard in the event that the ungrounded, or hot, conductor comes in contact with the case or frame of the appliance (*Figure 2–11*). This condition can occur in several ways. In this example, assume that the motor winding becomes damaged and makes connection to the frame of the motor. Because the frame of the motor is connected to the frame of the appliance, the grounding conductor provides a circuit path to ground. If enough current flows, the circuit breaker will open. Without a grounding conductor connected to the frame of the appliance, the frame would become hot (in the electrical sense) and anyone touching the case and a grounded point, such as a water line, would complete the circuit to ground. The resulting shock could be fatal. For this reason, the grounding prong of a plug should never be cut off or bypassed.

2–7 The Volt

Voltage is defined as the potential difference between two points of a conducting wire carrying a constant current of 1 ampere when the power dissipated between these points is 1 watt. Voltage is also referred to as **potential difference** or **electromotive force (EMF).** It is the force that pushes the electrons through a wire and is often referred to as electrical pressure. A **volt** is the amount of potential necessary to cause 1 coulomb to produce 1 joule of work. One thing to remember is that voltage cannot flow. Voltage in an electrical circuit is like pressure in a water system (*Figure 2–12*). To say that voltage flows through a circuit is like saying that pressure flows through a pipe. Pressure can push water through a pipe, and it is correct to say that water flows through a pipe, but it is not correct to say that pressure flows through a pipe. The same is true for voltage. Voltage pushes current through a wire, but voltage cannot flow through a wire.

Voltage is often thought of as the potential to do something. For this reason it is frequently referred to as potential, especially in older publications and service manuals. Voltage must be present before current can flow, just as pressure must be present before water can flow. A voltage, or potential, of 120 volts is present at a common wall outlet, but there is no flow until some device is connected and a complete circuit exists. The same is true in a water system. Pressure is present, but water cannot flow until the valve is opened and a path is provided to a region of lower pressure. The letter *E*, which stands for EMF, or the letter *V*, which stands for volt, can be used to represent voltage in an algebraic formula. This text uses the letter *E* to represent voltage in an algebraic formula.

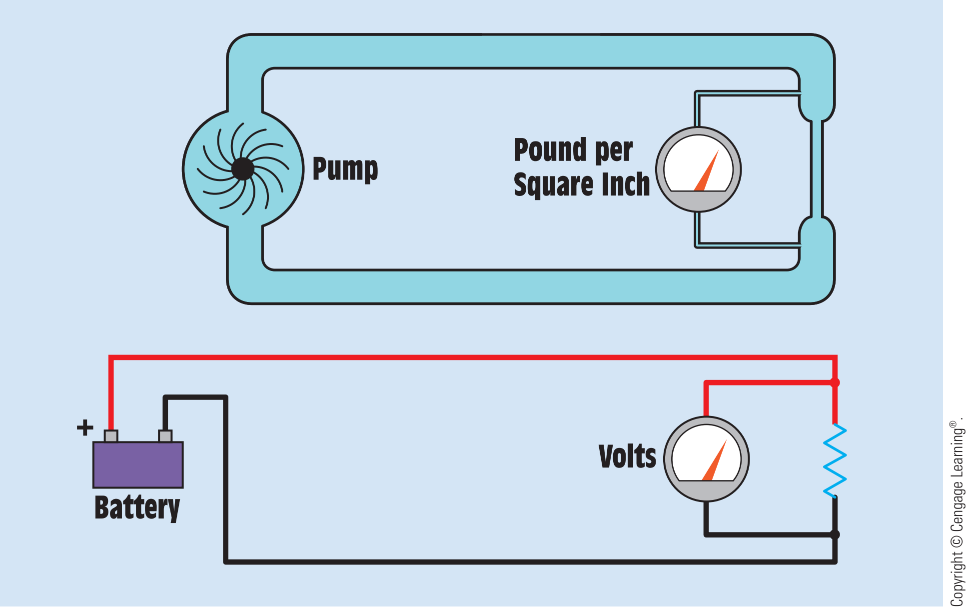

FIGURE 2–12 Voltage in an electric circuit can be compared to pressure in a water system.

2–8 The Ohm

An **ohm** is the unit of **resistance** to current flow. It was named after the German scientist Georg S. Ohm. The symbol used to represent an ohm, or resistance, is the Greek letter omega (Ω). The letter R, which stands for resistance, is used to represent ohms in an algebraic formula. An ohm is the amount of resistance that allows 1 ampere of current to flow when the applied voltage is 1 volt. Without resistance, every electric circuit would be a short circuit. All electric loads, such as heating elements, lamps, motors, transformers, and so on, are measured in ohms. In a water system, a reducer can be used to control the flow of water; in an electric circuit, a resistor can be used to control the flow of electrons *(Figure 2–13)*.

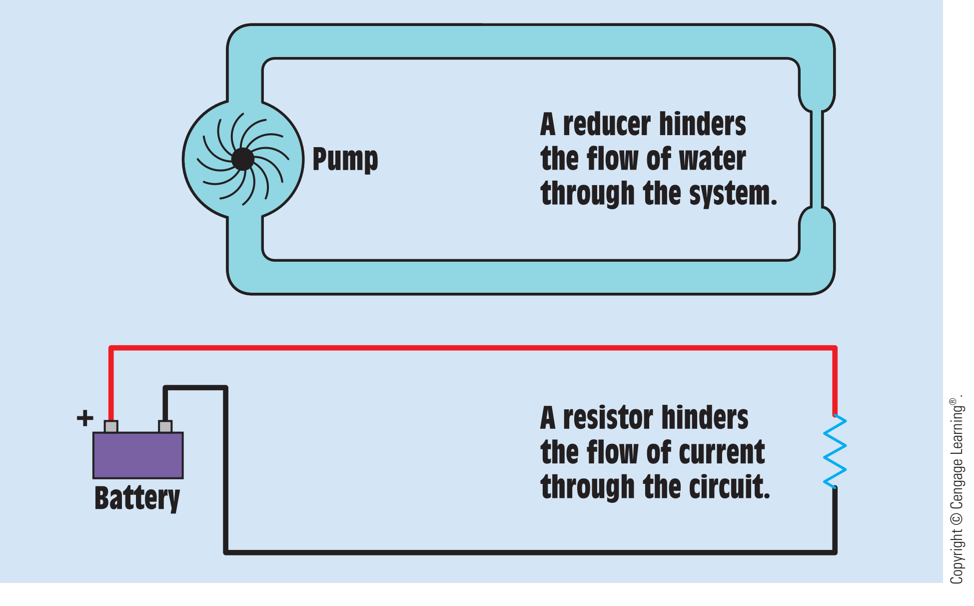

FIGURE 2–13 A resistor in an electric circuit can be compared to a reducer in a water system.

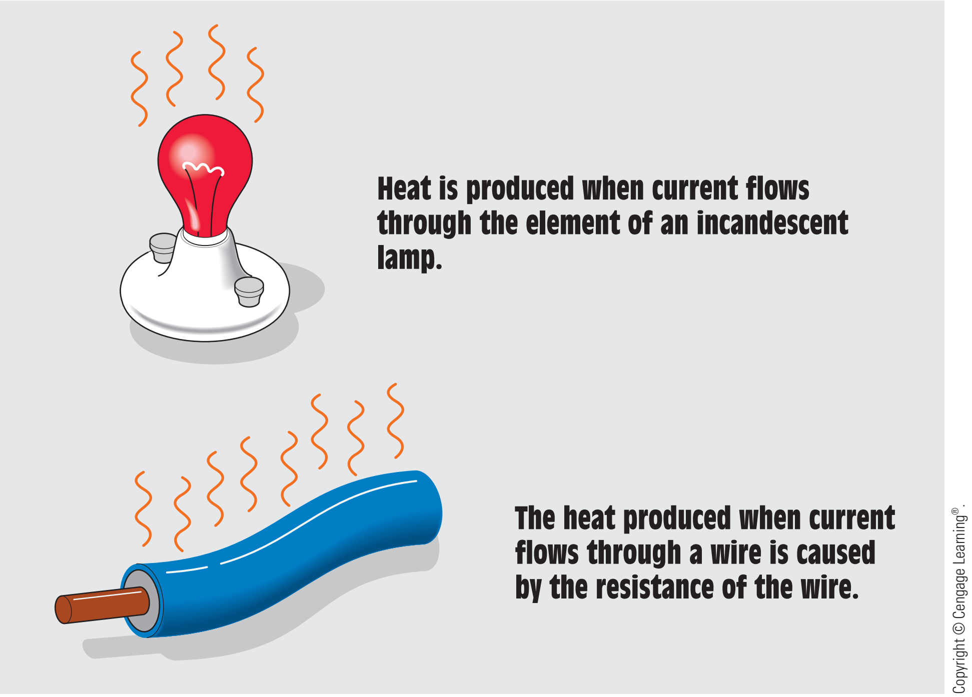

FIGURE 2–14 Heat is produced when current flows through resistance.

To understand the effect of resistance on an electric circuit, imagine a person running along a beach. As long as the runner stays on the hard, compact sand, he or she can run easily along the beach. Likewise, current can flow easily through a good conductive material, such as a copper wire. Now imagine that the runner wades out into the water until it is knee deep. He or she will no longer be able to run along the beach as easily because of the resistance of the water. Now imagine that the runner wades out into the water until it is waist deep. His or her ability to run along the beach will be hindered to a greater extent because of the increased resistance of the water against his or her body. The same is true for resistance in an electric circuit. The higher the resistance, the greater the hindrance to current flow.

Another fact an electrician should be aware of is that any time current flows through a resistance, heat is produced (*Figure 2–14*). That is why a wire becomes warm when current flows through it. The elements of an electric range become hot, and the filament of an incandescent lamp becomes extremely hot because of resistance.

Another term similar in meaning to resistance is **impedance.** Impedance is most often used in calculations of AC rather than DC. Impedance is discussed to a greater extent later in this text.

Green Tip: Larger wire size will result in less resistance. Less resistance reduces the voltage drop and consequently the amount of power loss due to heating the conductor. ■

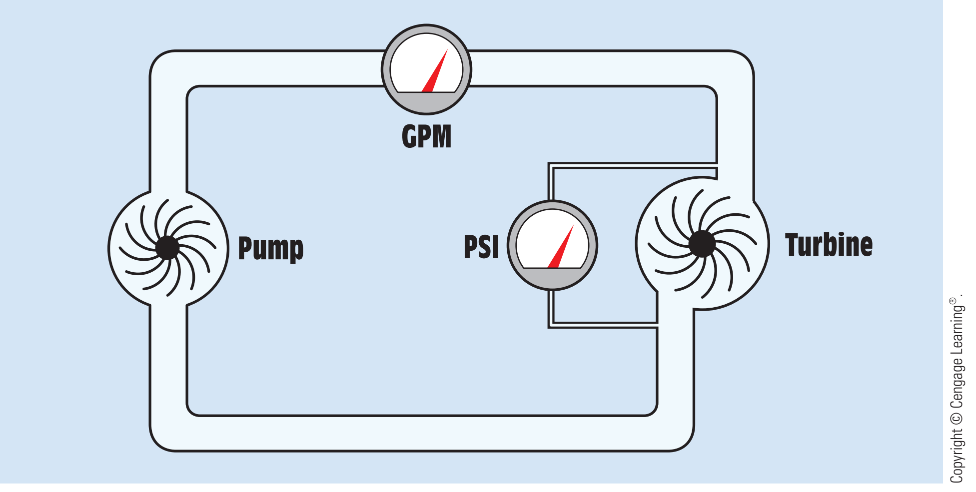

FIGURE 2–15 Force equals flow rate times pressure.

2–9 The Watt

Wattage is a measure of the amount of power that is being used in a circuit. The **watt** was named in honor of the English scientist James Watt. In an algebraic formula, wattage is generally represented either by the letter *P*, for power, or *W*, for watts. It is proportional to the amount of voltage and the amount of current flow ($P = E \times I$). To understand watts, return to the example of the water system. Assume that a water pump has a pressure of 120 pounds per square inch (PSI) and causes a flow rate of 1 gallon per second. Now assume that this water is used to drive a turbine, as shown in *Figure 2–15*. The turning force or torque developed by the turbine is proportional to the amount of water flow and the pressure forcing it against the turbine blades. If the pressure is increased and the flow rate remains constant, the water will strike the turbine blades with greater force and the torque will increase. If the pressure remains constant and a greater volume of water is permitted to flow, the turbine blades will be struck by more pounds of water in the same amount of time and torque will again increase. As you can see, the torque developed by the turbine is proportional to both the pressure and the flow rate of the water.

The power of an electric circuit is very similar. *Figure 2–16* shows a resistor connected to a circuit with a voltage of 120 volts and a current flow of 1 ampere. The resistor shown

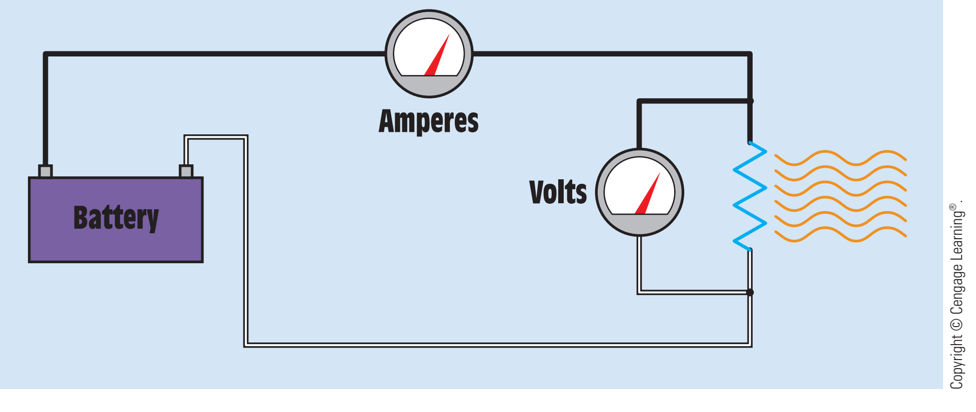

FIGURE 2–16 Amperes times volts equals watts.

represents an electric heating element. When 120 volts force a current of 1 ampere through it, the heating element will produce 120 watts of heat (120 V × 1 A = 120 W). If the voltage is increased to 240 volts, but the current remains constant, the element will produce 240 watts of heat (240 V × 1 A = 240 W). If the voltage remains at 120 volts, but the current is increased to 2 amperes, the heating element will again produce 240 watts (120 V × 2 A = 240 W). Notice that the amount of power used by the heating element is determined by the amount of current flow and the voltage driving it.

An important concept concerning **power** in an electric circuit is that before true power, or watts, can exist, there must be some type of energy change or conversion. In other words, electric energy must be changed or converted into some other form of energy before there can be power or watts. It makes no difference whether electric energy is converted into heat energy or mechanical energy; there must be some form of energy conversion before watts can exist.

Formulas that may be used to determine power in a circuit are

$$P = EI$$

$$P = I^2R$$

$$P = \frac{E^2}{R}$$

where

P = power or watts
I = current or amps
E = volts
R = resistance in ohms

2–10 Other Measures of Power

The watt is not the only unit of power measure. Many years ago, James Watt decided that in order to sell his steam engines, he would have to rate their power in terms that the average person could understand. He decided to compare his steam engines to the horses he hoped his engines would replace. After experimenting, Watt found that the average horse working at a steady rate could do 550 foot-pounds of work per second. A foot-pound (ft-lb) is the amount of force required to raise a 1 pound weight 1 foot. This rate of doing work is the definition of a **horsepower (hp)**:

$$1 \text{ hp} = 550 \text{ ft-lb/s}$$

Horsepower can also be expressed as 33,000 foot-pounds per minute (550 ft-lb/s × 60 s/min = 33,000 ft-lb/min):

$$1 \text{ hp} = 33{,}000 \text{ ft-lb/min}$$

It was later calculated that the amount of electric energy needed to produce one horsepower was 746 watts:

$$1 \text{ hp} = 746 \text{ W}$$

Another measure of energy frequently used in the English system of measure is the **British thermal unit (BTU)**. A BTU is defined as the amount of heat required to raise the temperature of 1 pound of water 1 degree Fahrenheit. In the metric system, the calorie is used instead of the BTU to measure heat. A calorie is the amount of heat needed to raise the temperature of 1 gram of water 1 degree Celsius. The **joule** is the SI equivalent of the watt. A joule is defined as 1 newton-meter. A newton is a force of 100,000 dynes, or about 3-½ ounces, and a meter is about 39 inches. The joule can also be expressed as the amount of

1 Horsepower =	746 Watts
1 Horsepower =	550 Ft-lb/s
1 Watt =	0.00134 Horsepower
1 Watt =	3.412 BTU/hr
1 Wattsecond =	1 Joule
1 BTU-hr =	0.293 Whr
1 Cal/s =	4.19 Watts
1 Ft-lb/s =	1.36 Watts
1 BTU =	1050 Joules
1 Joule =	0.2388 Cal
1 Cal =	4.187 Joules

FIGURE 2–17 Common power units.

work done by 1 coulomb flowing through a potential of 1 volt, or as the amount of work done by 1 watt for 1 second:

$$1 \text{ joule} = 1 \text{ wattsecond}$$
$$1 \text{ watt} = 1 \text{ joule/s}$$

The chart in *Figure 2–17* gives some common conversions for different quantities of energy. These quantities can be used to calculate different values.

EXAMPLE 2–1

An elevator must lift a load of 4000 lb to a height of 50 ft in 20 s. How much horsepower is required to operate the elevator?

Solution

Find the amount of work that must be performed, and then convert that to horsepower:

$$4000 \text{ lb} \times 50 \text{ ft} = 200{,}000 \text{ ft-lb}$$
$$\frac{200{,}000 \text{ ft-lb}}{20 \text{ s}} = 10{,}000 \text{ ft-lb/s}$$
$$\frac{10{,}000 \text{ ft-lb/s}}{550 \text{ ft-lb/s}} = 18.18 \text{ hp}$$

EXAMPLE 2–2

A water heater contains 40 gallons of water. Water weighs 8.34 lb per gallon. The present temperature of the water is 68°F. The water must be raised to a temperature of 160°F in one hour. How much power will be required to raise the water to the desired temperature?

Solution

First determine the weight of the water in the tank, because a BTU is the amount of heat required to raise the temperature of 1 pound of water 1 degree Fahrenheit:

$$40 \text{ gal} \times 8.34 \text{ lb per gal} = 333.6 \text{ lb}$$

The second step is to determine how many degrees of temperature the water must be raised. This amount will be the difference between the present temperature and the desired temperature:

$$160^{\circ}\text{F} - 68^{\circ}\text{F} = 92^{\circ}\text{F}$$

The amount of heat required in BTU will be the product of the pounds of water and the desired increase in temperature:

$$333.6 \text{ lb} \times 92^{\circ}\text{F} = 30{,}691.2 \text{ lb-degrees or BTU}$$

$$1 \text{ Whr} = 3.412 \text{ BTU/hr}$$

Therefore,

$$\frac{30{,}691.2 \text{ BTU}}{3.412 \text{ BTU/hr}} = 8995.1 \text{ Whr}$$

2–11 Ohm's Law

In its simplest form, **Ohm's law** states that ***it takes 1 volt to push 1 ampere through 1 ohm.*** Ohm discovered that all electric quantities are proportional to each other and can therefore be expressed as mathematical formulas. He found that if the resistance of a circuit remained constant and the voltage increased, there was a corresponding proportional increase of current. Similarly, if the resistance remained constant and the voltage decreased, there would be a proportional decrease of current. He also found that if the voltage remained constant and the resistance increased, there would be a decrease of current; and if the voltage remained constant and the resistance decreased, there would be an increase of current. This finding led Ohm to the conclusion that ***in a DC circuit, the current is directly proportional to the voltage and inversely proportional to the resistance.***

Because Ohm's law is a statement of proportion, it can be expressed as an algebraic formula when standard values such as the volt, the ampere, and the ohm are used. The three basic Ohm's law formulas are

$$E = I \times R$$

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

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

where

E = EMF, or voltage (in volts)

I = intensity of current, or amperage (in amps)

R = resistance (in ohms)

The first formula states that the voltage can be found if the current and resistance are known. Voltage is equal to amperes multiplied by ohms. For example, assume that a circuit has a resistance of 50 ohms and a current flow through it of 2 amperes. The voltage connected to this circuit is 100 volts.

$$E = I \times R$$
$$E = 2\text{ A} \times 50\ \Omega$$
$$E = 100\text{ V}$$

The second formula states that the current can be found if the voltage and resistance are known. In the example shown, 120 volts are connected to a resistance of 30 ohms. The amount of current flow will be 4 amperes.

$$I = \frac{E}{R}$$
$$I = \frac{120\text{ V}}{30\ \Omega}$$
$$I = 4\text{ A}$$

The third formula states that if the voltage and current are known, the resistance can be found. Assume that a circuit has a voltage of 240 volts and a current flow of 10 amperes. The resistance in the circuit is 24 ohms.

$$R = \frac{E}{I}$$
$$R = \frac{240\text{ V}}{10\text{ A}}$$
$$R = 24\ \Omega$$

Figure 2–18 shows a simple chart that can be a great help when trying to remember an Ohm's law formula. To use the chart, cover the quantity that is to be found. For example, if the voltage, E, is to be found, cover the E on the chart. The chart now shows the remaining letters IR *(Figure 2–19)*; thus, $E = I \times R$. The same method reveals the formulas for current (I) and resistance (R).

A larger chart, which shows the formulas needed to find watts as well as voltage, amperage, and resistance, is shown in *Figure 2–20*. The letter P (power) is used to represent the value of watts. Notice that this chart is divided into four sections and that each section contains three different formulas. To use this chart, select the section containing the quantity to be found and then choose the proper formula from the given quantities.

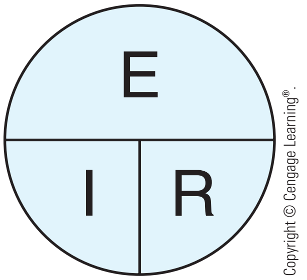

FIGURE 2–18 Chart for finding values of voltage, current, and resistance.

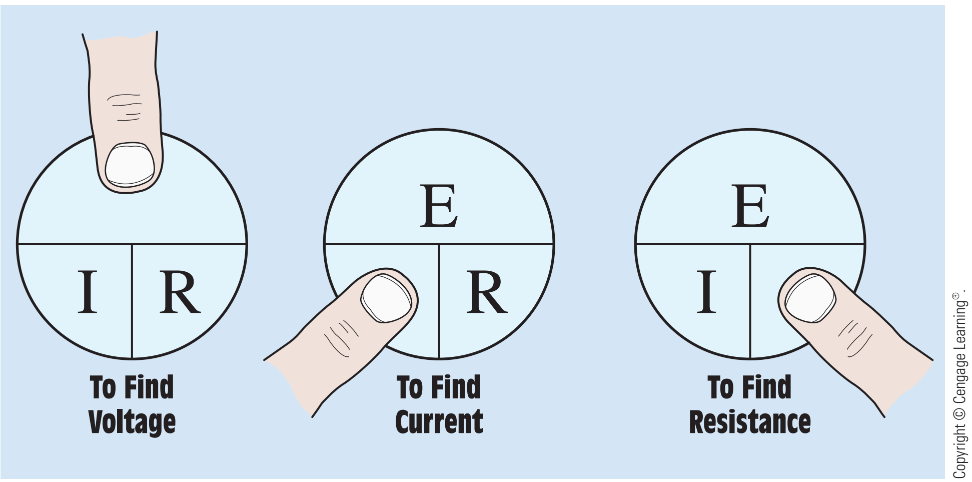

FIGURE 2–19 Using the Ohm's law chart.

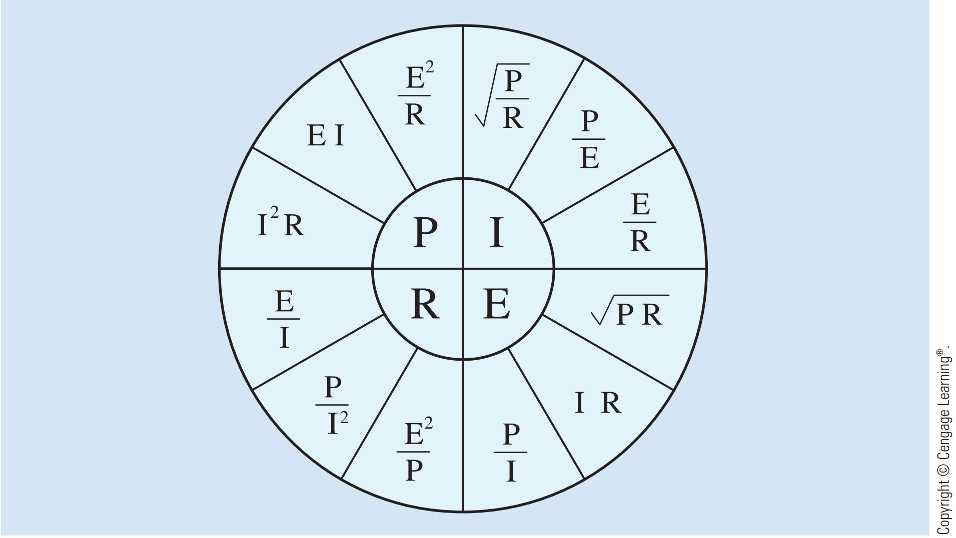

FIGURE 2–20 Formula chart for finding values of voltage, current, resistance, and power.

EXAMPLE 2–3

An electric iron is connected to 120 V and has a current draw of 8 A. How much power is used by the iron?

Solution

The quantity to be found is watts, or power. The known quantities are voltage and amperage. The proper formula to use is shown in *Figure 2–21*.

$$P = EI$$
$$P = 120\ \text{V} \times 8\ \text{A}$$
$$P = 960\ \text{W}$$

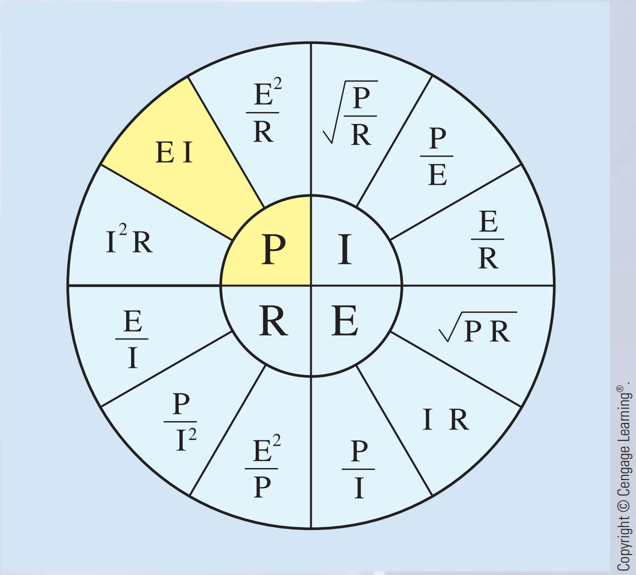

FIGURE 2–21 Finding power when voltage and current are known.

EXAMPLE 2–4

An electric hair dryer has a power rating of 1000 W. How much current will it draw when connected to 120 V?

Solution

The quantity to be found is amperage, or current. The known quantities are power and voltage. To solve this problem, choose the formula shown in *Figure 2–22*.

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

$$I = \frac{1000\ W}{120\ V}$$

$$I = 8.333\ A$$

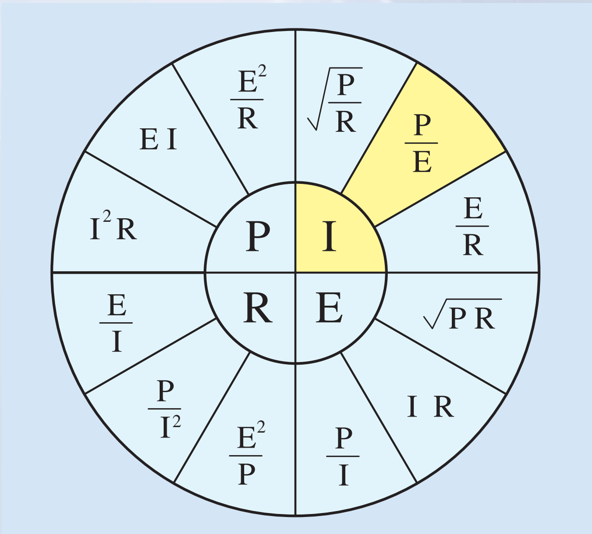

FIGURE 2–22 Finding current when power and voltage are known.

EXAMPLE 2–5

An electric hotplate has a power rating of 1440 W and a current draw of 12 A. What is the resistance of the hotplate?

Solution

The quantity to be found is resistance, and the known quantities are power and current. Use the formula shown in *Figure 2–23*.

$$R = \frac{P}{I^2}$$

$$R = \frac{1440\ W}{12\ A \times 12\ A}$$

$$R = \frac{1440\ W}{144\ A}$$

$$R = 10\ \Omega$$

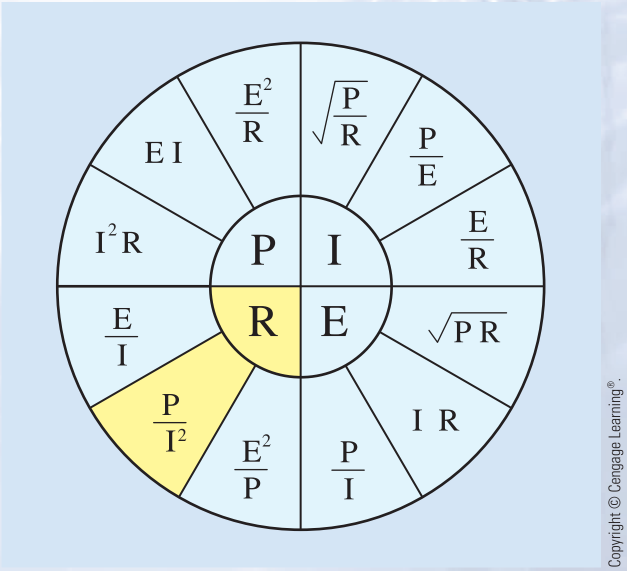

FIGURE 2–23 Finding resistance when power and current are known.

2–12 Metric Prefixes

Metric prefixes are used in the electrical field just as they are in most other scientific fields. A special type of notation, known as *engineering notation,* is used in electrical measurements. Engineering notation is similar to scientific notation except that engineering notation is in steps of 1000 instead of 10. The chart in *Figure 2–24* shows standard metric prefixes. The first step above the base unit is deka, which means 10. The second prefix is hecto, which means 100, and the third prefix is kilo, which means 1000. The first prefix below the base unit is deci, which means $\frac{1}{10}$; the second prefix is centi, which means $\frac{1}{100}$; and the third is milli, which means $\frac{1}{1000}$.

The chart in *Figure 2–25* shows prefixes used in engineering notation. The first prefix above the base unit is kilo, or 1000; the second prefix is mega, or 1,000,000; and the third prefix

Kilo	1000
Hecto	100
Deka	10
Base Unit	1
Deci	$\frac{1}{10}$ or 0.1
Centi	$\frac{1}{100}$ or 0.01
Milli	$\frac{1}{1000}$ or 0.001

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FIGURE 2–24 Standard metric prefixes.

ENGINEERING UNIT	SYMBOL	MULTIPLY BY	
Tera	T	1,000,000,000,000	X 10^{12}
Giga	G	1,000,000,000	X 10^{9}
Mega	M	1,000,000	X 10^{6}
Kilo	k	1,000	X 10^{3}
Base Unit		1	
Milli	m	0.001	X 10^{-3}
Micro	μ	0.000,001	X 10^{-6}
Nano	n	0.000,000,001	X 10^{-9}
Pico	p	0.000,000,000,001	X 10^{-12}

FIGURE 2–25 Standard prefixes of engineering notation.

is giga, or 1,000,000,000. Notice that each prefix is 1000 times greater than the previous prefix. The chart also shows that the first prefix below the base unit is milli, or $^1/_{1000}$; the second is micro, represented by the Greek mu (μ), or $^1/_{1,000,000}$; and the third is nano, or $^1/_{1,000,000,000}$.

Metric prefixes are used in almost all scientific measurements for ease of notation. It is much simpler to write a value such as 10 MΩ than it is to write 10,000,000 ohms, or to write 0.5 ns than to write 0.000,000,000, 5 second. Once the metric prefixes have been learned, measurements such as 47 kilohms (kΩ) or 50 milliamperes (mA) become commonplace to the technician.

The SI System

Note that the term *metric* is commonly used to indicate a system that employs measurements that increase or decrease in steps of 10. The prefixes just discussed are commonly referred to as *metric* units of measure. These prefixes are actually part of the SI (System Internationale) system that was adopted for use in the United States in 1960 by the 11th General Conference on Weights and Measures (abbreviated CGPM from the

Quantity	Unit	Symbol
Length	Meter	m
Mass	Kilogram	kg
Time	Second	s
Electric current	Ampere	A
Thermodynamic temperature	Kelvin	K
Amount of substance	Mole	mol
Luminous intensity	Candela	cd
Phase angle	Radian	rad
Solid angle	Sterdian	sr

FIGURE 2–26 SI base and supplementary units.

Quantity	Unit	Symbol	Formula
Frequency	Hertz	Hz	l/s
Force	Newton	N	$(kg \cdot m)/s^2$
Pressure, stress	Pascal	Pa	N/m^2
Energy, work, quantity of heat	Joule	J	$N \cdot m$
Power, radiant flux	Watt	W	J/s
Quantity of electricity, charge	Coulomb	C	$A \cdot s$
Electric potential, electromotive force	Volt	V	W/A
Capacitance	Farad	F	C/V
Electric resistance	Ohm	Ω	V/A
Conductance	Siemens	S	A/V
Magnetic flux	Weber	Wb	$V \cdot s$
Magnetic flux density	Tesla	T	Wb/m^2
Inductance	Henry	H	Wb/A
Luminous flux	Lumen	lm	$cd \cdot sr$
Illuminance	Lux	lx	lm/m^2

FIGURE 2–27 Derived SI units.

official French name *Conference Generale des Poids et Mesures*). The intention of the SI system is to provide a worldwide standard of weights and measures. The SI system uses seven base and two supplementary units that are regarded as dimensionally independent (*Figure 2–26*). From these base and supplementary units, other units have been derived. Some of these units commonly used in the electrical field are shown in *Figure 2–27*.

SUMMARY

- A coulomb is a measure of charge.
- An ampere (A) is 1 coulomb per second.
- The letter *I*, which stands for intensity of current flow, is normally used in Ohm's law formulas.
- Voltage is referred to as electric pressure, potential difference, or electromotive force. An E or a V can be used to represent voltage in Ohm's law formulas.
- An ohm (Ω) is a measurement of resistance (R) in an electric circuit.
- The watt (W) is a measurement of power in an electric circuit. It is represented by either a W or a P (power) in Ohm's law formulas.
- Electric measurements are generally expressed in engineering notation.
- Engineering notation differs from scientific notation in that it uses steps of 1000 instead of steps of 10.
- Before current can flow, there must be a complete circuit.
- A short circuit has little or no resistance.
- An open circuit has infinite resistance.

REVIEW QUESTIONS

1. What is a coulomb?
2. What is an ampere?
3. Define voltage.
4. Define ohm.
5. Define watt.
6. An electric heating element has a resistance of 16 Ω and is connected to a voltage of 120 V. How much current will flow in this circuit?
7. How many watts of heat are being produced by the heating element in Question 6?
8. A 240-V circuit has a current flow of 20 A. How much resistance is connected in the circuit?
9. An electric motor has an apparent resistance of 15 Ω. If 8 A of current are flowing through the motor, what is the connected voltage?
10. A 240-V air-conditioning compressor has an apparent resistance of 8 Ω. How much current will flow in the circuit?
11. How much power is being used by the motor in Question 10?
12. A 5-kW electric heating unit is connected to a 240-V line. What is the current flow in the circuit?
13. If the voltage in Question 12 is reduced to 120 V, how much current would be needed to produce the same amount of power?
14. Is it less expensive to operate the electric heating unit in Question 12 on 240 V or 120 V?

PRACTICAL APPLICATIONS

You are an electrician on the job. The electrical blueprint shows that eight 500-W lamps are to be installed on the same circuit. The circuit voltage is 277 V and is protected by a 20-A circuit breaker. A continuous-use circuit can be loaded to only 80% of its rating. Is a 20-A circuit large enough to carry this load? ■

PRACTICAL APPLICATIONS

You have been sent to a new home. The homeowner reports that sometimes the electric furnace trips the 240-V, 60-A circuit breaker connected to it. Upon examination, you find that the furnace contains three 5000-W heating elements designed to turn on in stages. For example, when the thermostat calls for heat, the first 5000-W unit turns on. After some period of time, the second unit will turn on, and then, after another time delay, the third unit will turn on. What do you think the problem is, and what would be your recommendation for correcting it? Explain your answer. ■

PRACTICAL APPLICATIONS

You are an electrician installing the wiring in a new home. The homeowner desires that a ceiling fan with light kits be installed in five different rooms. Each fan contains a light kit that can accommodate four 60-watt lamps. Each fan motor draws a current of 1.8 amperes when operated on high speed. It is assumed that each fan can operate more than three hours at a time and therefore must be considered a continuous-duty device. The fans are to be connected to a 15-ampere circuit. Because the devices are continuous duty, the circuit current must be limited to 80% of the continuous connected load. How many fans can be connected to a single 15-ampere circuit? How many circuits will be required to supply power to all five fans? ■

PRACTICAL APPLICATIONS

A homeowner is installing a swimming pool. You have been asked to install a circuit to operate a 600-watt underwater light and a circulating pump. The motor nameplate reveals that the pump has a current draw of 8.5 amperes. The devices are considered continuous duty. Can the power to operate both of these devices be supplied by a single 20-ampere circuit? ■

PRACTICE PROBLEMS

Ohm's Law

Fill in the missing values.

Volts (E)	Amperes (I)	Ohms (R)	Watts (P)
153 V	0.056 A		
	0.65 A	470 Ω	
24 V			124 W
	0.00975 A		0.035 W
		6.8 kΩ	0.86 W
460 V		72 Ω	
48 V	1.2 A		
	154 A	0.8 Ω	
277 V			760 W
	0.0043 A		0.0625 W
		130 kΩ	0.0225 W
96 V		2.2 kΩ	

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