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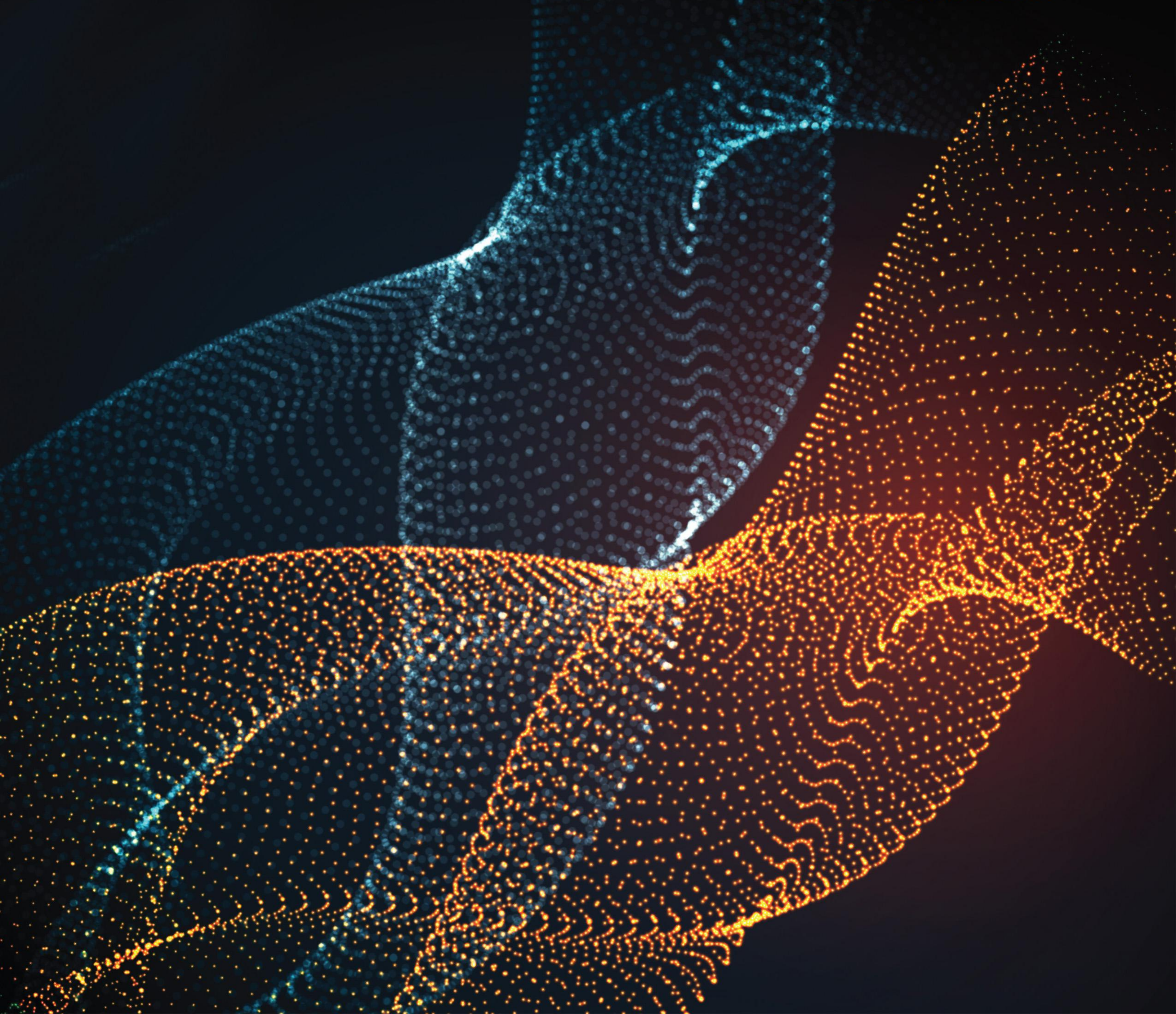
11th edition

ELECTRICITY

for Refrigeration, Heating and Air Conditioning

Russell E. Smith
Coleman Simmons



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Australia • Brazil • Canada • Mexico • Singapore • United Kingdom • United States

***Electricity for Refrigeration, Heating and Air Conditioning*, 11E**
Russell E. Smith
Coleman Simmons

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PREFACE

The heating, ventilation, air conditioning and refrigeration (HVAC/R) industry is a rapidly evolving and changing field. Changes and upgrades in technology is a constant factor that today's HVAC/R technicians must face. Over the past three decades, we have seen HVAC/R thermostats and control systems transition from primarily electro-mechanical controls to solid-state analog controls, and now, advanced variable-speed systems using communicating and, in some cases, wireless control systems. In the past, the air conditioning equipment used to condition residential homes was primarily composed of single-stage, unitary equipment. Today, it is common to find multi and variable speed equipment and mini-split systems used to condition residential dwellings. There have also been many advances made in electric motor technology over the past 20 years. We address the following technological advancements in 11th Edition of *Electricity for Refrigeration, Heating, and Air Conditioning*:

1. The section on thermostats has been improved and expanded to include more information and graphics on electronic and communicating thermostats.
2. Some of the wiring diagrams and schematics have been updated or replaced to better reflect modern control systems.
3. The section on ECM motors has been updated and expanded to now include information and graphics on constant torque (X-13) motors.
4. The section on mini-split and ductless heating and cooling systems has been updated and expanded.
5. The chapter on residential air conditioning systems has been heavily updated to include new and additional information and graphics.
6. Additional information and graphics on troubleshooting control devices and system has been added to multiple sections of the text.
7. Extensive updates and additions have been made to the art to reflect electrical devices and systems presently used in the industry.
8. Additional practice service calls have been added to applicable chapters.

Today's technicians face the difficult task of having to service, troubleshoot and repair many older systems using older mechanical and analog control technology, while at the same time, technicians must also install, service, troubleshoot and repair new equipment using advanced, sophisticated control systems. Technicians must also stay up-to-date as technological advancements are being made and introduced to the HVAC/R industry each day. This text is written with a blend of theory and practicality suitable for vocational/technical or technical and community college students, as well as for industry practitioners who wish to upgrade their knowledge and skills. The purpose of this text is to assemble concepts and procedures that will enable readers to work successfully in the HVAC/R industry.

ORGANIZATION

It is difficult to organize an electrical text to be used in refrigeration, heating, and air-conditioning programs in educational institutions because of the many different types of programs and the variety of the delivery of information. The information covered in this text is organized from the very basics to the circuitry and troubleshooting of control systems in the industry. The organization is industry driven because of the correlation of industry standards and the many new developments that continue to be made. Electrical devices are covered in detail in a systematic order with the troubleshooting of the components following an explanation of how they work. Installing and Troubleshooting control systems should be the objective of most students and industry personnel using this text and is covered in detail.

FEATURES OF THIS EDITION

The features of this text are designed to enhance the learning experience:

- A chapter on **Electrical Safety** provides students with an awareness of the dangers of working with electricity, while **Caution** notes integrated throughout the chapters explain how to prevent and avoid accidents on the job.
- **Examples** walk students through important math equations and calculations essential to understanding how refrigeration, heating, and air-conditioning systems work.
- **Green Technology** features information relative to practices that technicians can implement to protect the environment and ultimately the health and safety of the communities they serve.
- **Service Calls** reinforce procedures that are commonly used in the industry, while **Review Questions** and **Practice Service Calls** provide students with the opportunity to evaluate what they have learned and hone their troubleshooting skills.
- **Delmar Online Training Simulation: HVAC 4.0** references are integrated throughout the text as helpful tools for those classrooms utilizing this enhanced supplement to the text. For more details on this training simulation or to find out more about our MindTap offering, contact your sales representative or go to www.cengage.com/simulationstation.

- **Appendix A** and **Appendix B** provide reference charts to review various types of motors, as well as to study electrical symbols commonly used in schematics, including switches, thermostats, contactors, relays, and other electrical devices.

NEW IN THIS EDITION

New technology has brought about rapid changes in the thermostats and control systems used in the heating and air-conditioning industry. As a result, this has prompted the following changes for this edition:

- Due to the rapid change in the design, technology, and availability of electronic thermostats, the thermostat section has been heavily revised and expanded while removing some of the material on the older thermostats and focusing on the more advanced digital, communicating, and wi-fi thermostats.
- The section on DC motors and controls has been updated and expanded because of their use in unitary and mini-split heating and cooling systems.
- The section on mini-split air conditioning and heat pump systems has been updated and expanded.
- Many new and updated art, graphics, and diagram changes and additions have been made to reflect recent changes in technology.
- New illustrated examples of troubleshooting procedures for control devices and systems have been added to applicable chapters.

ALSO AVAILABLE

Companion Site

Additional instructor resources for this product are available online. Instructor assets include an Instructor's Manual, a Solution and Answer Guide, an Educator's Guide, PowerPoint® slides, and a test bank powered by Cognero®. Sign up or sign in at www.cengage.com to search for and access this product and its online resources.

Mindtap for Electricity for Refrigeration, Heathing and Air Conditioning, 10th Edition

NEW! The *MindTap for Electricity for Refrigeration, Heating and Air Conditioning*, 11th Edition, features an integrated course offering a complete digital experience for the student and teacher. This MindTap is highly customizable and combines assignments, videos, lab exercises, simulations, and quizzing along with the enhanced ebook to enable students to directly analyze and apply what they are learning and to allow teachers to measure skills and outcomes with ease.

- *A Guide:* Relevant interactivities combined with prescribed readings, featured multimedia, and quizzing to evaluate progress will guide students from basic knowledge and comprehension to analysis and application.
- *Personalized Teaching:* Teachers are able to control course content: hiding, rearranging existing content, or adding and creating their own content to meet the needs of their specific program.
- *Promote Better Outcomes:* Through relevant and engaging content, assignments and activities, students are able to build the confidence they need to ultimately lead them to success. Likewise, teachers are able to view analytics and reports that provide a snapshot of class progress, time in course, engagement, and completion rates.

Lab Manual

The *Complete HVAC Lab Manual* combines content from *Electricity for Refrigeration, Heating and Air Conditioning* and *Refrigeration and Air Conditioning Technology* to support the concepts learned in these texts—and beyond. Divided by HVAC subject areas and correlated to specific content in companion texts, it features over 250 lab exercises including step-by-step procedures, questions, and problem sets to help students to evaluate their knowledge of the technical content and to practice essential skills.

Delmar Online Training Simulation: HVAC (Dots: HVAC) 4.0

is an immersive simulation that offers a rich learning experience that mimics field performance. It challenges learners to master diagnostic and troubleshooting skills across seven pieces of HVAC equipment found in industry—**Gas Furnaces, Oil Furnaces, Gas Boilers, Commercial Air Conditioners, Split Residential Air Conditioners, Heat Pumps and Walk-In Commercial Freezers**. Soft skills are also included within the Simulation. To create successful learning outcomes, the Delmar Online Training Simulation: HVAC offers more than **170 scenarios**, which allow students to troubleshoot and build diagnostic and critical thinking skills.

Key Features:

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- An easy-to-use and intuitive Gradebook/Administrative Tool to track student performance and understanding
- User Feedback Reports provide immediate analysis to help identify and correct problems to aid student learning

Delmar Online Training Simulations HVAC 4.0
ISBN: 9780357635803

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Sealed Unit Parts Co.

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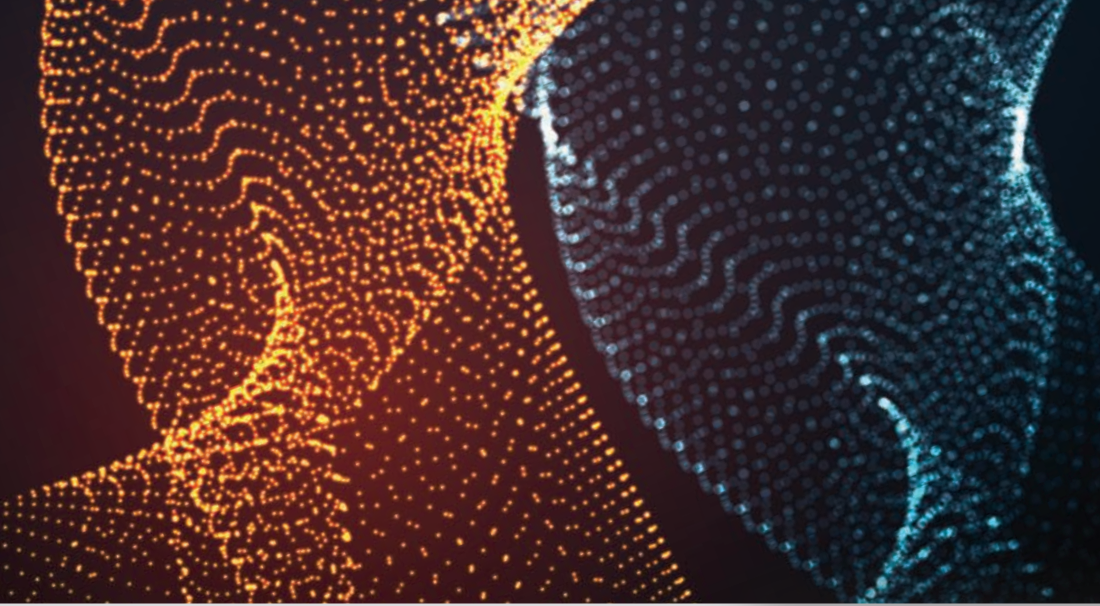
Coleman Simmons is an instructor and the program chair for the Air Conditioning Technology program at Athens Technical College in Athens, Georgia. Mr. Simmons has worked in the HVAC/R field for over 20 years and holds multiple NATE specialty certifications. He holds an AS in Air Conditioning Technology and a BS in Specialty (Mechanical, Electrical and Plumbing) Construction Management.



1

Electrical Safety

Key Terms

Arc flash
Arc arc fault circuit interrupter (AFCI)
Cardiopulmonary resuscitation (CPR)
Circuit breaker
Circuit lockout
Conductor
Double insulated
Electrical shock
Electromotive force (EMF)
Fuse
Ground
Ground fault circuit interrupter (GFCI)
Grounding adapter
Live electrical circuit
National Electrical Code® (*NEC*®)
Three-prong plug

Learning Objectives

After completing this chapter, you should be able to:

- Explain the effect of electric current on the human body.
- List the injuries that are possible from an electrical shock.
- Explain the basic procedures that should be followed in the event of an electrical shock.
- Explain the importance of properly grounding tools and appliances.
- Safely use electrical hand tools and electrical meters.
- Follow the principles of safety when installing and servicing heating and air-conditioning equipment.

INTRODUCTION

Electricity is very commonplace in our environment today; in fact, it's hard for us to envision life without electricity. No matter what part of our lives we examine, electricity plays an important role, from our home life to our places of employment. Our homes are filled with personal electric appliances like toothbrushes and hair dryers, small electric appliances like mixers and toasters, major appliances like washers and refrigerator/freezers, and large equipment that heat and cool our living spaces. Many people work in environments that use large electrical equipment that are powered by an extremely high-voltage source. No matter what a person does, the individual is very likely to come near electrical power sources that are dangerous.

The single most important element to remember when dealing with electrical circuits is to respect them. It is impossible for a service technician to adequately troubleshoot heating and air conditioning with the electrical power turned off, so it is imperative to use safe procedures when the power is on. Many troubleshooting procedures can be performed with the electric power to the equipment interrupted, such as checking the condition of electric motors, relays, contactors, transformers, and other electrical devices. However, there are other times when troubleshooting requires a connection to the power source: checking power available to the equipment, checking power available to a specific electrical device, or checking the voltage drop across a set of contacts in a relay, for example. The important thing for an Heating, Ventilation, Air Conditioning and Refrigeration technician to know is when it is necessary to have the power to the unit on or off.

CAUTION Always perform repairs with the power off.

One of the most important things that a service technician must learn is how to safely work around equipment when the power is being supplied to the equipment. Good service technicians cannot fear being shocked, but they must always pay attention to what they are doing and not get careless when they are working around live electrical circuits.

A **live electrical circuit** is one that is being supplied with electrical energy. It is possible for an installation technician to completely install a heating and air-conditioning system without the power being turned on until it is time to check the system for proper operation. No matter what part of the HVAC industry a person works in, it is imperative that the technician respects electricity and knows how to properly work around it without being injured.

1.1 ELECTRICAL INJURIES

Electrical shocks and burns are common hazards to personnel who are employed in the heating and air-conditioning industry. It is impossible to install or troubleshoot air-conditioning equipment without working close to electrical devices that are being supplied with electrical energy. It is the responsibility of the technician to develop a procedure for working around live electric circuits without coming in contact with conductors and electrical components that are being supplied with electrical power.

Electrical shock occurs when a person becomes part of an electrical circuit. When electricity passes through the human body, the results can range from death to a slight, uncomfortable stinging sensation, depending upon the amount of electricity that passes through the body, the path that the electricity takes, and the amount of time that the electricity flows. Technicians should never allow themselves to become the conductor between two wires or a hot and a ground in an electrical circuit.

The amount of electrical energy needed to cause serious injury is very small. The electrical energy supplied to an electrical circuit is called **electromotive force (emf)**, and it is measured in volts. In the heating and air-conditioning industry, the technician often is in close proximity to 24 volts, which is used for the control circuits of most residential systems; 120 volts, which is used to operate most fan motors in gas furnaces; 240 volts, which is used to operate compressors in residential condensing units; and much higher voltages, which are used to operate compressors in commercial and industrial cooling systems. The heating and air-conditioning technician is often around voltages that can cause serious injury or even death.

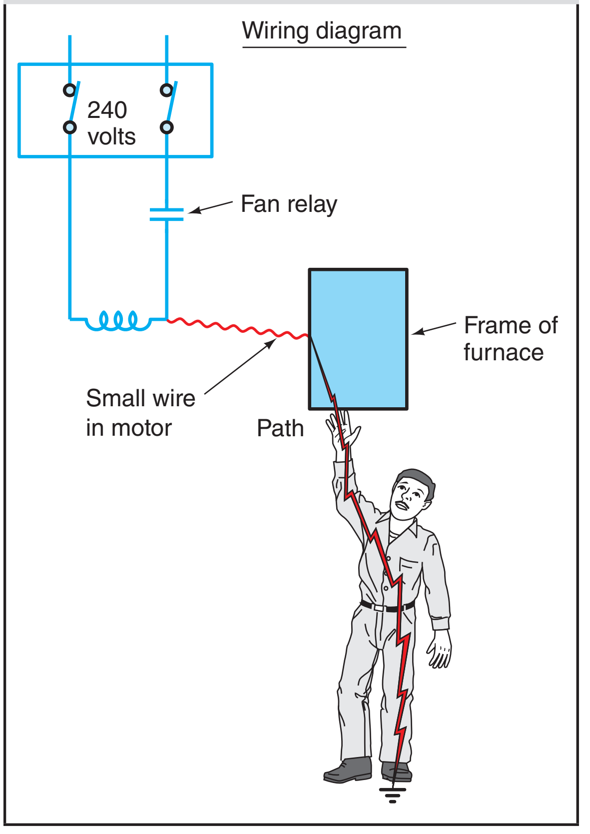
Your body can become part of an electrical circuit in many ways. First, your body can become part of an electrical circuit if you come in contact with both a conductor that is being supplied with power and the neutral conductor or ground at the same time, as shown in **Figure 1.1**. The ground in an electrical system is a conductor primarily used to protect against faults in the electrical system and does not normally carry current.

FIGURE 1.1

Technician becoming part of an electrical circuit by coming in contact with *L*1 and neutral

FIGURE 1.2

Technician coming in contact with a conductor (shorted fan motor) and ground



The neutral is a current-carrying conductor in normal operation and is connected to the ground. Another way that you can become part of an electrical circuit is to come in contact with both a conductor supplied with power and with the ground, as shown in **Figure 1.2**. A conductor is a wire or other device that is used as a path for electrical energy to flow. You may become part of the electrical circuit if you touch two conductors supplied with electrical energy, as shown in **Figure 1.3**.

The severity of injury from electric shock is directly related to the path that current flow takes in the body. The current flow is the amount of electrons flowing in a circuit and is measured in amperes. For example, if the thumb and index finger of the same hand come in contact with a conductor that is supplied with electrical energy and a neutral as shown in **Figure 1.4**, then the path would only be from the thumb to the index finger. If you touch a **conductor** being supplied with electrical energy with one hand and another conductor being supplied with electrical energy with the other hand, then the electrical path would be

FIGURE 1.3

Technician touching *L*1 and *L*2 in an electrical disconnect

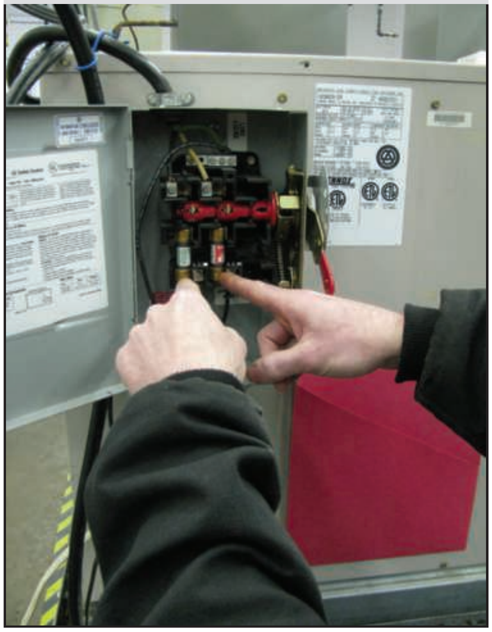
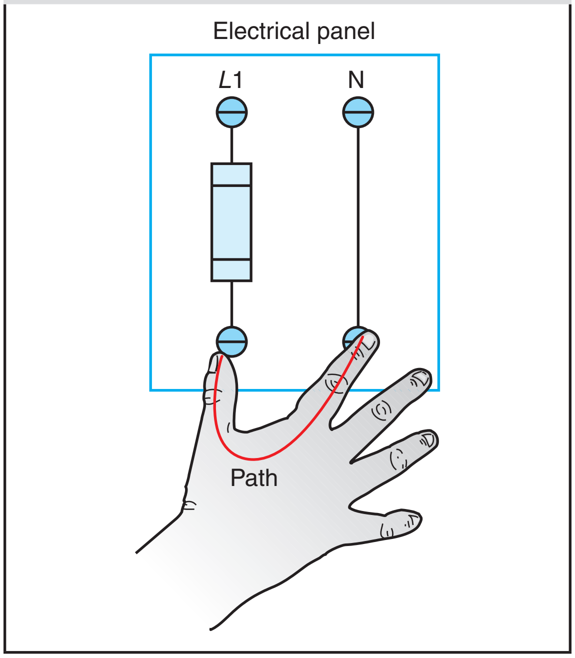


FIGURE 1.4

Electrical path from technician's thumb to index finger



from one hand up the arm and across the heart to the other arm and to the hand, as shown in **Figure 1.5**. If the path is through an arm and a leg, then it would also cross or come near to the heart. When the path of electrical flow crosses the heart, the risk of serious injury increases. Most fatal electrical accidents happen when the electrical flow passes near or through the heart. When the electrical path crosses near or through the heart for only a short period of time, it can cause ventricular fibrillation of the heart, in which the heart only flutters instead of beats and the blood flow to the body stops. Unless the heartbeat is returned to normal quickly with immediate medical attention, the person will usually die.

The other injury caused by electrical shock is burns to the body. This usually occurs when the technician is shocked with high voltage. Electrical burns can come from an electrical arc, such as the arc from a high-voltage transformer, the arcing of high voltage, and a short circuit to ground, where electrons are allowed to flow unrestricted. For example, if you are working in an electrical panel with a screwdriver and allow the blade of the screwdriver to touch a ground while in contact with a conductor that is being supplied with electrical energy, the potential difference is tremendous, and sparking will usually occur, as shown in **Figure 1.6**. If the resistance is very small, then the current flow in the circuit will be very large.

FIGURE 1.5

Electrical path across a technician's heart

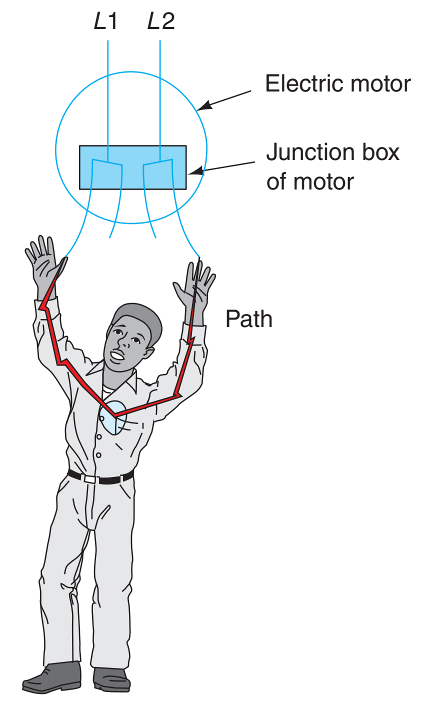
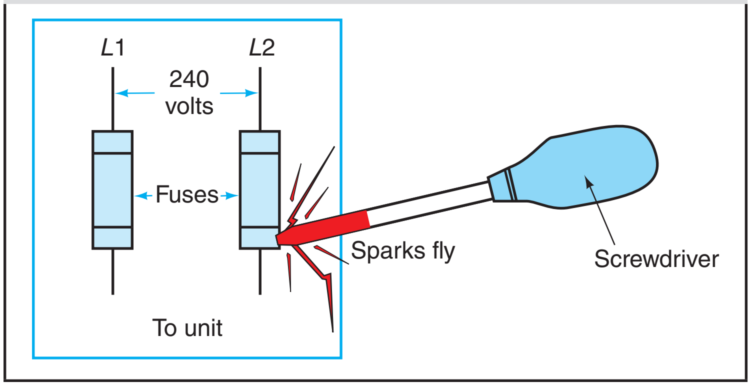


FIGURE 1.6

Screwdriver shorted between *L*2 and ground



A current flow through the body of 0.015 ampere or less can prove fatal. By comparison, the current draw of a 60-watt light bulb is only 0.50 ampere.

The following values can be associated with the feel of electrical shock: (1) 0.001 ampere (1 milliampere), a person can feel the sensation; (2) 0.020 ampere (20 milliamperes), a person might not be able to let go; (3) 0.100 ampere (20 milliamperes) can cause ventricular fibrillation; and (4) 0.200 ampere and above (>200 milliamperes) can cause severe burns and respiratory paralysis.

Another danger of electrical shock is a person's reaction when shocked. For example, if you are working on a ladder and get shocked, you could fall off the ladder. If you are using an electrically powered hand tool and a short occurs, then you might drop the tool, causing personal injury to yourself or others. Technicians should keep in mind that their reactions when getting shocked could endanger others, so they must be cautious and attentive when working near live electrical circuits.

Technicians should be aware of the danger of electrical shock when using ladders that conduct electricity, such as aluminum ladders. If at all possible, the technician should use nonconductive ladders on all jobs. The two primary types of nonconductive ladders used today are wood and fiberglass. Nonconductive ladders work as well as the aluminum ladders except that they lack the same ease of handling because of their added weight. Whenever you are using a ladder, you should make sure that you do not position the ladder under electrical conductors that you might accidentally come in contact with when climbing the ladder.

FIGURE **1.7**

Arc flash in disconnect between *T*1 and *T*3

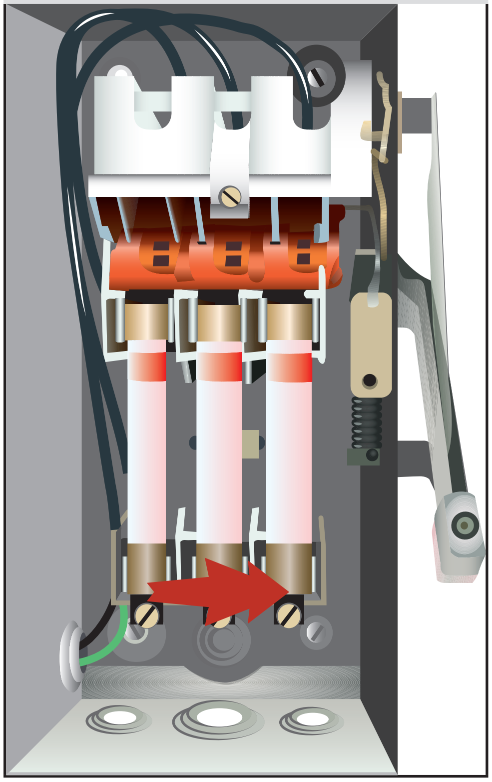


FIGURE **1.8**

Safety gloves

In an **arc flash**, an electric current leaves its intended path and travels through the air to an unintended path, for example, an arc from the line voltage source from line 1 in an enclosed switch to line 3 in the same switch or even to a ground outside the enclosure. See **Figure 1.7**. Arc flashes generally occur in higher-voltage applications (480 volts and above) but can occur at much lower voltages. The result of an arc flash is often violent in nature and can cause serious injury or even death to a technician. The refrigeration, heating, and air conditioning technician occasionally is called on to work with electrical systems and equipment using higher voltage. The technician should wear personal protective equipment in the form of gloves and safety glasses. A pair of recommended safety gloves to be used around high voltages is shown in **Figure 1.8**.

Arc flashes can cause serious injury due to the violent nature of the arc flash explosion. The injuries can range from life-threatening to minor. The typical results of an arc flash are burns to the technician, often molten metal pieces thrown from the conductor, hearing damage due to the sound blast, and high heat. The proximity of the technician to the flash will determine the severity of injury. The most effective and foolproof way to prevent injury from an arc flash is to eliminate the risk by disconnecting the power source going to the equipment. Of course, this is not always possible, so in rare cases, technicians are required to work around live equipment, at which time they should check with a supervisor, use personal protective equipment, and work with insulated tools.

Arc flashes can be caused by the simplest and overlooked reasons, such as dust and other impurities on the conductors, dropping tools, condensation within the enclosure, and corrosion. More common causes are the technician's accidentally touching a conductor, material failure such as a broken or missing insulation on a conductor, and faulty installations.

1.2 DEALING WITH SHOCK VICTIMS

The first concern when assisting an electrical shock victim, who is still in contact with an electrical source, is personal safety. If an electrical accident occurs, personnel trying to assist a shock victim should not touch a person who has been in contact with an electrical source. The rescuing party should think fast, proceed with caution, and request medical assistance.

Often when people receive an electrical shock, they cannot let go of the conductor that is the source of the electrical energy. The person who is trying to help should never come in direct contact with the victim. If you try to remove a shock victim from an electrical source that is holding the victim, you become part of the circuit, and there will be two victims instead of one. Rescuers should think before they act. If the switch to disconnect the power source is close by, then turn the switch off. If the switch to disconnect the electrical power source is not close by or cannot be located, then use some nonconductive material to push the victim away from the electrical source. The material used to remove the victim from the electrical source should be dry to reduce the hazard of shock to the person attempting the rescue. If wires are lying close to the victim and the rescuer is unsure if the individual is still connected to a power source, then the wires should be moved with a nonconductive material. When moving conductors or a victim who is still connected to a power source, you should never get too close to the conductors or the person.

As soon as the shock victim is safely away from the electrical source, the rescuer should start first aid procedures. The rescuer should see if the victim is breathing and has a heartbeat. If these vital signs are absent, then **cardiopulmonary resuscitation (CPR)** should be started as soon as possible, or permanent damage may occur. At least one person on each service or installation truck should be trained to perform CPR in case of an accident requiring it. You should be trained before administering CPR.

1.3 NATIONAL ELECTRICAL CODE®

The ***National Electrical Code®*** and ***NEC®*** are registered trademarks of the National Fire Protection Association, Inc., Quincy, MA 02269. The *NEC®* specifies the minimum standards that must be met for the safe installation of electrical systems. The *NEC®* is revised every four years.

Technicians should make sure when using the *NEC*® that the latest edition is being used. The information in the *NEC*® and local codes must be followed and adhered to when making any type of electrical connection in a structure. The *NEC*® is made up of nine chapters, with each of the first eight chapters divided into articles. Chapter 9 contains miscellaneous tables used in the design of electrical systems. The following is a list of the main topics of the eight chapters:

Chapter 1	General
Chapter 2	Wiring and Protection
Chapter 3	Wiring Methods and Materials
Chapter 4	Equipment for General Use
Chapter 5	Special Occupancies
Chapter 6	Special Equipment
Chapter 7	Special Conditions
Chapter 8	Communications Systems
Chapter 9	Tables

Chapters 1 through 4 are directly related to the electrical standards of the refrigeration, heating, and air-conditioning industry. Articles in Chapter 4 that apply directly to the industry include:

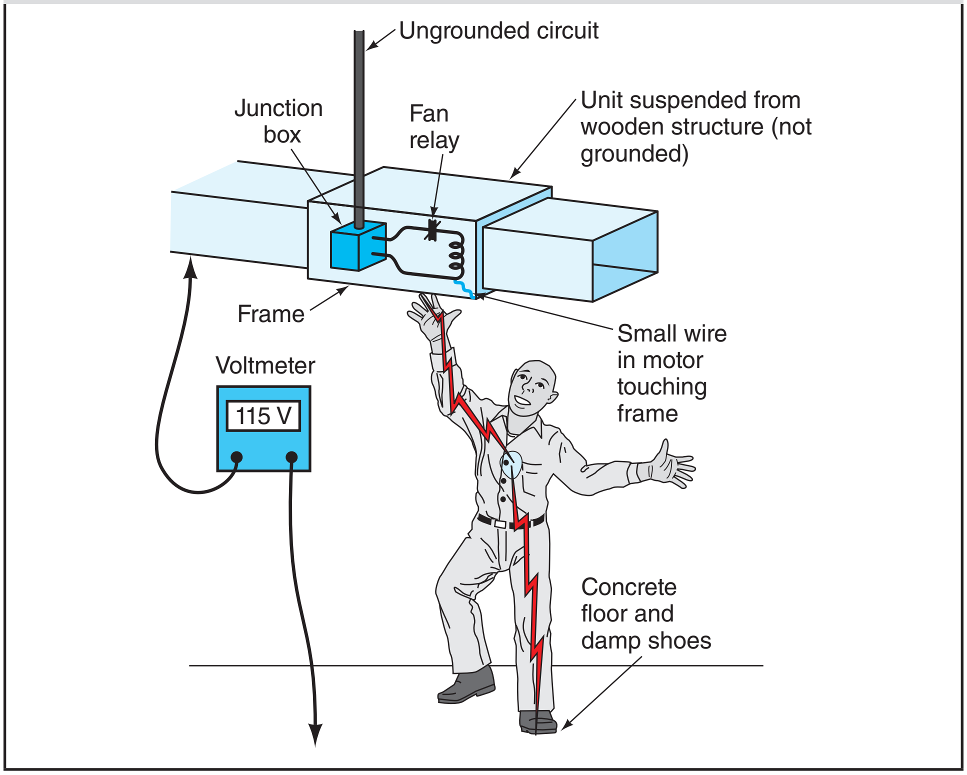
Article 400	Portable Cords and Cables
Article 422	Appliances
Article 424	Fixed Electric Space-Heating Equipment
Article 430	Motors, Motor Controls, and Controllers
Article 440	Air-Conditioning and Refrigeration Equipment

1.4 ELECTRICAL GROUNDING

The **ground** wire is used in an electrical circuit to allow current to flow back through the ground instead of through a person and causing electrical shock. For example, if a live electrical conductor touched the frame or case of an air-conditioning unit and was not grounded, then whoever touched that air-conditioning unit would become part of the electrical circuit if the individual provided a ground. In other words, that person would receive an electrical shock, which could cause bodily harm or even death. This condition is shown in **Figure 1.9**. The ground wire forces the path of electrical current flow to pass through the electrical device that is used to protect the circuit, such as a fuse or circuit breaker. The ground wire is identified by the color green in almost all cases.

FIGURE 1.9

Technician receives electrical shock from grounded fan motor



If an electrically powered tool requires a ground, it is equipped with a **three-prong plug**, as shown in **Figure 1.10**. On this type of plug, the semicircular prong is the grounding section of the plug and should never be cut off or removed. The same goes for extension cords; the grounding prong should never be removed for convenience. It is important when using a power tool that requires a ground that the technician makes certain the receptacle is grounded. Electrical tools or cords with a ground prong that is altered should be taken out of service until replaced or repaired. A **grounding adapter** shown in **Figure 1.11** is a device that permits the connection of a three-prong plug to a two-prong receptacle. A grounding adapter should not be used on a power tool with a three-prong plug unless there is a sure ground that the grounding wire can be attached to. The technician should use caution when using grounding adapters because in many older structures grounding is not provided at the receptacle box. Most late-model power tools are **double insulated** and do not require a ground. This type of tool will have a plug with only two prongs, as shown in **Figure 1.12**.

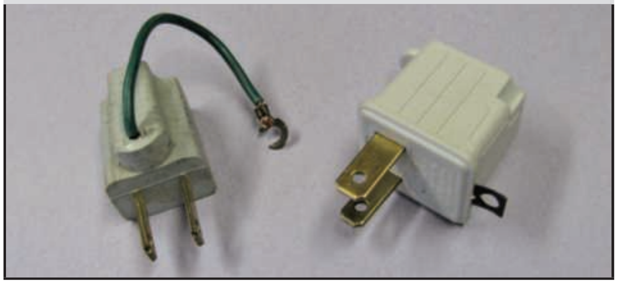
A **ground fault circuit interrupter (GFCI)** is an electrical device that will open the circuit, preventing current flow to the receptacle when

FIGURE 1.10

Electrical drill with three-prong grounded plug

FIGURE 1.11

Three-to-two prong grounding adapter



a small electrical leak to ground is detected. **Figure 1.13** shows a GFCI receptacle with an extension cord plugged into it. This type of receptacle is recommended for use with portable electric power tools. GFCIs are also available in the form of circuit breakers, as shown in **Figure 1.14(a)**. Portable GFCI interrupters are available for use where permanent units are not available, such as on job sites. They are designed to help protect the operator from being shocked. Use ground fault circuit interrupters when required by the *NEC*®. There are also circuit breakers available that will interrupt a circuit when an electrical arc is detected, known as **arc fault circuit interrupters (AFCI)**. **Figure 1.14(b)** shows an AFCI breaker that is capable of detecting dangerous electrical arcs that are often caused by loose connections or by damaged or frayed wiring. Electrical arcs may ignite combustible materials and cause structure fires. Dual purpose breakers are also available that act as both a GFCI and an AFCI. GFCI, AFCI, and dual purpose AFCI/GFCI breakers are very similar in their appearance.

FIGURE 1.12

Double-insulated drill with two-prong plug

FIGURE 1.13

Ground fault circuit interrupter receptacle

(Calkins/Shutterstock)

FIGURE 1.14

(a) Ground fault circuit interrupter breaker
(b) Arc fault circuit interrupter breaker

1.5 CIRCUIT PROTECTION

Electrical circuits in structures are designed to operate at or below a specific current (ampere) rating. Each electrical circuit should be protected, according to the *NEC*®. The wire or conductor of each circuit should be protected to prevent a higher current than it is designed to carry. The electrical components in the circuit are also a consideration when protection is a concern. The standard wire used for receptacles in most residences is #12 TW. The maximum current protection for this type of wire according to the *NEC*® is 20 amperes. However, if there is an electrical component in the circuit that requires protection at 10 amperes, the circuit protection should be at 10 amperes. If the current in the circuit becomes greater than the rating of the protective device, the device opens, disrupting the power source from the circuit.

The most common methods of circuit protection in structures are **fuses**, as shown in **Figure 1.15**, and **circuit breakers**, as shown in **Figure 1.16**. These devices protect the circuit by interrupting the flow of electrical energy to the circuit if the current in the circuit exceeds the rating of the fuse or circuit breaker. There are many types of fuses available today with special designs for particular purposes, but the primary purpose of any fuse is protection. Fuses are made with a short strip of metal alloy called an element that has a low melting point, depending on the rating of the fuse. If a larger current flow passes through the fuse than is designed to pass through the element, the

FIGURE 1.15

Fuses

FIGURE 1.16

Circuit breakers

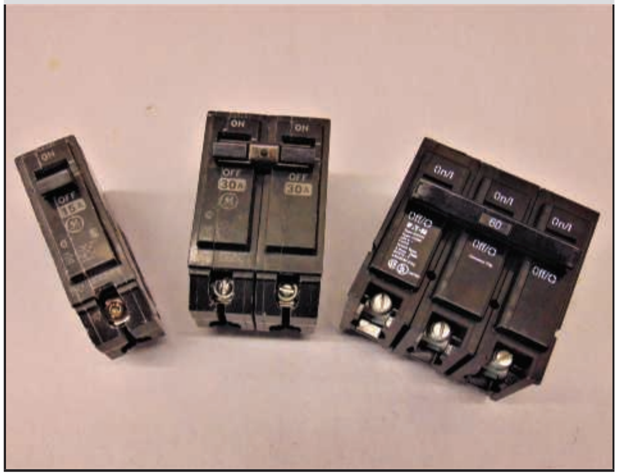
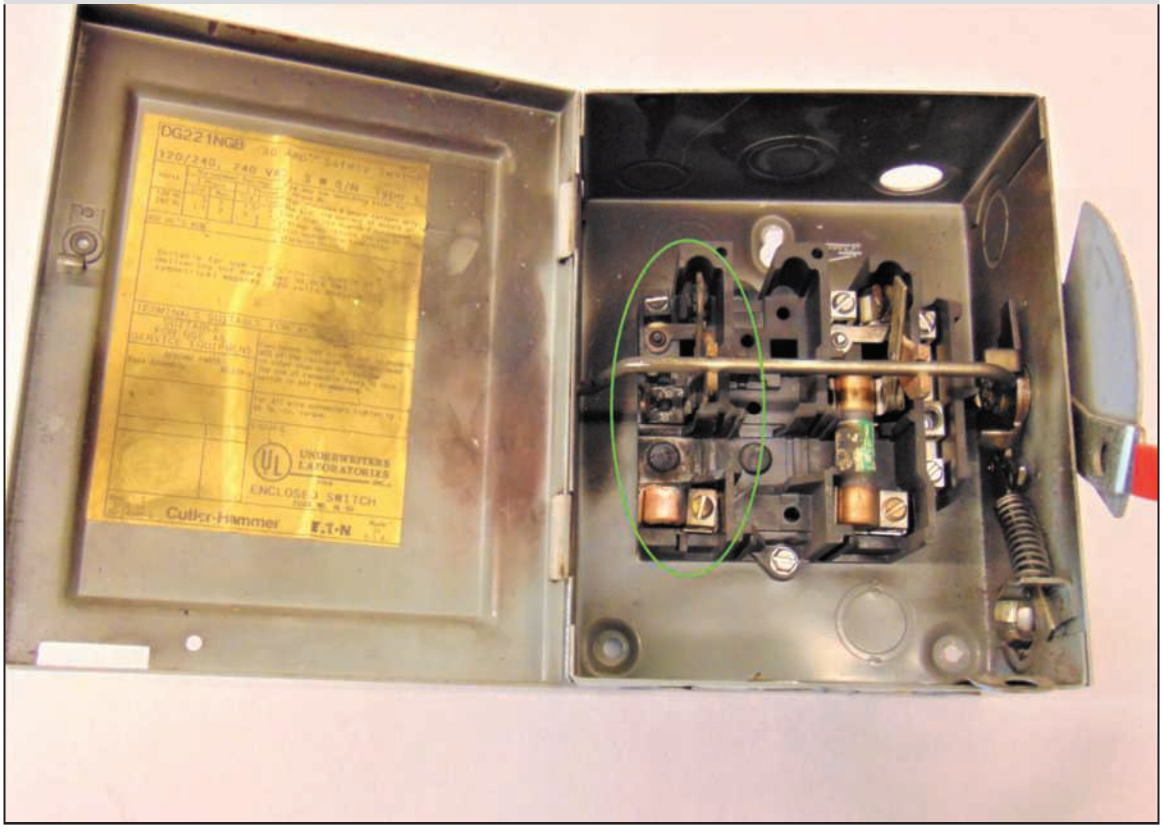


FIGURE 1.17

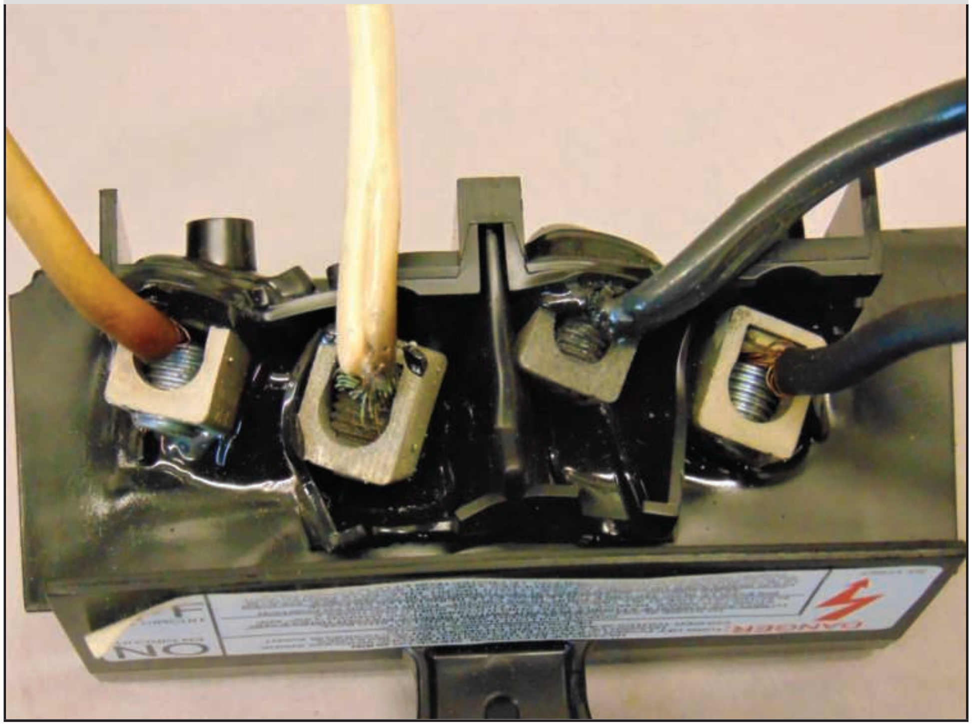
Result of overcurrent on disconnect switch with incorrectly sized fuses



element will melt and open the circuit. Circuit breakers look a lot like ordinary light switches placed in an electrical panel. If the current in the circuit that a circuit breaker is protecting exceeds the breaker's rating, then the switch of the circuit breaker will trip and interrupt the electrical energy going to the circuit. Fuses and circuit breakers should be sized for the particular application according to the *NEC*®. **Figure 1.17** shows a disconnect switch with the results of incorrectly sized fuses. **Figure 1.18** shows an example of damage caused to wires which can result from loose connections or undersized conductors. Technicians should never arbitrarily adjust the size of the fuse or circuit breaker without following the standards in the *NEC*® and local codes. Use only electrical conductors that are the proper size for the load of the circuit according to the *NEC*® to avoid overheating and possible fire.

FIGURE 1.18

Melted disconnect as the result of loose connections and under-sized wires



1.6 CIRCUIT LOCKOUT PROCEDURES

Circuit lockout is a procedure that is used to interrupt the power supply to an electrical circuit or equipment. When a technician is performing work on a circuit where there is a possibility that someone might accidentally restore electrical power to that circuit, the technician should place a padlock and/or a warning label on the applicable switch or circuit breaker. When you are working in a residence, the chance of the homeowner closing switches that might affect your safety is remote but still possible, so use some type of warning tag or verbally inform the homeowner. When working in a structure where there are many people who could open and close switches, you should make absolutely certain that the electrical energy is disconnected from the circuit. Once the circuit is opened, mark the circuit so others will not turn the circuit on while the repair is under way. In a commercial and industrial setting, this can be accomplished by using safety warning tags, padlocks, or locking devices made for that purpose. **Figure 1.19** shows a picture of a lockout tag-out kit used to safely disable an electrical device. **Figure 1.20** shows a disconnect switch with a lockout tag-out device installed. **Figure 1.21** shows a circuit breaker with a lockout tag-out device installed.

FIGURE **1.19**

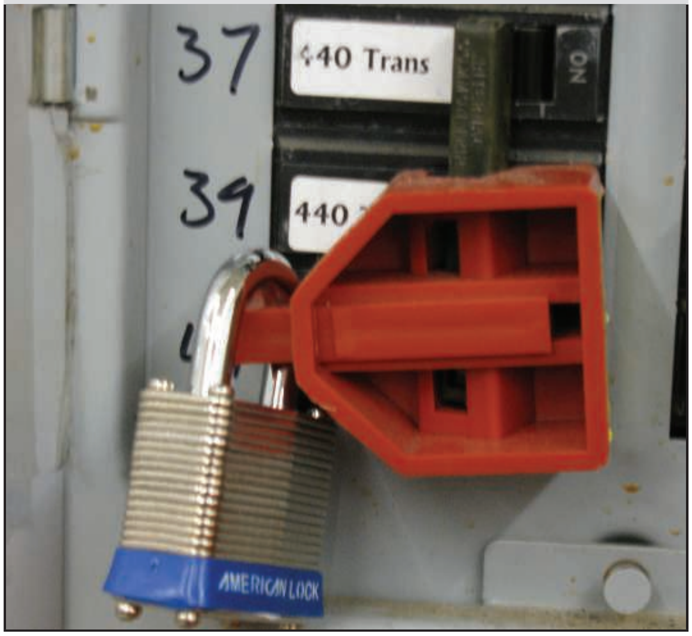
Lockout tag-out kit

FIGURE **1.20**

Lockout tag-out device installed on disconnect switch

FIGURE **1.21**

Lockout tag-out device installed on a circuit breaker



1.7 ELECTRICAL SAFETY GUIDELINES

1. Follow the *NEC*® as a standard when making electrical connections and calculating wire sizes and circuit protection.
2. Make sure the electrical power supply is shut off at the distribution or entrance panel and locked out or marked in an approved manner.
3. Always make sure the electrical power supply is off in the unit that is being serviced unless electrical energy is required for the service procedure.
4. Always keep your body out of contact with damp or wet surfaces when working on live electrical circuits. If you must work in damp or wet areas, make certain that some method is used to isolate your body from these areas.
5. Be cautious when working around live electrical circuits. Do not allow yourself to become part of the electrical circuit.
6. Use only properly grounded power tools connected to properly grounded circuits.
7. Do not wear rings, watches, or other jewelry when working in close proximity to live electric circuits.
8. Wear shoes with an insulating sole and heel.
9. Do not use metal ladders when working near live electrical circuits.
10. Examine all extension cords and power tools for damage before using.
11. Replace or close all covers on receptacles that house electrical wiring and controls.
12. Make sure that the meter and the test leads being used are in good condition.
13. Discharge all capacitors with a 20,000-ohm, 4-watt resistor before touching the terminals.
14. When attempting to help someone who is being electrocuted, do not become part of the circuit. Always turn the electrical power off or use a nonconductive material to push the person away from the source.
15. Keep tools in good condition, and frequently check the insulated handles on tools that are used near electrical circuits.

SUMMARY

Electricity cannot be seen but it certainly can be felt. It takes only a small amount of electricity to cause injury or even death. It is imperative that heating and air-conditioning technicians respect and be cautious around electrical circuits. It only takes a slip or careless move to find oneself in danger of electrocution or injury. The technician must be careful and cautious around live electrical circuits.

It would be ideal if you never had to work in close proximity with live electrical circuits, but that is not possible, especially when you are called on to troubleshoot heating and air-conditioning systems and equipment. You will be responsible for your own safety, and you should learn to respect and work carefully around live electrical circuits.

REVIEW QUESTIONS

1 True or False: A heating and air-conditioning service technician can usually troubleshoot heating and air-conditioning systems without the voltage being supplied to the equipment.

2 What is a live electrical circuit?

3 Which of the following voltages will a refrigeration, heating, and air-conditioning technician come in contact with in the industry?
a. 24 volts
b. 120 volts
c. 240 volts
d. all of the choices are correct

4 Electrical shock occurs when a person ________.
a. touches an insulated wire
b. touches an electric motor
c. becomes part of an electric circuit
d. touches a conductor that has power applied to it, but is making contact with a ground

5 What are the important elements of electrical safety when working around live circuits?

6 Which of the following conditions is the most dangerous and likely to cause serious injury?
a. The technician touches a ground with his thumb and a live wire with his index finger.
b. The technician touches a live wire with his hand but is standing on an insulated platform.
c. The technician touches a live wire with his right hand and accidentally touches his right elbow on the metal part of the same unit.
d. The technician touches a live conductor with his right hand and touches a ground with his left hand.

7 Which of the following is the standard by which electrical installations are measured in the United States?
a. *National Electrical Code®*
b. *United Electrical Code®*
c. *Basic Electrical Code®*
d. none of the choices are correct

8 True or False: A current flow of 0.1 ampere or less could be fatal.

9 What type of ladder would be the best choice for the technician to use on the job?
a. aluminum
b. fiberglass
c. wood
d. steel

10 What precautions should be taken when you see a coworker receiving an electrical shock?

11 True or False: It is recommended that at least one person on a truck know CPR.

12 True or False: The correct fuse size for an electrical circuit is one that is sized twice as large as needed for circuit protection.

13 What is the difference between a two-prong plug and a three-prong plug?

14 Which prong on a three-prong plug is the ground?
a. the left flat prong
b. the right flat prong
c. the center semicircular prong
d. none of the choices are correct

15 True or False: A grounding adapter does no good if it is not connected to an electrical ground.

CHAPTER 1 REVIEW

16 An electrical device that will open an electrical circuit, preventing current flow to the circuit if a small leak to ground is detected, is called a _________.
a. GFCI
b. common circuit breaker
c. fuse
d. receptacle

17 True or False: Receptacles used on the job site should be protected with a GFCI.

18 What precautions should you use when working in an area with a large number of people and you must disconnect the power from an appliance you are working on?

19 What is the difference between a fuse and a circuit breaker?

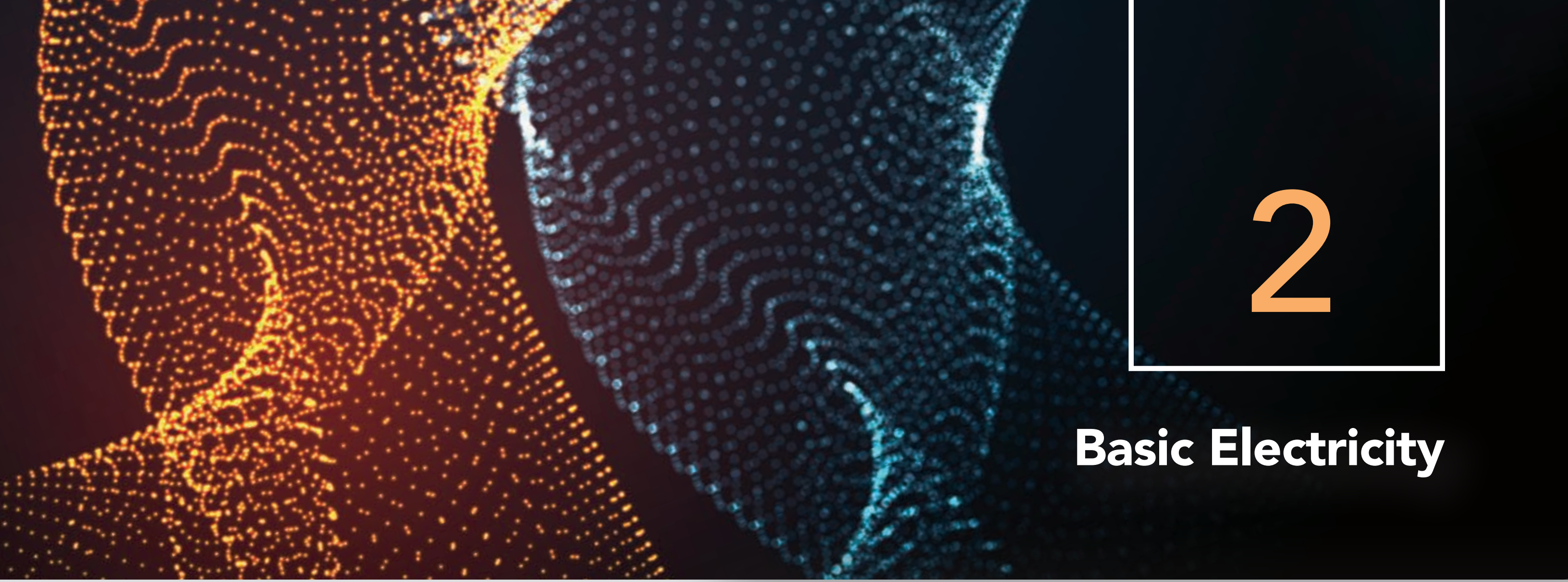
20 List at least five electrical safety rules that should be followed by refrigeration, heating, and air-conditioning technicians.

21 Which of the following Injuries could be caused by an electrical shock?
a. burns
b. ventricular fibrillation of the heart
c. Injury to body parts caused by reaction of an electrical shock
d. all the choices are correct

22 What is the danger when the path of an electron flow is passed near or through the heart?

LAB MANUAL REFERENCE

For experiments and activities dealing with material covered in this chapter, refer to the *Complete HVAC Lab Manual.*



2 Basic Electricity

Key Terms

Alternating current (AC)
Ampere
Atom
Compound
Conductor
Current
Direct current (DC)
Electric energy
Electric power
Electric pressure
Electricity
Electrode
Electrolyte
Electron
Element
Field of force
Free electron
Insulator
Kilowatt-hour
Law of electric charges
Matter
Molecule
Neutron
Nucleus
Ohm
Ohm's law
Power factor
Proton
Resistance
Seasonal energy efficiency ratio (SEER)
Static electricity
Volt
Voltage/potential difference/ electromotive force
Watt

Learning Objectives

After completing this chapter, you should be able to:

- Briefly explain the atomic theory and its relationship to physical objects and electron flow.
- Explain the flow of electrons and how it is accomplished.
- Explain electrical potential, current flow, and resistance and how they are measured.
- Explain electrical power and how it is measured.
- Explain Ohm's law.
- Calculate the potential, current, and resistance of an electrical circuit using Ohm's law.
- Calculate the electrical power of a circuit and the Btu/hour rating of an electrical resistance heater.

INTRODUCTION

Most control systems used in the heating, cooling, and refrigeration industry use electrical energy to maintain the desired temperature. Electrical components in systems that require rotation, such as compressors and fan motors, use electric motors to accomplish this rotation. Many other devices, such as electric heaters, solenoid valves, and signal lights, that are incorporated into equipment also require electrical energy for operation. The use of electricity can be seen in all aspects of the industry.

Along with all the electric devices used in systems today come problems that are, in most cases, electrical and they must be corrected by field service technicians. Thus, it is essential for all industry technicians to understand the basic principles of electricity, so they can perform their jobs in the industry.

We begin our study of electricity with a discussion of atomic structure.

2.1 ATOMIC THEORY

Matter is the substance of which a physical object is composed, whether it be a piece of iron, wood, or cloth, or whether it is a gas, liquid, or solid. Matter is composed of fundamental substances called **elements**. There are 110 natural elements that have been found in the universe. Elements, in turn, are composed of atoms. An **atom** is the smallest particle of an element that can exist alone or in combination. All matter is made up of atoms or a combination of atoms, and all atoms are electrical in structure.

Suppose a piece of chalk is broken in half and one piece discarded. Then the remaining piece is broken in half and one piece discarded. If this procedure is continued, eventually the piece of chalk will be broken into such a small piece that by breaking it once more there will no longer be a piece of chalk but only a molecule of chalk. A **molecule** is the smallest particle of a substance that has the properties of that substance. If a molecule of chalk is broken down into smaller segments, only individual atoms will exist, and they will no longer have the properties of chalk. The atom is the basic building block of all matter. The atom is the smallest particle that can combine with other atoms to form molecules.

Although the atom is a very small particle, it is also composed of several parts. The central part is called the **nucleus**. Other parts, called electrons, orbit around the nucleus. Each **electron** is a relatively small, negatively charged particle. The electrons orbit the nucleus in much the same way that the planets orbit the sun.

The nucleus, the center section of an atom, is composed of protons and neutrons. The **proton** is a heavy, positively charged particle. The proton has an electric charge that is opposite but equal to that of the electron. All atoms contain an equal number of protons and electrons. The **neutron** is a neutral particle, which means that it is neither positively nor negatively charged. The neutrons tend to hold the protons together in the nucleus.

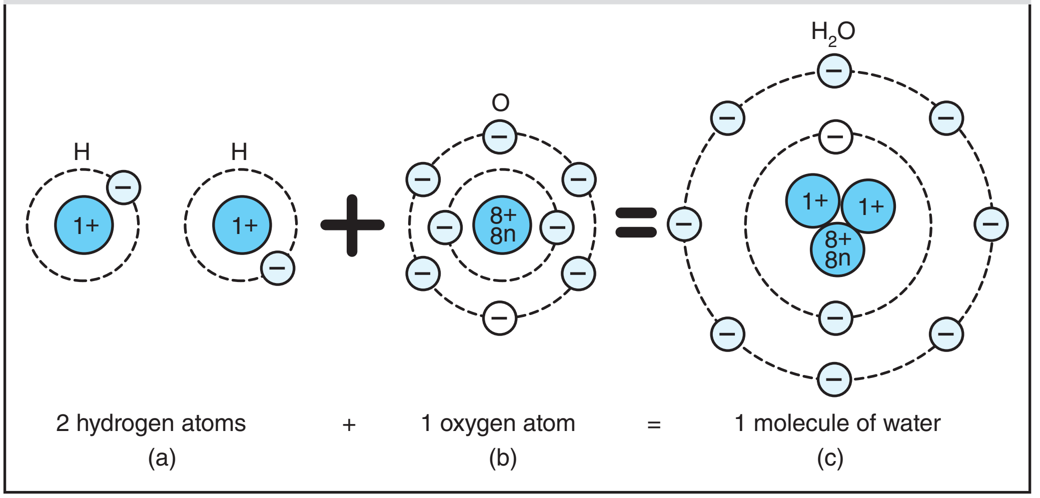
The simplest atom that exists is the hydrogen atom, which consists of one proton that is orbited by one electron, as shown in **Figure 2.1(a)**. Not all atoms are as simple as the hydrogen atom. Other atoms have more particles. The difference in each different atom is the number of electrons, neutrons, and protons that the atom contains. The hydrogen atom has one proton and one electron. The oxygen atom has eight protons, eight neutrons, and eight electrons, as shown in **Figure 2.1(b)**. The silver atom contains 47 protons, 61 neutrons, and 47 electrons. The more particles an atom has, the heavier the atom is. Because there are 110 elements, but millions of different types of substances, there must be some way of combining atoms and elements to form these substances.

When elements (and atoms) are combined, they form a chemical union that results in a new substance, called a **compound**. For example, when two hydrogen atoms combine with one oxygen atom, the compound *water* is formed. The atomic structure of one molecule of water is shown in **Figure 2.1(c)**.

The chemical symbol for a compound denotes the atoms that make up that compound. Refrigerant 22 (R-22) is a substance commonly used in refrigeration systems. A refrigerant is a fluid that absorbs heat inside

FIGURE 2.1

Atomic structure of a water molecule (one atom of oxygen and two atoms of hydrogen)



the conditioned area and releases heat outside the conditioned area. The chemical symbol for one molecule of R-22 is $CHClF_2$. One molecule of the refrigerant contains one atom of carbon, one atom of hydrogen, two atoms of fluorine, and one atom of chlorine. The chemical name for R-22 is monochlorodifluoromethane. All materials can be identified according to their chemical makeup, that is, the atoms that form their molecules.

2.2 POSITIVE AND NEGATIVE CHARGES

An atom usually has an equal number of protons and electrons. When this condition exists, the atom is electrically neutral because the positively charged protons exactly balance the negatively charged electrons. However, under certain conditions, an atom can become unbalanced by losing or gaining an electron. When an atom loses or gains an electron, it is no longer neutral. It is either negatively or positively charged, depending on whether the electron is gained or lost. Thus, in an atom, a charge exists when the number of protons and electrons is unequal.

Under certain conditions, some atoms can lose a few electrons for short periods. Electrons in the outer orbits of some materials, especially metals, can be easily knocked out of their orbits. Such electrons are referred to as **free electrons**, and materials with free electrons are called **conductors**. When electrons are removed from the atom, the atom becomes positively charged because the negatively charged electrons have been removed, creating an unbalanced condition in the atom.

An atom can just as easily acquire additional electrons. When this occurs, the atom becomes negatively charged.

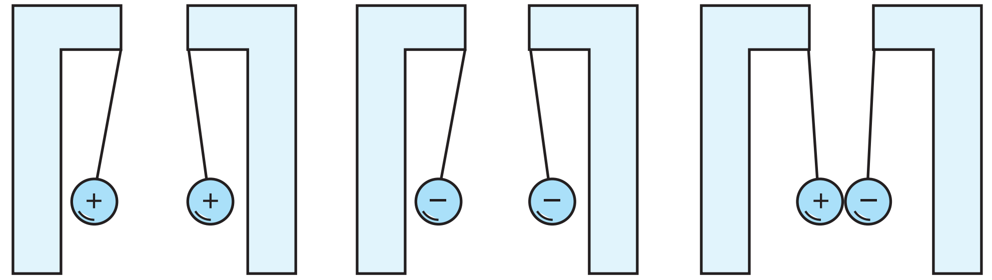
Charges are, thus, created when there is an excess of electrons or protons in an atom. When one atom is charged and an unlike charge is in another atom, electrons can flow between the two. This electron flow is called **electricity**.

An atom that has lost or gained an electron is considered unstable. A surplus of electrons in an atom creates a negative charge. A shortage of electrons creates a positive charge. Electric charges react to each other in different ways. Two negatively charged particles repel each other. Positively charged particles also repel each other. Two opposite charges attract each other. The **Law of electric charges** states that like charges repel and unlike charges attract. **Figure 2.2** shows an illustration of the law of electric charges.

All atoms tend to remain neutral because the outer orbits of electrons repel other electrons. However, many materials can be made to acquire a positive or negative charge by some mechanical means, such as friction. The familiar crackling when a hard rubber comb is run through hair on a dry winter day is an example of an electric charge generated by friction.

FIGURE 2.2

Like charges repel and unlike charges attract each other



(a) Repulsion of two positive charges (b) Repulsion of two negative charges (c) Attraction of positive and negative charges

2.3 FLOW OF ELECTRONS

The flow of electrons can be accomplished by several different means: friction, which produces static electricity; chemicals, which produces electricity in a battery; and magnetism (induction), which produces electricity in a generator. Other methods are also used, but the three mentioned here are the most common.

Static Electricity

The oldest method of moving electrons is by **static electricity**. Static electricity produces a flow of electrons by permanently displacing an electron from an atom. The main characteristic of static electricity is that a prolonged or steady flow of current is not possible. As soon as the charges between the two substances are equalized (balanced), electron flow stops.

Friction is usually the cause of static electricity. Sliding on a plastic seat cover in cold weather and rubbing silk cloth on a glass rod are two examples of static electricity produced by friction. Static electricity, no matter what the cause, is merely the permanent displacement or transfer of electrons. To obtain useful work from electricity, a constant and steady flow of electrons must be produced.

Electricity Through Chemical Means

Electricity can also be produced by the movement of electrons due to chemical means. A battery produces an electron flow by a chemical reaction that causes a transfer of electrons between two **electrodes**. An electrode is a solid conductor through which an electric current can pass. One electrode collects electrons and one gives away electrons. The dry cell battery uses two electrodes made of two dissimilar metals inserted in a pastelike **electrolyte**. Electricity is produced when a chemical reaction occurs in the electrolyte between the electrodes, causing an electron flow. The construction of a dry cell battery is shown in **Figure 2.3**. A dry cell battery is shown in **Figure 2.4**.

The container of a dry cell battery, which is made of zinc, is the negative electrode (gives away electrons). The carbon rod in the center of the dry cell is the positive electrode (collects electrons). The space between the electrodes is filled with an electrolyte, usually manganese dioxide paste. The acid paste causes a chemical reaction between the carbon electrode and the zinc case. This reaction displaces the electrons, causing an electron flow. The top of the dry cell is sealed to prevent the electrolyte from drying and to allow the cell to be used in any position. The dry cell battery will eventually lose all its power because energy is being used and not being replaced.

The storage battery is different from a dry cell battery because it can be recharged. Thus, it lasts somewhat longer than a dry cell battery. But it, too, will eventually lose all its energy.

The storage battery consists of a liquid electrolyte and negative and positive electrodes. The electrolyte is diluted sulfuric acid. The positive electrode is coated with lead dioxide and the negative electrode is sponge lead. The chemical reaction between the two electrodes and the electrolyte displaces electrons and creates voltage between the plates. The storage battery is recharged by reversing the current flow into the battery. The storage battery shown in **Figure 2.5** is commonly used in automobile electric systems.

FIGURE 2.3

Construction of a dry cell battery

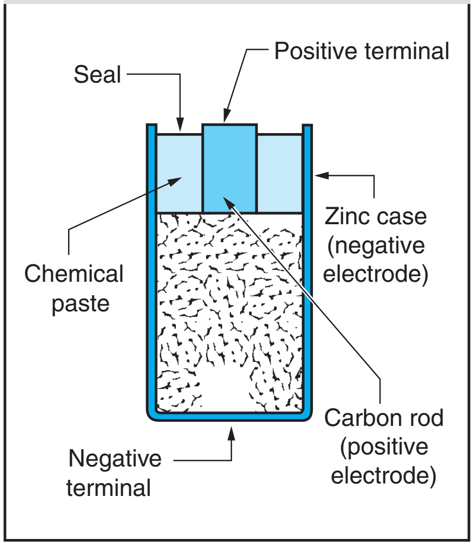
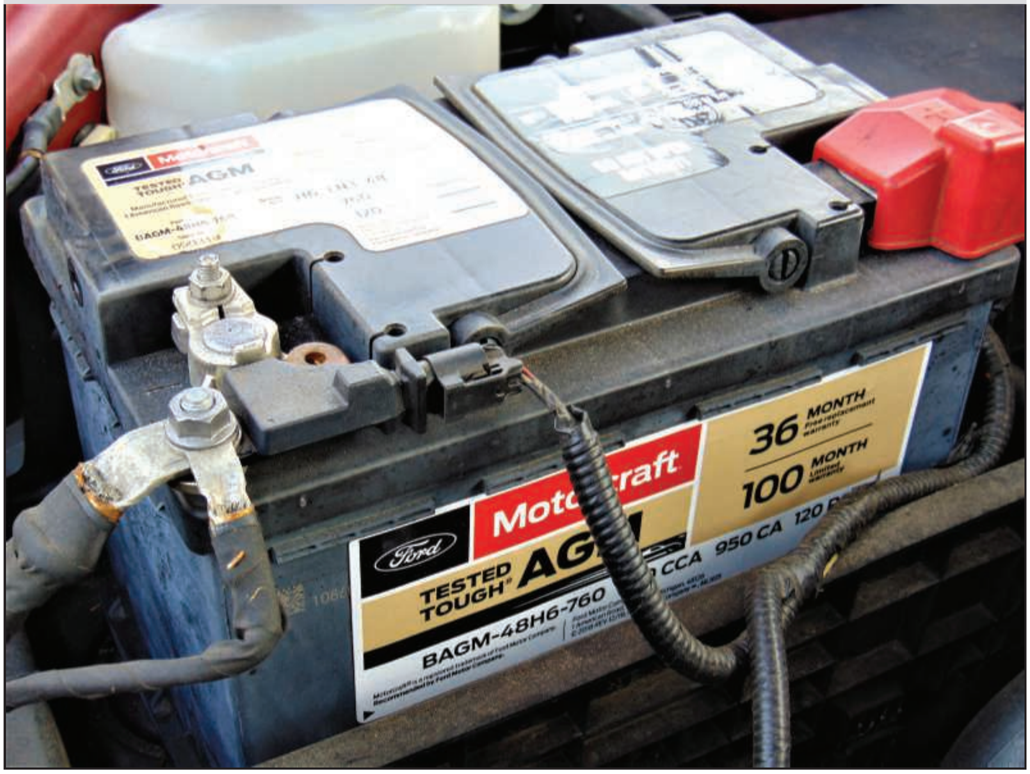


FIGURE 2.4

Dry cell battery

FIGURE 2.5

Common storage battery used in automobile electrical system



Electricity Through Magnetism

The magnetic or induction method of producing electron flow uses a conductor to cut through a magnetic field, which causes a displacement of electrons. The alternator, generator, and transformer are the best examples of the magnetic method. **Figure 2.6** shows a gasoline powered alternating current generator. The magnetic method is used to supply electricity to consumers.

The flow of electrons in a circuit produces magnetism, which is used to cause movement, or thermal energy, which in turn is used to cause heat. A magnetic field is created around a conductor—an apparatus for electrons to flow through—when there is a flow of electrons in the conductor. The flow of electrons through a conductor with a resistance will cause heat, such as in an electric heater.

The heating, cooling, and refrigeration industry uses magnetism to close relays and valves and to operate motors by using coils of wire to increase the strength of the magnetic field.

FIGURE 2.6

Gasoline powered alternating current generator

2.4 CONDUCTORS AND INSULATORS

The structure of an atom of an element is what makes it different from the atom of another element. The number of protons, neutrons, and electrons and the arrangement of the electrons in their orbits vary from element to element. In some elements, the outer electrons rotating around the nucleus are easily removed from their orbits. As stated earlier, elements that have atoms with this characteristic are called *conductors*. A conductor can transmit electricity or electrons.

Most metals are conductors, but not all metals conduct electricity equally well. The most common conductors are silver, copper, and aluminum. The high cost of silver prevents it from being used widely. Its use is largely limited to contacts in certain electrical switching devices, such as contactors and relays. Copper, almost as good a conductor as silver, is usually used because it is less expensive.

Materials that do not easily give up or take on electrons are called **insulators**. An insulator retards the flow of electrons. Glass, rubber, and asbestos are examples of insulators. Thermoplastic is one of the best insulators used to cover wire today. How well an insulator prevents electron flow depends on the strength of the potential applied. If the potential is strong enough, the insulator will break down, causing electrons to flow through it.

There is no perfect insulator. All insulators will break down under certain conditions if the potential is high enough. Increasing the thickness of the insulation helps overcome this problem.

Conductors and insulators are important parts of electric circuits and electric systems. They are widely used in all electric components in the industry.

2.5 ELECTRIC POTENTIAL

In a water system, water can flow as long as pressure is applied to one end of a pipe and the other end of the pipe is open. The greater the pressure in a water system, the greater the quantity of water that will flow. Similarly, in an electrical system, electrons will flow as long as electric pressure is applied to the system. **Voltage**, **potential difference**, and **electromotive force** emf are terms used to describe electric pressure.

Recall that the Law of electric charges states that unlike charges attract. Consequently, there is a pull, or *force*, of attraction between two dissimilarly charged objects. We call this pull of attraction a **field of force**.

Another way of looking at this is to picture excess electrons (the negative charge) as straining to reach the point where there are not enough electrons (the positive charge). If the two charges are connected by a conductor, the excess electrons will flow to the point where there are not enough electrons. But if the two charges are separated by an insulator, which prevents the flow of electrons, the excess electrons cannot move. Hence, an excess of electrons will pile up at one end of the insulator, with a corresponding lack, or deficiency, of electrons at the other end.

As long as the electrons cannot flow, the field of force between the two dissimilarly charged ends of the insulator increases. The resulting strain between the two ends is called the **electric pressure**. This pressure can become quite great. After a certain limit is reached, the insulator can no longer hold back the excess electrons, as discussed in the previous section. Hence, the electrons will rush across the insulator to the other end.

Electric pressure that causes electrons to flow is called *voltage*. Voltage is the difference in electric potential (or electric charge) between two points. The **volt** (V) is the amount of pressure required to force 1 **ampere** (A, the unit of measurement for current flow) through a resistance of 1 **ohm** (Ω, the unit of measurement for resistance; Ω is the Greek letter omega). In the industry, voltage is almost always measured in the range of the common volt. In other areas, the voltage may be measured on a smaller scale of a millivolt (mV), or one-thousandth of a volt. For larger measurements of the volt, the kilovolt (kV), equal to 1000 volts, is used.

1 millivolt = 0.001 volt

1 kilovolt = 1000 volts

FIGURE 2.7

A dry cell battery supplying electric potential (voltage) to an electric circuit

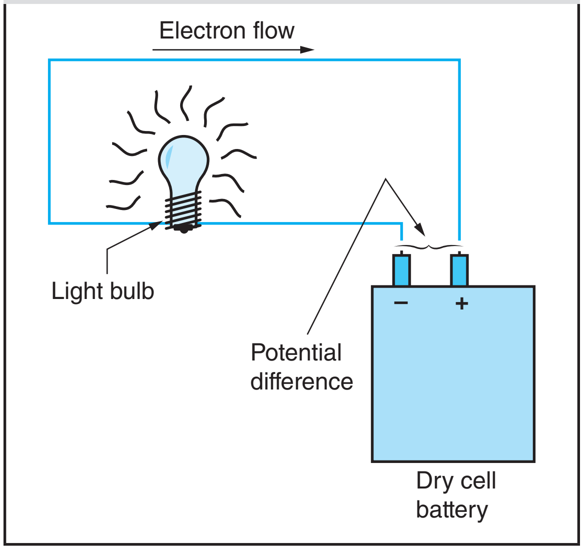
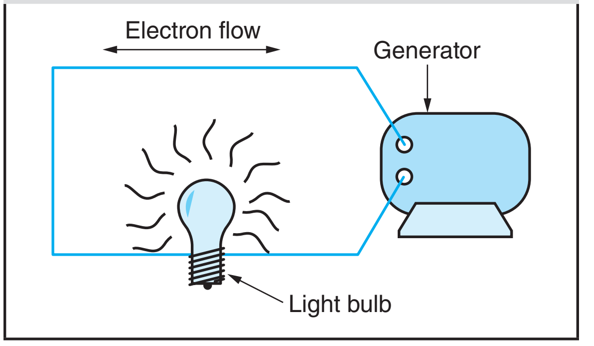


FIGURE 2.8

An AC generator supplying electric potential (voltage) to an electric circuit



To maintain electric pressure, we must have some way to move electrons in the same manner that water pressure moves water. In an electric circuit, this can be maintained by a battery, as shown in **Figure 2.7** or by a generator or alternator, as shown in **Figure 2.8**. The battery forces electrons to flow to the positive electrode and causes electric pressure. A generator causes electric pressure by transferring electrons from one place to another.

Electromotive force (emf) can be produced in several ways. The easiest method to understand is the simple dry cell battery, discussed in Section 2.3. The most popular method of producing an emf is by using an AC generator. The AC generator is supplied with power from another source. Then a wire loop is rotated through the magnetic field created by the voltage being applied, and an emf is produced through the wire loop. We will discuss these ideas in more detail in succeeding sections.

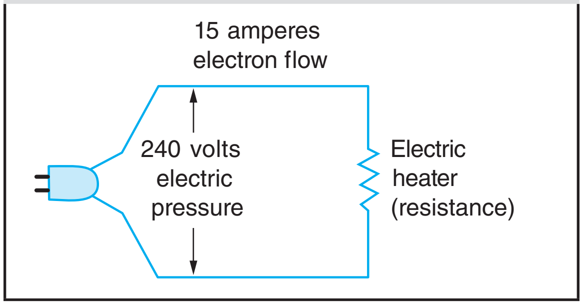
2.6 CURRENT FLOW

Electrons flowing in an electric circuit are called **current**. Current flow can be obtained in an electric circuit by a bolt of lightning, by static electricity, or by electron flow from a generator. **Figure 2.9** shows an electric system with electric pressure; the quantity of electrons flowing is also given.

There are two types of electric current: **direct current** and **alternating current**. Direct current flows in one direction. It is the type of current produced by dry cell batteries. Direct current is rarely used in the industry as a main power source but is used in some modern control circuits.

FIGURE 2.9

An electric system; electric potential forces electrons through a wire (conductor) to a load (electric heater)



Alternating current reverses its direction at regular intervals. It is the type of current supplied to most homes by electric utility companies. It is the most commonly used source of electric potential in the heating, cooling, and refrigeration industry. Alternating current will be discussed in more detail in Chapter 7.

The current in an electric circuit is measured in amperes (A). An ampere is the amount of current required to flow through a resistance of 1 ohm with a pressure of 1 volt. An ampere is measured with an ammeter. In the industry, the ampere is used almost exclusively. If a smaller unit of ampere measurement is required, the milliampere (mA), which is one-thousandth of an ampere, can be used. For larger measurements of amperes, the kiloampere (kA) can be used. One kiloampere equals 1000 amperes.

1 milliampere = 0.001 ampere

1 kiloampere = 1000 amperes

The current that an electric device draws can be used as a guide to the correct operation of the equipment by installation and service technicians. The electric motor is the largest current-drawing device in most heating, cooling, and refrigeration systems. The larger the electric device (load), the larger the current flow. Any electric device that uses electricity requires a certain current when operating properly.

2.7 RESISTANCE

Resistance is opposition to the flow of electrons in an electric circuit and is measured in ohms. The electrical device or load in an electrical circuit that will produce some useful work is known as or represents the resistance of that circuit. **Figure 2.10** shows two electric systems with different resistances. One ohm is the amount of resistance that will allow 1 ampere to flow with a pressure of 1 volt. The industry uses simple ohms for resistance in most cases because the scale is broad enough for most applications. In some special cases, the microhm (μΩ), which is one-millionth of an ohm, is used for extremely small resistance readings. Larger resistance readings are read in megohms (MΩ); 1 megohm is equal to 1 million ohms.

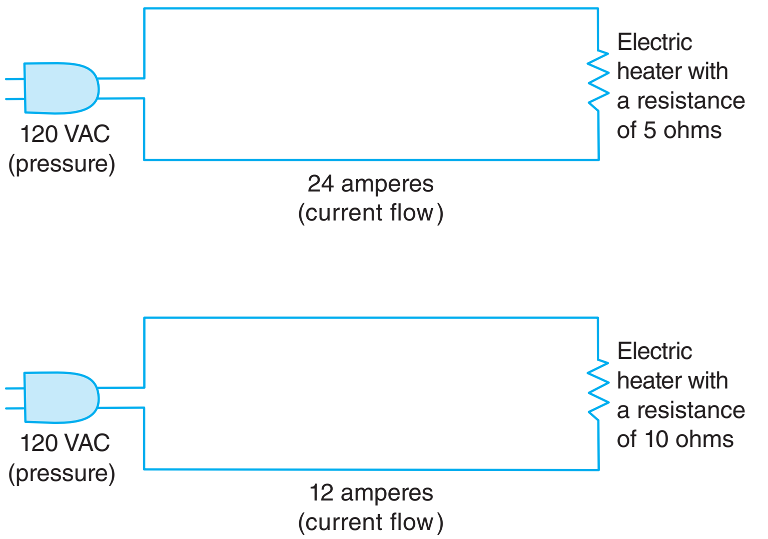
1 microhm = 0.000001 ohm

1 megohm = 1,000,000 ohms

All electric devices will have a certain resistance. That resistance depends on the size and purpose of the device. As service technicians, you will have to become familiar with this value in components. If the resistance deviates far from the specified value or the estimated value, the device can be considered faulty.

FIGURE 2.10

Two electric circuits with different resistances



2.8 ELECTRIC POWER AND ENERGY

When electrons move from the negative to the positive end of a conductor, work is done. **Electric power** is the rate at which the electrons do work. That is, electric power is the rate at which electricity is being used. The power of an electric circuit is measured in **watts** (W). A watt of electricity is 1 ampere flowing with a pressure of 1 volt. The electric power of a circuit is the voltage times the amperage.

$$\text{electric power} = \text{voltage} \times \text{amperage}$$

In an AC circuit, the voltage and current are not in phase. To obtain the correct power consumed by the circuit, the product of the voltage times the amperage must also be multiplied by a **power factor**. The power factor is the true power (measured with a wattmeter) divided by the calculated power and is expressed as a percentage. In a DC circuit, the product of the voltage times the amperage gives the power of the circuit; the power factor is not needed.

The industry uses the units of watts for devices that consume a small amount of power. Examples of such devices are small electric motors and small resistance heaters. Other units used are the horsepower (hp) and the British thermal unit (Btu). One horsepower is equal to 746 watts. One watt is equal to 3.41 Btu per hour (Btu/hour).

$$1 \text{ horsepower} = 746 \text{ watts}$$

$$1 \text{ watt} = 3.41 \text{ Btu/hour}$$

These conversion figures are often used in the industry to calculate the Btu rating of an electric heater if the watt rating is known. The horsepower conversion is used to calculate the horsepower of a motor only if the watts are known.

The rate at which electric power is being used at a specific time is called **electric energy**. Electric energy is measured in watt-hours (Wh). For example, if a 5,000-watt electric heater is running for 2 hours, it consumes 10,000 watt-hours of electric energy.

The wattage rating or consumption of any electric device only denotes the amount of power the device is using. However, time must be considered when calculating electric energy, that is, the power being consumed over a definite period. Watt-hours give the number of watts used for a specific period of time.

The units of kilowatts (kW) are usually used to determine the amount of electricity consumed. Thus, an electric utility calculates the power bill of its customers using **kilowatt-hours** (kWh) because the watt-hour readings would be extremely large. The kilowatt-hour reading is relatively small. One thousand watts used for 1 hour equals 1 kilowatt-hour. All electric meters used to measure the consumption of electricity record consumption in kilowatt-hours.

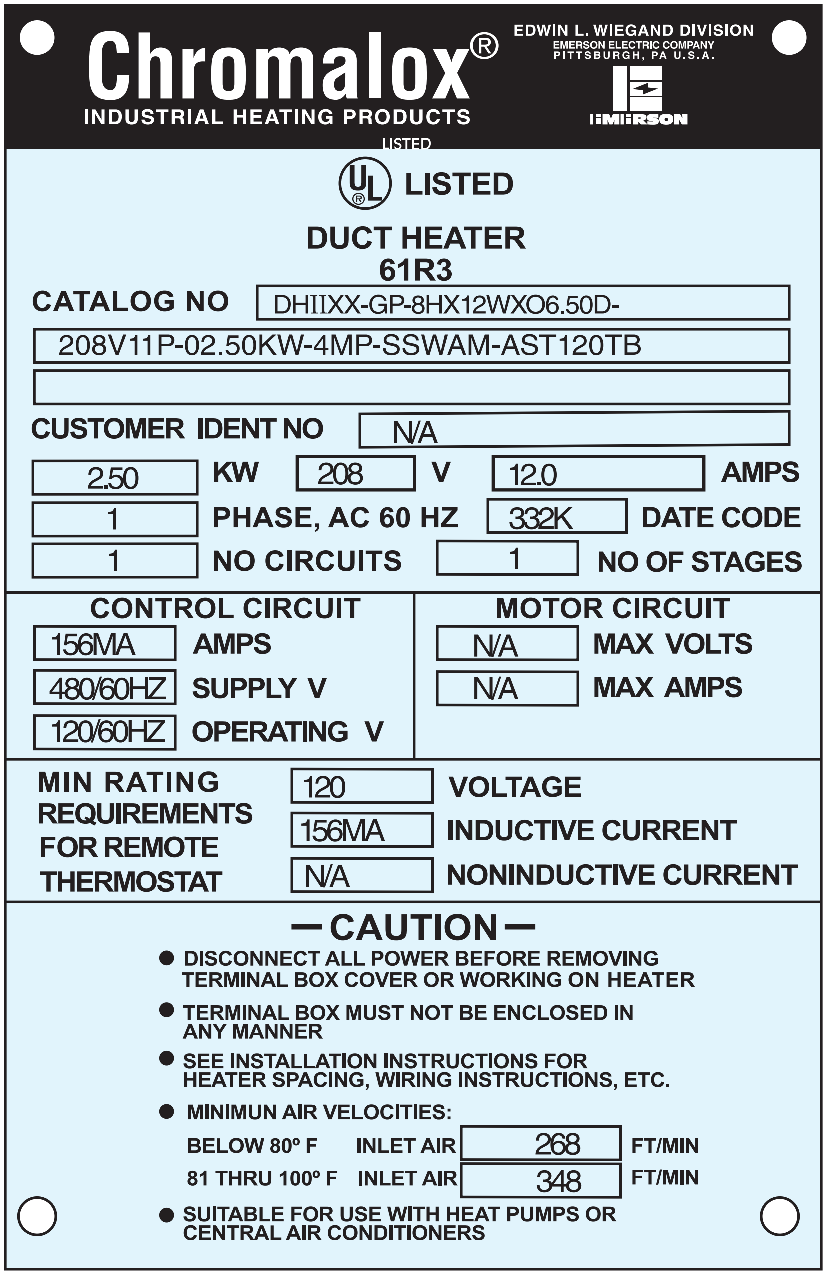
Heating and air-conditioning technicians are often required to make a calculation for the output of an electric heater in Btus rather than in watts. The industry rates electric heating equipment in watts or kilowatts, which does not give consumers figures that they can understand. Most consumers are familiar with the term Btu and know basically what it means in terms of heat output. Therefore, the customer often will request the Btu output rather than the wattage of a heating appliance. The Btu output can be easily calculated by multiplying the number of watts by the conversion factor of 3.41 Btu/hour. **Figure 2.11** shows an electric data plate for an electric heater. The wattage on the data plate is 2.50 kilowatts. Therefore, the Btu output is

$$2500 \times 3.41 \text{ Btu/hour} = 8525 \text{ Btu/hour}$$

Another term that is used because of the high cost of energy is the **seasonal energy efficiency ratio (SEER)** of an air-conditioning unit or heat pump, measured in Btu's per watt. The SEER is the Btu output of the equipment divided by the power input with a seasonal adjustment. For example, if an air-conditioning unit has a SEER of 10, it will produce 10 Btu of cooling per watt of power consumed by the equipment. All air-conditioning manufacturers use SEER ratings for their equipment. The standards for SEER are set by the Air-Conditioning, Heating, and Refrigeration Institute (AHRI).

FIGURE 2.11

Data plate of an electric heater



Courtesy of Chromalox®, Wiegard Industrial Division of Emerson Electric Co.

2.9 OHM'S LAW

The relationship among the current, emf, and resistance in an electric circuit is known as **Ohm's law**. In the nineteenth century, George Ohm developed the mathematical comparisons of the major factors in an electric circuit. Stated in simple terms, Ohm's law says it will take 1 volt of electrical pressure to push 1 ampere of electrical current flow through 1 ohm of electrical resistance; in other words, the greater the voltage the greater the current, and the greater the resistance the lesser the current. Ohm's law is represented mathematically as "current is equal to the emf divided by the resistance." The following equation expresses Ohm's law:

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

In the equation, I represents the current in amperes, E represents the emf in volts, and R represents the resistance in ohms. Ohm's law can also be expressed by the following two formulas:

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

In any of the three formulas, when two elements of an electric circuit are known, the missing factor can be calculated. Ohm's law must be modified for AC calculations to account for the effects of coils and capacitors in AC circuits. Alternating current will be discussed in Chapter 7. However, the general ideas or principles of Ohm's law apply to AC circuits.

The following examples show the relationships of the voltage, current, and resistance in an electric current.

Example 1 What is the current in the circuit shown in **Figure 2.12**?

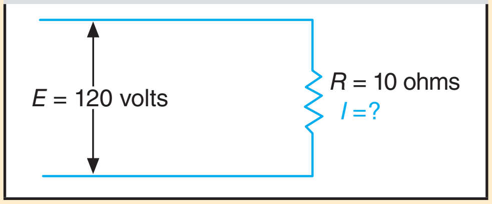
STEP 1 $I = \frac{E}{R}$

STEP 2 $I = \frac{120}{10}$

STEP 3 $I = 12$ amperes

FIGURE 2.12

Simple electric circuit for Example 1



Example 2 What is the resistance of a 100-watt light bulb if the voltage is 120 volts and the current is 0.83 ampere?

STEP 1 $R = \frac{E}{I}$

STEP 2 $R = \frac{120}{0.83}$

STEP 3 $R = 145$ ohms

Example 3 What is the voltage supplied to the circuit in **Figure 2.13**?

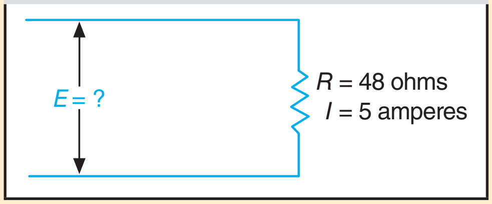
STEP 1 $E = IR$

STEP 2 $E = 5 \times 48$

STEP 3 $E = 240$ volts

FIGURE 2.13

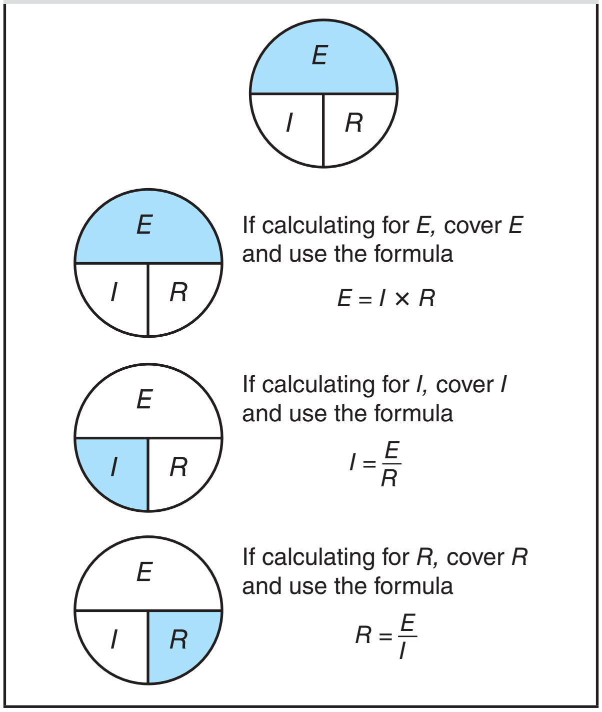
Simple electric circuit for Example 3



Ohm's law allows the calculation of the missing factor if the other two factors are known or can be measured. **Figure 2.14** shows a simple method for remembering Ohm's law. If one of the factors in the circle is covered, the letters remaining in the circle give the correct formula for calculating the covered factor.

FIGURE 2.14

Using Ohm's law (not applicable on AC inductive circuits)



2.10 CALCULATING ELECTRIC POWER

Electric power can be calculated by using the formula $P = IE$. Two other formulas can be used to calculate the electric power of an electric circuit by substituting in the following equations:

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

The letter designations in these formulas are the same as in Ohm's law, with P representing power in watts.

The following three examples show the electric power calculations of three electric circuits.

Example 4 What is the power consumption of an electric circuit using 15 amperes and 120 volts?

STEP 1 $P = IE$

STEP 2 $P = 15 \times 120$

STEP 3 $P = 1800$ watts

Example 5 What is the current of an electric heater rated at 5000 watts on 240 volts?

STEP 1 $I = \frac{P}{E}$

STEP 2 $I = \frac{5000}{240}$

STEP 3 $I = 20.8$ amperes

Example 6 What is the power of an electric circuit with 5 amperes current and 10 ohms resistance?

STEP 1 $P = I^2R$

STEP 2 $P = 5^2 \times 10$

STEP 3 $P = 25 \times 10$

STEP 4 $P = 250$ watts

SUMMARY

Everything—solids, liquids, and gases—is composed of matter. Matter can be broken down into molecules (the smallest particles of physical objects) and atoms (the smallest particles of an element that can exist alone or in combination). An atom is composed of a nucleus (the central part) and electrons (negatively charged) that orbit around the nucleus, much like the planets orbit the sun. The nucleus is composed of protons (positively charged) and neutrons (no charge). The number of protons is usually equal to the number of electrons, making the atom electrically neutral. When an atom loses electrons, it becomes positively charged. When it gains electrons, it becomes negatively charged. The Law of electric charges states that like charges repel and unlike charges attract. Materials can be made to acquire positive or negative charges.

Electrons can be made to flow by the use of friction, chemicals, and magnetism. A conductor is a material capable of transmitting electrons or electricity. Most metals are conductors. An insulator is a material that resists or prevents electron flow.

There are four important factors in any electric circuit: emf, current, resistance, and power. The emf of an electric circuit is the actual pressure in the circuit, much like water pressure in a water system. The emf in an electric circuit is measured in volts. The voltage (pressure) must be sufficient to overcome the resistance of the circuit. Alternating current is used almost exclusively in the industry to supply electric power to equipment.

The number of electrons flowing in an electric circuit is called the current flow. The current flow of an electric circuit is measured in amperes. An ampere is the amount of current that will flow through a resistance of 1 ohm with a pressure of 1 volt.

The resistance of an electric circuit is measured in ohms. All electric loads have some resistance. Electric power is the rate at which electric energy is being used in an electric circuit. Electric power is measured in watts and kilowatts. Electric utility companies use kilowatt-hours in most cases to charge their customers for the electric energy that they have consumed. The kilowatt-hour is a measure of electric energy and takes into consideration the amount of time and the power consumption. One thousand watts used for a period of 1 hour equals 1 kilowatt-hour. Voltage, amperage, resistance, and wattage often use the prefixes kilo- or milli- to represent larger or smaller quantities of these factors and to avoid the use of extremely large or small numbers.

Ohm's law gives the relationship among the current, emf, and resistance in an electric circuit. Ohm's law states the relationship mathematically. When any two factors in an electric circuit are known or can be measured, the formulas for Ohm's law can be used to find the third factor. Electric power can be calculated by using the formula $P = IE$.

REVIEW QUESTIONS

1 All physical objects are composed of __________.
a. substances
b. matter
c. neutrons
d. solids

2 What is an atom?

3 Which of the following is a part of the atom?
a. electron
b. proton
c. neutron
d. all of the choices are correct

4 What is static electricity?

5 Name three ways electricity can be produced.

6 What part do protons and electrons play in the production of electricity?

7 Which of the following is the simplest atom that exists?
a. carbon
b. hydrogen
c. oxygen
d. sulfur

8 What are the four most important characteristics of an electric circuit?

9 What is electromotive force?

10 Electromotive force is commonly measured in __________.
a. amperes
b. ohms
c. volts
d. watts

11 What is current?

12 How is current measured?
a. amperes
b. ohms
c. volts
d. watts

13 What is resistance?

14 How is resistance commonly measured?
a. amperes
b. ohms
c. volts
d. watts

15 What is electrical power?

16 How is electrical power commonly measured?
a. amperes
b. ohms
c. volts
d. watts

17 Where do electrons exist in an atom, and what is their charge?

18 True or False: All atoms tend to lose electrons.

19 State the law of electric charges.

20 What is a proton? Where does it normally exist in an atom, and what is its charge?

21 Describe briefly the method a dry cell battery uses to produce voltage.

22 What is a conductor?

CHAPTER 2 REVIEW

23 Which of the following is the best conductor?
a. wood
b. thermoplastic
c. copper
d. cast iron

24 What is an insulator?

25 Which of the following is the best insulator?
a. wood
b. thermoplastic
c. copper
d. cast iron

26 Why do metals make the best conductors?

27 How do electric utility companies charge customers for electricity?

28 What is the meaning of SEER when used in conjunction with an air-conditioning unit?

29 State Ohm's law.

30 True or False: Ohm's law applies to all types of electrical circuits.

31 What is the ampere draw of a 5,000-watt electric heater used on 120 volts?
a. 42 ampere
b. 45 ampere
c. 50 ampere
d. 52 ampere

32 What is the resistance of the heating element of an electric iron if the ampere draw is 8 amperes when 115 volts are applied?
a. 10 ohms
b. 12 ohms
c. 14 ohms
d. 16 ohms

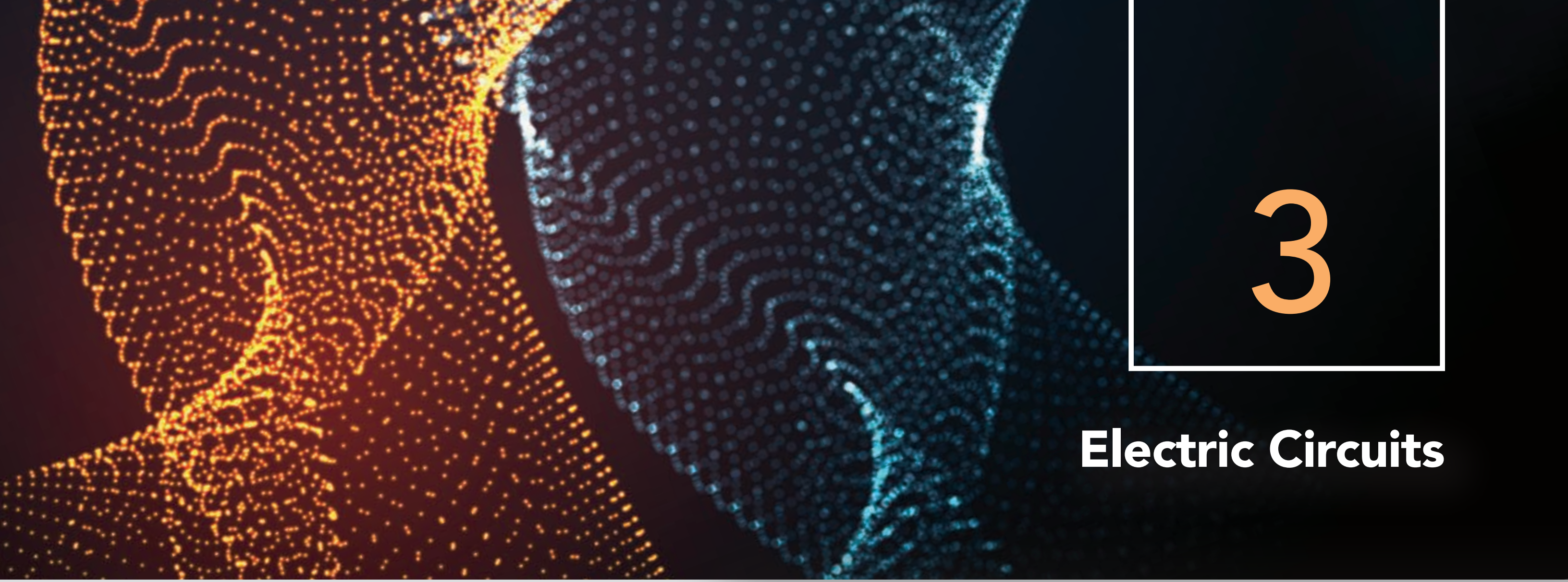
33 What is the voltage of a small electric heater if the heater is drawing 12 amperes and has a resistance of 10 ohms?
a. 120 volts
b. 240 volts
c. 60 volts
d. none of the choices are correct

34 What is the Btu/hour output of an electric heater rated at 15 kilowatts?
a. 51.15 Btu/hour
b. 51,150 Btu/hour
c. 5115 Btu/hour
d. none of the choices are correct

35 What is the kilowatt output of an electric heater that has an ampere draw of 50 amperes if the voltage source is (a) 208 volts? (b) 240 volts?

LAB MANUAL REFERENCE

For experiments and activities dealing with material covered in this chapter, refer to the *Complete HVAC Lab Manual*.



3

Electric Circuits

Key Terms

Closed
Control circuit
Electric circuit
Open
Parallel circuit
Power circuit
Series circuit
Series-parallel circuit
Voltage drop

Learning Objectives

After completing this chapter, you should be able to:

- Explain the concepts of a basic electric circuit.
- Explain the characteristics of a series circuit.
- Explain the characteristics of a parallel circuit.
- Describe how series circuits are used as control circuits in the air-conditioning industry.
- Describe how parallel circuits are used as power circuits in the air-conditioning industry.
- Explain the relationship and characteristics of the current, resistance, and electromotive force in a series circuit.
- Explain the relationship and characteristics of the current, resistance, and electromotive force in a parallel circuit.
- Calculate the current, resistance, and electromotive force in a series circuit.
- Calculate the current, resistance, and electromotive force in a parallel circuit.
- Explain the characteristics of the series-parallel circuit.
- Describe how series-parallel circuits are utilized in the air-conditioning industry.

INTRODUCTION

The electrical circuitry in a modern heating, cooling, and refrigeration system is important to the technicians who install or work on the electrical systems. Any electrical system used in the industry is composed of various types of circuits. Each type is designed to do a specific task within the system. We will look at some commonly used types of circuits in this chapter.

The two most important kinds of circuits are parallel circuits and series circuits. A **parallel circuit** is an electric circuit that has more than one path through which electricity may flow. A parallel circuit is designed to supply more than one load in the system.

A **series circuit** is an electric circuit that has only one path through which electricity may flow. It is usually used for devices that are connected in the circuit for safety or control.

A **series-parallel circuit** is an electrical circuit that has a combination of series and parallel circuits. Most electrical systems in equipment or control systems are made up of a combination of parallel and series circuits. Electrical loads that require electrical power for operation are usually connected in parallel, which allow them to receive full supply voltage for operation. Switches used in electrical circuits to control these loads are connected in series, breaking the circuit if the switch opens.

You must understand the circuitry in air-conditioning, heating, and refrigeration control and power systems to do an effective job of installing and servicing the equipment.

We begin our study with a discussion of the basics of electric circuits.

3.1 BASIC CONCEPTS OF ELECTRIC CIRCUITS

An **electric circuit** is the complete path of an electric current, along with any necessary elements, such as a power source and a load. When the circuit is complete so that the current can flow, it is termed **closed** or *made* (**Figure 3.1**). When the path of current flow is interrupted, the circuit is termed **open**, or *broken* (**Figure 3.2**). The opening and closing of electrical switches connected in series with electrical loads control the operation of loads in the circuit.