INDUSTRIAL ELECTRICITY

TENTH EDITION

MICHAEL E. BRUMBACH

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CENGAGE

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***Industrial Electricity*, Tenth Edition**
Michael E. Brumbach

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IP Project Manager: Betsy Hathaway

Designer: Felicia Bennett

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For Kathy:
Thanks for taking care of us,
making us smile no matter how bad the day was.
I'm blessed to have you!

CONTENTS

PREFACE

The continued growth and technological advances of the electrical and electronics industry result in many challenges for those entering or working in the field of industrial electrical maintenance. Not only must you be knowledgeable in these fields, but you must also stay abreast of changes and advancements.

A thorough knowledge of electrical theory is not enough to be successful as an electrical technician. You must also learn to apply the knowledge that you have gained. Since *Industrial Electricity* was first published, it has proven to be a valuable tool for beginners and experienced technicians alike. This text covers the theory of electricity and various applications. In addition, this text goes beyond the basic theories by introducing installation, maintenance, and troubleshooting applications as well.

The tenth edition of *Industrial Electricity* represents a significant revision to the ninth edition. The text remains well illustrated, now in color. Terms are defined when introduced, and a glossary is included as well. Each chapter begins with objectives and key terms and ends with a summary and review questions. To aid the instructor, an *Instructor's Guide,* detailing answers to the review questions, is available to course instructors.

Some content from the ninth edition has been deleted due to its obsolescence. For example, component-level, or even board-level, troubleshooting is no longer economical in most situations. Therefore, the chapter on Basic Industrial Electronics has been deleted.

On the other hand, there is an ever-increasing amount of computerization and automation being incorporated within the manufacturing environment. As a result, material on distributed control system (DCS), supervisory control and data acquisition (SCADA), and computerized maintenance management system (CMMS) has been added.

NEW FOR THE TENTH EDITION

The tenth edition is now published in full color. In addition, new chapters on Safety and Predictive and Preventive Maintenance have been added. In keeping with the changing technologies and resulting changes in the demands on the industrial electrician, the chapters on Electrical Heat, Basic Industrial Electronics, and DC Electronic Variable Speed Drives have been deleted. These changes resulted in a reorganization of the chapters into, what is hoped to be, a more logical presentation. Following is a more detailed, chapter-by-chapter, description of these changes:

Chapter 1—Safety

- New chapter that introduces the student to a culture of safety, safety organizations, codes and ordinances, arc flash, hazardous materials, PPE, tools and test equipment, and work practices

Chapter 2—Language of Electricity

- Revised chapter (formerly Chapter 1—Language of Electricity)

Chapter 3—Electrical Fundamentals

- Revised chapter (formerly Chapter 2—Electrical Fundamentals)

Chapter 4—Test Equipment

- Revised chapter (originally Chapter 4—Test Equipment)
- Added content on:
  - voltage testers
  - portable, handheld oscilloscope
  - thermal imaging camera
  - phase rotation meter
  - power quality meter
  - process clamp meter

Chapter 5—Basic Resistive Electrical Circuits

- Revised chapter (originally Chapter 5—Basic Resistive Electrical Circuits)

Chapter 6—Alternating Current

- Revised chapter (formerly Chapter 7—Alternating Current)

Chapter 7—Reactive Circuits and Power Factor

- Revised chapter (formerly Chapter 8—AC Circuits)

Chapter 8—Conductor Types and Sizes

- Revised chapter (formerly Chapter 9—Conductor Types and Sizes)
  - Revised to NFPA 70 2020 edition standards

Chapter 9—Electrical Installation

- Combination of two former chapters (Chapter 10—Wiring Methods and Chapter 11—Wiring Applications)
  - Revised to NFPA 70 2020 edition standards

Chapter 10—Magnets and Magnetism

- Revised chapter (formerly Chapter 6—Magnets and Magnetism)

Chapter 11—Transformers and Electrical Distribution

- Combination of two former chapters (Chapter 12—Transformers and Chapter 13—Electrical Distribution)

Chapter 12—DC Machines

- Combination of two former chapters (Chapter 16—DC Generators and Chapter 17—DC Motors)

Chapter 13—AC Machines

- Combination of two former chapters (Chapter 18—AC Generators (Alternators) and Chapter 19—AC Motors)

Chapter 14—Control and Controlled Devices

- Part of and revised former chapter (Chapter 20—Motor Control Devices and Circuits)

Chapter 15—Motor Control Circuits

- Part of and revised former chapter (Chapter 20—Motor Control Devices and Circuits)

Chapter 16—Variable Frequency Drives (VFDs)

- Revised chapter (formerly Chapter 23—AC (Inverter) Drives)
- Added information on installation, initialization, and troubleshooting

Chapter 17—Programmable Controllers (PLCs and PACs)

- Revised chapter (formerly Chapter 24—Programmable Logic Controllers)
- Added information on:
  - PACs
  - IEC 61131-3
  - Industry 4.0
  - distributed control system (DCS)
  - supervisory control and data acquisition (SCADA)

Chapter 18—Lighting

- Revised chapter (formerly Chapter 14—Lighting)
- Added information on:
  - LED lamps
  - lighting maintenance

Chapter 19—Predictive and Preventive Maintenance

- New chapter that introduces the student to predictive maintenance, preventive maintenance, maintenance procedures, and computerized maintenance management system (CMMS)

INSTRUCTOR RESOURCES TO THIS PRODUCT

Additional instructor resources for this product are available online.

- Instructor's Manual
- Educator's Guide
- PowerPoint slides
- Test bank powered by Cognero
- Image Gallery

ABOUT THE AUTHOR

Michael E. Brumbach

Mike is a retired associate dean for the Industrial and Engineering Technology Division at York Technical College in Rock Hill, SC. Prior to serving as associate dean, Mike was the Industrial Maintenance Department program chair as well as an instructor in Industrial Maintenance. Mike retired with 28 years of service with York Technical College, having spent the previous 11 years working in industry. Mike possesses an AS degree and was a member of the National Fire Protection Association (NFPA) and the American Society for Nondestructive Testing (ASNT). He is also coauthor of the Cengage titles *Electronic Variable Speed Drives* and *Industrial Maintenance*.

You may e-mail Mike at mbrumbach@comporium.net.

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CHAPTER 1

SAFETY

OBJECTIVES

After studying this chapter, the student will be able to:

- Describe what is meant by a *culture of safety*.
- Describe the application of NFPA 70E and OSHA guidelines.
- Identify areas of safety concern within a given work area.
- List the steps involved in an Arc Flash Risk Assessment.
- Explain the Hazardous Materials diamond.
- Describe several types of Personal Protective Equipment (PPE).
- Identify areas of concern when using ladders and scaffolds.
- Describe the safety requirements for hand and power tools.
- Describe the requirements and precautions when using electrical test equipment.
- Identify safety concerns when working around machinery.
- List the areas of concern when working on live, electrified equipment.

KEY TERMS

In this chapter, you will learn the following key terms:

- Electrocution
- Safety
- Hazard
- OSHA
- NFPA
- Culture of safety
- Hazardous materials
- Personal Protective Equipment (PPE)
- NFPA 70E
- Accident
- Ampere
- Electrical lockout
- Voltmeter
- Tagout
- Current
- Arc
- Arc flash
- Arc blast
- Arc Flash Risk Assessment
- Risk
- NIOSH
- UL®
- ANSI
- NEMA
- Hazardous Material Information Guide (HMIG)
- Material Safety Data Sheet (MSDS)
- Ohmmeter
- Megger®
- Pinch point

INTRODUCTION

Working as an electrician can be both exciting and rewarding. A great sense of satisfaction is achieved after completing an electrical installation, solving an electrical problem, or restoring electrical power. However, working around and with electricity is not without danger. It only takes a split second to suffer an electrical shock or, worse, **electrocution**. This is not meant to scare you. In the industry, the term *respect* is used. You need to respect electricity and what the dangers are. This chapter will help you understand the need for **safety**, both mental and physical. In so doing, you will learn to respect electricity and work safely around and with electricity so that you will have a long, rewarding career.

A CULTURE OF SAFETY

Safety. What comes to mind when you see, hear, or say the word *safety*? Do you think of procedures and equipment that are designed to protect you from various **hazards**? Or do you think of unnecessary rules and gear that is hot, cumbersome, and heavy and gets in your way of getting the job done? Hopefully, your mindset is of the former mentality. There is no place for individuals who do not take safety seriously. They pose a danger, not only to themselves but also to others around them.

SAFETY

So, what is safety? The website Safeopedia.com defines *safety* as "a concept that includes all measures and practices taken to preserve the life, health, and bodily integrity of individuals." Safeopedia.com goes on to say, "Ensuring the safety of workers is both necessary and beneficial for any organization. Regulatory bodies such as **OSHA** and the **NFPA** mandate a variety of safety measures employers must take and have the authority to impose fines if their investigations reveal a violation of these standards."

Unfortunately, there are individuals who do not take safety seriously. They think it is a joke. They even tease or ridicule others who employ safety practices. These individuals pose a danger not only to themselves but also to others and to their organization. Whether an individual or organization, there needs to be an established **culture of safety**. Individuals who do not adhere to this culture of safety should face disciplinary action, which could include loss of pay, suspension, or even termination. While this may seem harsh, the realities are that safety violations result in injuries or fatalities. Safety *must* be taken very seriously at *all* times by *all* individuals and the *entire* organization. This is where a culture of safety comes in.

In a culture of safety, *all* employees believe in safety, they appreciate the need for safety, and they exhibit a safe demeanor in their daily activities. This culture of safety reaches not only all employees but the entire work environment as well. Certain key elements need to be in place to create and maintain a culture of safety. These are as follows:

- A well-defined statement of the purpose and objectives of the organization's safety program.
  - What hazards exist, what are the desired results, and why is this important?
- Identify the roles and responsibilities.
  - Establish and document the performance and duties of both management and employees.
- Define key elements and principles.
  - Employee training
  - Workplace assessment
  - Disciplinary action
  - Success recognition
- Assess work area.
  - Inspect and identify hazards and required safety equipment.
- Identify and list specific handling practices for **hazardous materials**.
  - Inspect and identify hazardous materials and required safety equipment.
- Assess electrical safety.
  - Inspect and identify hazards and required safety equipment.
- **Personal Protective Equipment (PPE)**
  - Identify situations when PPE is required and to what degree.
  - Identify PPE provided by employer and employee.
- Training
  - Qualification training for unqualified employees
  - Ongoing training for qualified employees

With these elements in place, and constant reinforcement, a culture of safety will exist. Safeopedia.com explains that "[a] positive safety culture is the culture of a workplace in which all employees think of safety as an important thing and behave in a way that prioritizes their own safety as well as the safety of those around them. This includes using proper personal equipment, following the safety laws, and just generally being conscious of safety and safe practices at all times."

NFPA 70E AND OSHA GUIDELINES

Probably anytime workplace safety is discussed, two standards will be mentioned: **NFPA 70E** and OSHA. These two standards combine to form the core of a comprehensive workplace safety environment. NFPA 70E, the *Standard for Electrical Safety in the Workplace*, is published and updated every 3 years by the National Fire Protection Association (NFPA). Occupational Safety and Health Administration (OSHA) is part of the U.S. Department of Labor. Its mission (from the OSHA.gov website) is, "With the Occupational Safety and Health Act of 1970, Congress created the Occupational Safety and Health Administration (OSHA) to ensure safe and healthful working conditions for working men and women by setting and enforcing standards and by providing training, outreach, education and assistance."

These two standards are used in conjunction with each other so that the OSHA guidelines explain *what* an employer shall do and NFPA 70E specifies *how* it shall be done.

SAFETY

You should familiarize yourself with OSHA standard 1910.333. This standard, as shown on the OSHA.gov website, states, "Safety-related work practices shall be employed to prevent electric shock or other injuries resulting from either direct or indirect electrical contacts, when work is performed near or on equipment or circuits which are or may be energized. The specific safety-related work practices shall be consistent with the nature and extent of the associated electrical hazards."

You should also familiarize yourself with NFPA 70E. The standard, as stated in the NFPA 70E website, states:

> This standard addresses electrical safety-related work practices, safety-related maintenance requirements, and other administrative controls for employee workplaces that are necessary for the practical safeguarding of employees relative to the hazards associated with electrical energy during activities such as the installation, inspection, operation, maintenance, and demolition of electric conductors, electric equipment, signaling and communication conductors and equipment, and raceways. This standard also includes safe work practices for employees performing other work activities that can expose them to electrical hazards as well as safe work practices for the following:
>
> (1) Installation of conductors and equipment that connect to the supply of electricity
> (2) Installations used by the electric utility, such as office buildings, warehouses, garages, machine shops, and recreational buildings that are not an integral part of a generating plant, substation, or control center

SAFETY IN THE WORK AREA

Being aware of the surroundings and potential hazards is the first step in safety. Survey the surrounding area before starting any work. If an unsafe condition or a potential hazard is noticed during the survey of the surrounding area, try to correct it, thereby eliminating the unsafe condition. If the unsafe condition cannot be removed, then perhaps it can be reduced, and all involved must exhibit a heightened awareness of the dangers.

Accidents could kill or injure a person. An accident, according to Safeopedia.com is, " . . . an unplanned, unforeseen, and unexpected event that has a negative effect on all activities of the individual who is involved in the accident. An accident can result in death, injury, disease or infection, loss of property, damage to environment, or a combination thereof. Accidents can come with business consequences as well, such as compensation costs, loss of productivity, and a decrease in employee morale."

SAFETY

Safety Concerns before Starting the Work

The following precautions should be taken before starting the work. They may seem obvious, but it is amazing how often we overlook these precautions and begin work in an unsafe environment.

- Be certain that all workers involved in the job have the necessary skills and qualifications to perform the work.
- Familiarize yourself with the job at hand.
- Identify all the obvious safety concerns, and then think about the not so obvious ones. Ask yourself, "What would happen if . . . ?"

- Verify that all required safeguards or safety devices are present and in working order.
- Know the location of the nearest fire extinguisher and first aid kit.
- Ensure access to two-way radios and/or emergency phones.
- Notify all appropriate personnel of the nature of the work to be performed.
- Verify that all personnel involved with the job are familiar with the safety and emergency policies and procedures as related to the work that is to be performed.
- Plan safety into the job.
- Maintain a neat and an orderly work site.
- Do not attempt the work when tired or taking medications that cause drowsiness or if lighting is insufficient.
- Check for atmospheric hazards such as dust, vapors, or gases that may ignite from an electrical arc or spark.

Securing the Area

When maintenance is being performed, the area in which you are working may have to be secured. For instance, a portion of a catwalk or subfloor may have to be removed to gain access to a cable tray or the damaged part of a machine. In this case, a hazardous condition has been created. The area needs to be roped off so that people are aware of the hazard and its location. Awareness prevents falls and injury. If you are working overhead, and there is a chance that something will be dropped or will fall, once again, secure the area to prevent people from entering the hazardous area. Securing an area can also prevent curious people from getting too close to you. Your undivided attention must be given when you are working on a machine or a piece of equipment. Any distractions could prove to be dangerous. Securing the area keeps these distractions at a safe distance, allowing you to focus on the task at hand.

CAUTION

Worker Safety

You need to think about the situation that you are working in and evaluate it to determine how safe it is and where the dangers lie. The following are some items to check to increase your awareness.

- For work on energized circuits, a minimum of two workers should work together. If one worker needs to leave the work site, the remaining worker should not perform any work on the energized circuit.
- Before performing any type of work or act, think about the consequences of that work or act. Do not take chances or cut corners!
- Always work carefully. Place yourself in the safest position to avoid slips, falls, or backing into energized parts.
- Make certain you are satisfied that you are working in the safest environment possible.
- Do not continue if you feel uncomfortable because of your or a coworker's actions.
- Always exercise caution. Treat all circuits as energized, even when you know they are not!
- Remove all jewelry (watches, rings, bracelets, etc.). Gold, for example, is an excellent conductor of electricity, and any jewelry can become caught in moving machinery!
- Do not hesitate to obtain medical treatment for all injuries, no matter how minor they may seem.

Lifting

Many people each year injure themselves while performing the simple act of lifting. The injury comes from lifting too much weight or lifting improperly. The first thing to do is to know your facility's policy on lifting. Most facilities require the use of a lifting girdle or belt. This is to provide support to the back while lifting. Next, determine whether the item is too heavy to lift. This factor varies from person to person. If it is decided that the load is not too heavy, then proceed with the lifting action. If the load is too heavy, do not be ashamed to ask for help. Here are some very simple steps to ensure safety while lifting.

- Place both feet around and beside what is to be lifted, if possible.
- Make sure that a good footing has been established.
- Bend down at the knees into a squatted position. This is illustrated in Figure 1-1.
- Grasp the object that is to be lifted, and get a firm grip on it.
- Straighten the back so it is as close as possible to a 90-degree angle from the floor.
  - Keep the back straight through the entire lift.
  - Do not, at any time, arch the back.

FIGURE 1-1 Proper stance for lifting.

- Once a firm grip has been established and the back is straight, proceed with the lift by straightening the legs.
- Be sure to keep the load close to the body while lifting it.
- Lift slowly.
- Do not twist or turn the body during the lift.
  - Lift the load straight up with the legs.
- Once the load has been completely lifted, then you can turn or rotate at the waist if necessary.
- Reverse the process when setting the load down.
  - Once again, remember to keep the back as straight as possible through the entire process of setting the load down.

CAUTION

The Shop

The working environment needs to be kept clean and safe. The workplace is dangerous enough without adding any unnecessary hazards. This applies to not only the plant floor but the shop area as well. Keeping the shop area clean helps create a safe working atmosphere.

Creating a cleaning roster for the shop spreads the work among all shop members so that one person is not doing all the cleaning. Once a shop is cleaned, try to keep it clean. Keep the floor free of debris and slippery fluids.

Place oily, dirty rags in their proper storage containers, and send them out for cleaning on a regular basis. If oily rags are left piled up without ventilation for an extended period of time, combustion may occur.

Store hazardous materials in their proper places. For instance, spray cans and other combustible products must be kept in a cool, ventilated place away from a source of ignition.

Lighting is important. The working environment should be well lit to provide the best visibility possible.

Try to keep all of the areas that you are working in clean and clear of debris. Also keep the machinery and equipment clean. A clean machine is easier to work on than a dirty one. Sometimes it is impossible to keep a machine or a piece of equipment clean due to its process, but it should be kept as clean as possible.

SAFETY

Electrical Safety

Every year, tens of thousands of people are injured by accidental contact with an energized electrical circuit. Over 1000 of these individuals will lose their lives because of this accidental contact. A common misconception is that it takes a lot of current or voltage to cause injury or death. This is not true! An electrical current of only 0.0025 **ampere** can be sensed. A current of only 0.025 ampere causes you to be held by the circuit. Death can occur with a current as low as 0.15 ampere. These current amounts, and their effects, depend on many variables. How moist is your skin? How well connected to the circuit are you? What path must the current take through your body? How much voltage is present?

SAFETY

It is vital that you become aware of electrical safety practices and observe caution when working around electrical circuits. By learning about some general electrical safety concerns, and by using some forethought, you will be able to safely perform work on electrical circuits not only for you but for your coworkers as well.

Electrical safety must be everyone's concern. Whether the electrician, operator, or supervisor, all must take responsibility for electrical safety. Most facilities have extensive and specific rules regarding electrical safety. You should follow the rules and procedures at your facility to the letter. If you are unclear or uncertain about the nature or application of any of your facility's procedures, you should not hesitate to discuss the matter with your supervisor immediately.

General Electrical Safety Precautions

The following is a list of general safety precautions that should be observed during work on or around electricity.

- All electrical equipment (motors, generators, pumps, control equipment, conductors, etc.) must be installed so that all energized parts are properly insulated or adequately guarded.
- An adequate clear workspace must be maintained around all energized equipment. This workspace is necessary for the inspection, repair, or replacement of the electrical equipment.
- Ensure that all conductors are adequately protected by cable trays, conduit, or metal-sheathed cable as per the policies and procedures at your facility.
- Identify all circuit conductors, disconnects, switchgear, and so on with clear identification tags.
- Ensure that all electrical drawings are kept up to date and are accurate.
- Replace all permanent equipment guards that have been removed or damaged.
- Maintain good housekeeping practices before, during, and after any work performed.
- Always follow your facility's policies and procedures and/or the *National Electrical Code.*

SAFETY

Lockout/Tagout

You may think of an electrician when you hear the term *lockout*, but this safety rule should also apply to all maintenance personnel. Every facility should issue all maintenance personnel a lockout with an identification tag on it. However, there are some facilities that do not do this. The purpose of the lockout procedure is to prevent injury or death by removing all hazardous energies that are present on a machine before any repairs are performed.

FIGURE 1-2 Multi-lock lock-out hasp.

An **electrical lockout** is accomplished by turning off the main disconnect that supplies power to the machine and locking the handle of the disconnect in the off position so that it cannot be turned back on until all lockouts are removed. This action removes two safety hazards. First, if the machine is locked out, there should be no electricity on the machine, thus preventing injury by electric shock. Second, removing the control voltage prevents the machine from being accidentally started while you or your hands are inside the machine. Disconnects are not all that can be locked out. Circuit breakers and valves can also be locked out once they are placed in a safe position. All maintenance personnel who are working on a machine need to place their lockout, with an identification tag, on the disconnecting means of the hazardous energy. Using multi-lock hasps allows room for everyone to attach their personal lock on the disconnecting means. See Figure 1-2. Before any work is to be started on a machine that has been locked out, make sure the machine is clear of personnel, and verify that all energies have been isolated. Bleed off any stored energies or pressures (they could be hydraulic, pneumatic, or capacitive), and press all start buttons.

SAFETY

A **voltmeter** must be used to verify the absence of electricity. If there is verification that all energies have been isolated and removed, then all repairs may begin. Make sure that you are the only person who removes your lockout. The only other person who has the authority to remove a lockout, besides you, is the plant engineer. However, they can remove your lockout only in the case of an

FIGURE 1-3 Tag used for the tag-out procedure.

emergency or if you are not on company grounds, and your immediate supervisor is present at the lockout when it is removed. The purpose of your supervisor being present is to verify your absence. Most lockout locks come with only one key, and most employers are extremely strict concerning the losing of a lockout key. It is not uncommon to have a zero tolerance policy concerning the violation of their lockout/tagout policies. If a key is lost, it typically means that you have lost your job. At no time should a lockout be cut off unless the key is lost and both you and your supervisor are present. Lockout procedures are very strict for your safety. There are strict OSHA regulations that must be followed when using the lockout procedure. For this information, see the safety officer in your facility.

Tagout is simply the placement of a tag on an energy isolation device. This tag is a prominent warning to others of your presence on the machine. See Figure 1-3. *The tagout does not lock out the energy isolation device*; it just warns of your presence on the machine. Anyone seeing a tagout should investigate to find the location of the person who tagged out the machine before starting the machine. Figure 1-4 shows a typical lockout cabinet. The devices in the cabinet can be used to lock out all the various types of energy that may injure personnel.

The Buddy System

Whenever possible, the buddy system should be used. This simply means that maintenance personnel need to work in pairs. If something were to go wrong and you were injured, your buddy, or partner, could go get help. Normally, this is not

FIGURE 1-4 Lock-out cabinet.

a problem on first shifts because there are usually more maintenance personnel on the first shift, allowing the formation of teams or crews. However, some facilities use a skeleton crew on the off shifts. This simply means that the maintenance department uses as few personnel as possible for maintenance on the second and third shifts. In this case, it is possible for only one or two maintenance people to be on duty during these off shifts. If you are one of these individuals, upon receiving a work request, it is important to notify somebody of your destination and the approximate time of your return. Once notified, they would know where to look for you if an extended period of time were to elapse with no contact from you.

All personnel who work alone should have a two-way radio in their possession in the case of an emergency. The other radio should be in the possession of someone who can help if the maintenance personnel should call because of an emergency.

All facilities should have no fewer than two maintenance personnel on every shift. If an accident were to happen, there would be an immediate response. This is important because when someone is injured, seconds may make the difference between life and death!

SAFETY

ARC FLASH RISK ASSESSMENT

Whenever an electrical **current** flows or jumps through the air, from one conductive material to another, an electrical **arc** occurs. If the current is small, the arc may produce minimal or no ill effects. However, currents typically found in manufacturing and power generation can produce devastating arcs. These arcs are accompanied by **arc flashes** and **arc blasts**.

An arc flash is an explosive flash of light that occurs when high currents arc, through the air, between conductive materials. When this occurs, the air is rapidly heated. If the heating is rapid and high enough (up to 35,000°F), an arc blast occurs. The intense, white-hot flash of light can cause temporary or permanent blindness. Metal components may break up and/or vaporize resulting in flying debris of chunks of molten metal, which can cause physical harm to nearby personnel. The intense heat can produce life-threatening or deadly burns to individuals in the vicinity. This heat also causes the surrounding air to rapidly expand with an explosive force of thousands of pounds per square inch. This is violent enough to knock nearby workers off their feet as well as cause damage to their ears, lungs, brain, and/or other internal organs. There are tens of thousands of arc flash incidents every year. This results in thousands of burns and hospitalizations with hundreds of fatalities each year.

Being aware of the hazards associated with working with electricity is vital; it should be obvious that these hazards need to be recognized and policies and procedures are put into place to reduce or eliminate the mechanisms that could improve workplace safety, both personal and environmental. One such procedure is an **Arc Flash Risk Assessment**.

This is a good time to explain the difference between a hazard and a **risk**. A hazard is the source of potential injury or damage. According to Safeopedia.com, "[A]hazard is any object, situation, or behavior that has the potential to cause injury, ill health, or damage to property or the environment." Safeopedia.com also identifies different types of hazards. They are as follows:

- Physical Hazards: These are the most common hazards and they include extremes of temperature, ionizing or non-ionizing radiation, excessive noise, electrical exposure, working from heights, and unguarded machinery.
- Mechanical Hazards: These are usually created by machinery, often with protruding and moving parts.
- Chemical Hazards: These appear when a worker is exposed to chemicals in the workplace. Some are safer than others, but for workers who are more sensitive to chemicals, even common solutions can cause illness, skin irritation, or breathing problems.
- Biological Hazards: These include the viruses, bacteria, fungus, parasites, and any living organism that can infect or transmit diseases to human beings.
- Ergonomic Hazards: Including considerations of the total physiological demands of the job upon the worker, even beyond productivity, health, and safety.
- Psychosocial Hazards: These may arise from a variety of psychosocial factors that workers may find to be unsatisfactory, frustrating, or demoralizing.

Risk, on the other hand, is the likelihood and severity of the injury. Safeopedia.com's definition of risk is, " . . . the probability and severity of a specific action or inaction that is expected or anticipated to occur. Examples of the various degrees of probability include frequent, likely, occasional, seldom or unlikely. Examples of severity can include catastrophic, critical, marginal, or negligible. Activities that are considered to be both frequent and catastrophic would be considered extremely high risk, while activities that are both unlikely and negligible would be considered low risk."

An Arc Flash Risk Assessment identifies hazards and risks within the work area. A detailed Arc Flash Risk Assessment is beyond the scope of this text. You should refer to NFPA 70E and obtain additional training to ensure that the assessment is done properly and accurately. In a nutshell, there are three fundamental steps to complete the assessment. They are as follows:

1. Identify the hazards.
   a. What potential risks exist while performing the work?
2. Assess the risk.
   a. Estimate the probability of occurrence.
   b. Estimate the severity of potential injuries.
3. Develop the required work protocols.
   a. Remove hazard.
   b. Replace a hazard with a less hazardous one.
   c. Replace/modify equipment/work area to isolate workers from the hazard.
   d. Educate and train workers in hazard/risk identification and safe decision-making.
   e. Identify the required PPE, both employer supplied and employee supplied.
   f. Develop and produce the required documentation/manuals of the formal processes and procedures to be followed in order to work safely in and around the expected conditions.

SAFETY

HAZARDOUS MATERIALS

A hazardous material is a material that exhibits one or more of the following properties:

- Flammability
- Explosiveness
- Toxicity
- Ability to oxidize
- Reacts with air or water to become one of the hazards mentioned earlier

Hazardous materials can cause significant adverse effects to the environment or humans. Interaction with these materials can lead to significant injury, illness, or property damage.

Organizations

There are many codes and charts that are required for hazardous materials and the areas in which they are stored. There are many laws, regulations, and codes that must be adhered to when using or working around hazardous materials. To better understand these laws, regulations, and codes, one must know about the organizations that develop these codes and standards to ensure a safe working environment. These organizations are represented by abbreviations such as OSHA, **NIOSH**, **UL®**, NFPA, **ANSI**, and **NEMA**.

CAUTION

OSHA, on occasion, visits a facility to give periodic inspections and safety audits. OSHA is a safety enforcement organization. As the name implies, OSHA is concerned about the occupational safety and health of all people. For this reason, they have instituted many laws and regulations that must be followed to ensure a safe working environment. OSHA has many training programs available. Most businesses recognize the need for a safety and health program. A good facility that cares about the safety of its employees will institute these safety programs into a regular agenda, thus heightening awareness throughout the facility of many safety issues that otherwise might go unnoticed. If an accident occurs at your facility, the first thing OSHA will ask for is a copy of the safety and health program. If these documents cannot be provided upon request, a hefty fine may result.

The National Institute for Occupational Safety and Health (NIOSH) is an organization that works with OSHA to develop and revise the recommended exposure limits for hazardous materials and conditions that may be found in the working environment. NIOSH also concentrates on researching and making recommendations for preventive measures that must be taken to counteract the adverse health effects of hazardous materials and the locations in which they are stored before a serious accident occurs. NIOSH, however, is primarily concerned with research, whereas OSHA is the organization that is responsible for the enforcement of these laws and standards.

Underwriters Laboratories Inc. (UL®) is an organization that tests equipment and products. These equipment and products must meet or exceed the minimum standards that are specified in national codes and standards. UL® is an independent company that works under contract with many manufacturers to ensure the conformity of their product to the national standards. Any equipment that has been tested by UL® and passed the required standards has the UL® label on it somewhere.

The NFPA is most commonly known for its many publications that are used and adopted as law to be enforced by local authorities having jurisdiction. Some of these publications are NFPA 70, NFPA 5000, NFPA 72, and NFPA 704.

NFPA 70 is better known as the *National Electrical Code*® (*NEC*®). The *NEC*® is a publication that is revised every 3 years and is usually adopted by local and/or state governments into law for local authorities to enforce. It gives strict guidelines for electrical installations. The sole purpose for this publication, as stated in *Article 90.1*(A) is," . . . the practical safeguarding of persons and property from hazards arising from the use of electricity."

NFPA 5000 is the NFPA Building Code. The goal of the NFPA in writing this publication is to have the best scientifically based codes and standards possible, developed in a fully open consensus process. The NFPA has been advised by adopting authorities that they want to adopt a full and coordinated set of codes for building safe and structurally sound buildings.

NFPA 72 is the National Fire Alarm Code. NFPA 72 sets minimum requirements for fire alarm systems, household fire warning equipment, protected premises fire alarm systems, systems with a supervising station (a facility that receives signals and is always staffed to respond), initiating devices (such as heat detectors, smoke detectors, radiant energy detectors, and fire-gas detectors), and audible and visible notification devices. NFPA 72 also covers inspection, testing, and maintenance of fire alarm systems.

NFPA 704 is the standard system for the identification of the hazards of materials for emergency response. The NFPA 704 standard provides a readily recognized and easily understood system for identifying specific hazards and their severity, using spatial, visual, and numerical methods to describe in simple terms the relative hazards of a material.

Identification

The NFPA 704 standard system can be seen in Figure 1-5. It addresses the health, flammability, instability, and related hazards that may be present as short-term, acute exposures that are most likely to occur as a result of fire, spill, or similar emergency. There are three main objectives for this system: (1) to provide an appropriate signal or alert for the protection of both public and private emergency response personnel; (2) to assist in planning for effective fire and emergency control operations, including cleanup; and (3) to assist all personnel in evaluating the hazards of a known hazardous material.

CAUTION

The symbol in Figure 1-5 is a diamond shape. It, in turn, has four smaller diamond shapes within it. Each of these smaller diamonds is a different color. To the lower right of the red diamond, there is a yellow diamond. At the bottom, there is a white diamond, and a blue diamond resides to the far left, just below the red diamond. Each colored diamond identifies the different hazards of a hazardous material. These are the flammability hazards, instability or reactivity hazards, the degree of health impact, and any special hazards that may arise during the use of the material. The red diamond represents the flammability, the yellow diamond represents the reactivity or susceptibility to the release of energy (instability), the white diamond represents the specific hazard, and the blue diamond represents the severity of health hazards or possible injury that may arise from handling the hazardous material. With the red, yellow, and blue diamonds, a hazard severity is identified by a numerical rating system that ranges from zero (0) to four (4), four being the most severe.

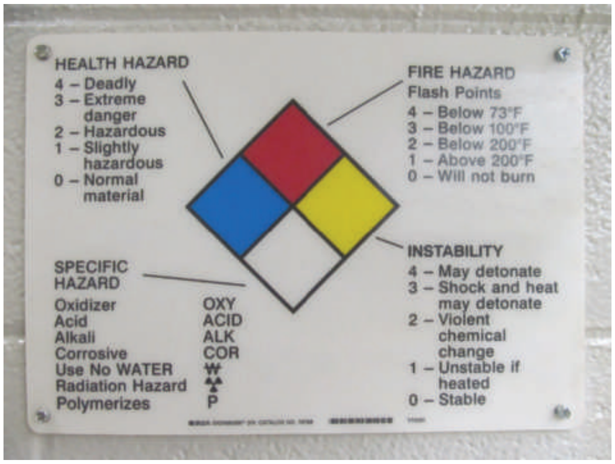

FIGURE 1-5 NFPA Standard 704.

In the red diamond (Flammability), a zero (0) severity indicates that the material does not burn. If there is a one (1) in the red diamond, then the material has a flash point above 200°F (93°C). If there is a two (2), the material has a flash point below 200°F (93°C) but above 100°F (38°C). If there is a three (3) present, the flash point is below 100°F (38°C) but above 73°F (23°C). A four (4) indicates that the material has a flash point below 73°F (23°C). A material with a four (4) for flammability has to be kept in a cool environment.

In the yellow diamond (Reactivity or Instability), a zero (0) severity indicates that the material is stable. If there is a one (1) in the yellow diamond, then the material is found to be unstable if heated. If there is a two (2) present, the material may have a violent chemical change at elevated temperatures and pressures, react violently with water, or form explosive mixtures with water. If there is a three (3) present, shock or heat may cause the material to detonate. A four (4) indicates that the material is very unstable and is capable of detonating itself or has an explosive decomposition or reaction at normal temperatures.

In the blue diamond (Health), a zero (0) severity indicates that the material, on exposure to fire conditions, would offer no hazard beyond that of ordinary combustible material. If there is a one (1) in the blue diamond, then the material is considered slightly hazardous, meaning that if exposed to this material irritation or minor residual injury may occur. If there is a two (2), the material is considered to be hazardous and intense or continued but not chronic; exposure could cause temporary incapacitation or possible residual injury. If there is a three (3) present, an extreme danger exists. Short exposure could cause serious temporary or residual injury. A four (4) indicates that the material is deadly and that even a very short exposure to this material could cause death or major residual injury.

The white diamond (Special) is a little different in that it does not use a numerical system as the other diamonds do. The purpose of this diamond is to list any specific hazards that may exist with a

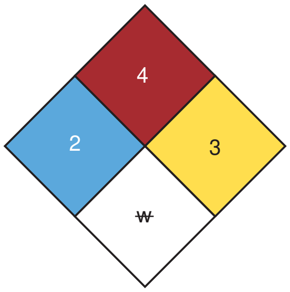

FIGURE 1-6 This symbol indicates that a material is reactive to water.

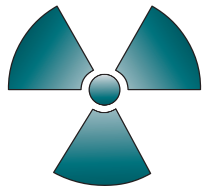

FIGURE 1-8 Symbol indicating a radiation hazard.

particular material. For example, if a material were to react unusually to water, as does magnesium, then a *W* with a slash across the center, as seen in Figure 1-6, would be seen in the white diamond, indicating that it would not be desirable to put water on this material. This information is helpful in the case of a fire. The addition of water to this type of hazardous material, in the event of a fire, only worsens the fire and could cause an explosion. Figure 1-7 shows an example of the NFPA Standards Hazard Identification System on a fence surrounding a gas processing plant. Notice that the fire hazard is rated at four (4), which means that the flash point is below 73°F (23°C); the Health Hazard is a three (3), which indicates Extreme Danger; the Instability is rated at three (3), which conveys that shock and heat may cause detonation; and the Specific Hazard is an Oxidizer.

Another specific hazard and its code that might be seen in the white diamond is OX, identifying an oxidizer. If a material were acidic, the white diamond would contain the word *ACID*. An ALK identifies an alkaline material. Corrosive materials are identified by COR, and finally, a material that has a radiation hazard is identified by the recognizable trefoil symbol that is shown in Figure 1-8. It is important to note that the name of the chemical or material will be either above or below the NFPA 704 standard symbol.

FIGURE 1-7 Example of NFPA Standard 704 hazard identification system in use.

The Hazardous Material Information Guide

The **Hazardous Material Information Guide (HMIG)**, which can be seen in Figure 1-9, has the same information as the NFPA 704 standard with one exception; the white section contains the necessary PPE that should be worn when handling the hazardous material instead of the special hazards that were listed for the NFPA 704 standard. A list of PPE ranges from *A* to *K* and includes a letter *X*. This index can be seen in Figure 1-10.

The Material Safety Data Sheet

OSHA Standard 29 CRF 1910.1200 is the regulation that states that any chemical mixture that is made by a manufacturer must have a **Material Safety Data Sheet (MSDS)** written for that particular chemical. An example of an MSDS is shown in Figure 1-11.

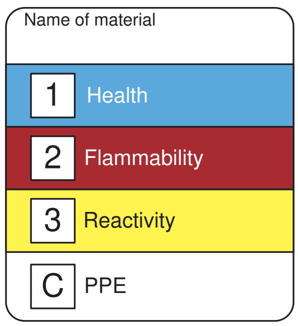

FIGURE 1-9 Hazardous Material Information Guide (HMIG).

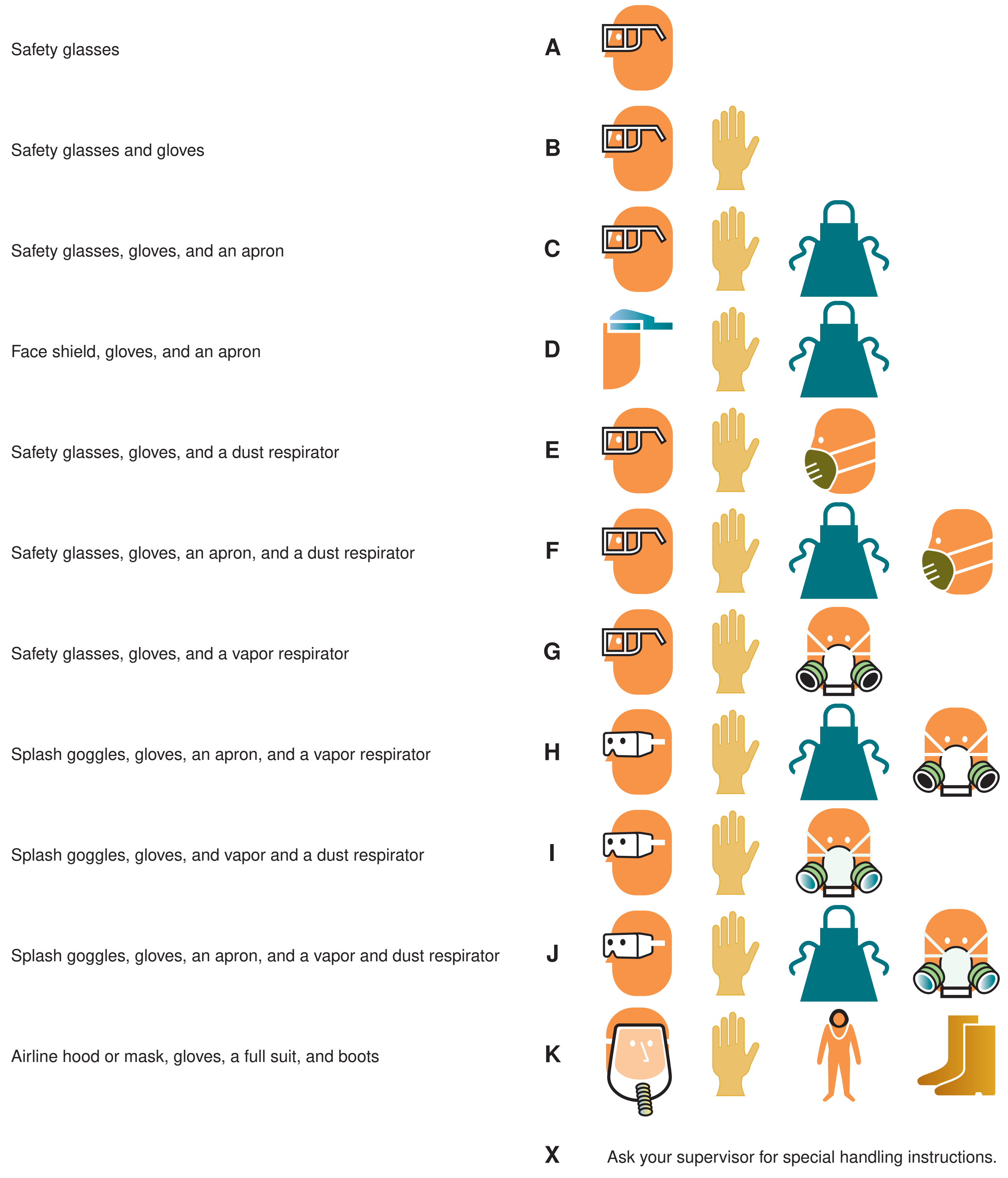

FIGURE 1-10 Recommended personal protective equipment (PPE) in the HMIG.

Standard 29 CRF 1910.1200 has a very specific purpose that is to ensure that the hazards of all chemicals produced or imported are evaluated and that information concerning their hazards is transmitted to employers and employees. This transmittal of information is to be accomplished by means of comprehensive hazard communication programs, which are to include container labeling and other forms of warning, MSDSs, and employee training. This is stated in Section (a)(1) of the standard.

Section (b)(1) of the standard requires chemical manufacturers or importers to assess the hazards of

MATERIAL SAFETY DATA SHEET
Date of Preparation – January 2000

SECTION I—PRODUCT IDENTITY

IDENTITY—	ACME A-1 Citrus Cleaner	
PART #—	8832456	
Manufacturer's Name—	ACME Quality Product 1234 Main Street Hometown, USA 00000-0000	Emergency Phone (800)-555-1234 Information Phone (800)-555-4321
HMIS CODES—	HEALTH – 2 FLAMMABILITY – 4 REACTIVITY – 0 SPECIAL – 0	

SECTION II—HAZARDOUS INGREDIENTS

INGREDIENT	CAS#	OSHA PEL	ACGIH TLV	STEL	%
Propane	74-98-6	1000PPM	2500PPM	760PPM	<5
Isobutane	78-28-5	N/A	N/A		<5
Ethyl Acetate	141–78-6	400PPM	400PPM		<5
Aliphatic vs Hydrocarbons	8052–41-3	100PPM	100PPM		<70

SECTION III — PHYSICAL DATA

PRODUCT WEIGHT—	6.39 lb/gal	765 g/l
SPECIFIC GRAVITY—	0.77	
BOILING POINT—	<0–412 F	<-18–211 C
MELTING POINT—	N/A	
VOLATILE VOLUME—	97%	
EVAPORATE RATE—	Slower than Ether	
VAPOR DENSITY—	Heavier than air	
VAPOR PRESSURE PSIG—	@70 F: 80–90	
SOLUBILITY IN WATER—	Slight	

SECTION IV—FIRE AND EXPLOSION HAZARD DATA

FLASH POINT— –156 F
EXTINGUISHING MEDIA— Carbon dioxide, Dry chemical, Foam, Water
UNUSUAL FIRE AND EXPLOSION HAZARDS
Store away from excessive heat. Do not use in the vicinity of an open flame or sparks. Do not use on surfaces that are hot. Over exposure may cause health hazard. Obtain medical attention if overexposure occurs.
SPECIAL FIRE FIGHTING PROCEDURES
Fire fighters should wear NIOSH approved positive pressure self-contained breathing apparatus. Aerosol containers may burst when heated.

SECTION V—REACTIVITY DATA

STABILITY—Stable
CONDITIONS TO AVOID—All sources of ignition.
INCOMPATIBILITY—None known.
HAZARDOUS DECOMPOSITION BYPRODUCTS—Carbon Dioxide, Carbon Monoxide
HAZARDOUS POLYMERIZATION—Will not occur.

MATERIAL SAFETY DATA SHEET
(continued)

SECTION VI—HEALTH HAZARD DATA

ROUTES OF ENTRY—Inhalation, skin absorption, indigestion
HEALTH HAZARDS (Acute and Chronic)—(ACUTE) Irritation of the skin, eyes, or respiratory system. May cause nervous system depression. Extreme overexposure may result in unconsciousness and possibly death.
(CHRONIC) This product contains no known carcinogen. Overexposure can cause permanent brain and nervous system damage.
SIGNS OF OVEREXPOSURE—
SKIN: Redness
INHALATION: Difficulty in breathing
INDIGESTION: Vomiting
Overexposure may also cause dizziness and loss of concentration.
EMERGENCY FIRST AID PROCEDURES:
SKIN—Wash affected area thoroughly with soap and water. Remove contaminated clothing and launder before reuse.
INHALATION—Remove from exposure into fresh air environment. Restore breathing.
INGESTION—Do NOT induce vomiting. Get medical attention immediately.
EYES—Flush eyes thoroughly with large amounts of water for 15 minutes. Get medical attention immediately.

SECTION VII—PRECAUTIONS FOR SAFE HANDLING AND USE

STEPS TO BE TAKEN IN CASE MATERIAL IS RELEASED OR SPILLED—Remove all sources of ignition. Ventilate and remove with inert absorbent.
WASTE DISPOSAL METHOD—Waste may be hazardous and should be tested for ignitability prior to discarding. Do not incinerate. Always depressurize container. Dispose of in accordance with Federal, State, and Local regulations.
PRECAUTIONS TO BE TAKEN WHEN HANDLING OR STORING—Keep away from any source of ignition. Gloves and safety spectacles with side shields should be worn when handling this product. Provide proper ventilation in the place of storage.

SECTION VIII—CONTROL MEASURES

RESPIRATORY PROTECTION—Self-Contained Breathing Apparatus if the above TLV limits are exceeded.
VENTILATION—Local exhaust.
MECHANICAL—None
OTHER PRECAUTIONS—Intentional misuse by deliberately concentrating and inhaling the contents can be harmful or fatal.

PROTECTIVE CLOTHING—Gloves and safety spectacles with side shields. No other protective clothing is required.

WORK/HYGIENIC PRACTICES—Do not use while smoking. Wash hands after use. Avoid breathing of vapors. Keep out of reach of children. Consult your physician if you have a medical condition prior to use.

FIGURE 1-11 An example of a Material Safety Data Sheet (MSDS).

chemicals that they produce or import and requires all employers to provide information to their employees about the hazardous chemicals to which they are exposed. This is accomplished by means of a hazard communication program, labels, and other forms of warning, MSDSs, and information and training. In addition, this section requires distributors to transmit the required information to employers.

The name of the chemical must be listed at the top of the MSDS. Each MSDS has eight sections following the name of the chemical, all listed in roman numerals, thus providing all the necessary information that is required in the 29 CRF 1910.1200 standard. Each section is listed as follows, along with the information that should be found in that section.

- Section I gives the name of the manufacturer, the address, and a telephone number for information. This section also contains the date that the MSDS was prepared.
- Section II contains the Hazard Ingredients/Identity Information. This is where all hazardous components and specific chemical identities are listed.
- Section III contains the Physical/Chemical Characteristics. This includes such information as the boiling point, melting point, specific gravity, appearance, color, and solubility in water.
- Section IV gives the Fire and Explosion Hazard Data. This is where the flash point can be found as well as the extinguishing media. Also, any special firefighting procedures are listed. Any unusual fire and explosion hazards that may exist are also listed here.
- Section V has the Reactivity Data. Stability, instability, certain conditions to avoid, material incompatibility, or any hazardous decomposition or components and specific chemical identities are listed. Also, any byproducts that may be produced will be listed in this section.
- Section VI contains the Health Hazard Data. Exposure limits, carcinogenicity, signs and symptoms of exposure, and emergency and first aid procedures are listed here.
- Section VII contains the Precautions for Safe Handling and Use. This lists the steps to be taken in the event of a spill or release, the proper method of disposal, all precautions that need to be considered in handling and storage, or any other precautions that may exist.
- Section VIII lists the Control Measures, which includes respiratory equipment, ventilation, and required PPE.
- Section IX is used for any Additional Comments that a manufacturer may have about its product.

FIGURE 1-12 MSDS Data Sheet Compliance Center.

Figure 1-12 shows a compliance center that contains all the MSDSs for all hazardous products that are used in that department.

SAFETY

Fire Safety

All industrial applications have some risk of fire. For this reason, it is important to know the components that are necessary for a fire to exist, the different classes of fire, and the proper procedure for quenching each. It is important to know this information before an event occurs. Trying to learn this information after a fire has started could cost someone their life. It is important to always stay prepared and stay calm in the case of an emergency. Staying calm is difficult to do if you are not trained and prepared.

For a fire to exist, three components must be present: fuel, heat, and oxygen. If only two of these components exist, there can be no fire. To extinguish a fire that has already started, just remove one of the three elements, and the fire will cease to exist.

SAFETY

Many industrial facilities maintain an emergency response or first responder team that is made up of employees who are working in the maintenance department. As a maintenance employee, you will most likely be asked to put out a fire as the need may arise. Keep in mind, however, that, in the event of a fire, the local fire department should be notified as soon as possible. The facility's emergency response team should be trained to put out fires, but they usually are not going to be trained to the level of a professional firefighter. The object of the emergency response or the first responder team is to extinguish the flame, if possible, or to contain the flame and prevent it from spreading in the event of a larger fire. It should also be the responsibility of the emergency response or first responder team to ensure the safety and proper evacuation of all nonessential personnel from the area in which the fire is being fought. Every employee who is working in an industrial environment must know the location of the nearest fire alarm and fire extinguisher and the class of each fire extinguisher. Often, a fire can be extinguished quickly if someone can get an extinguisher to the site quickly. When an extinguisher cannot be located, a fire can rapidly get out of control.

Fire Classifications

The combustible material classifies the fire; it is also the fuel of the fire. There are four classifications: Class A, Class B, Class C, and Class D. Class A fires are fires that burn ordinary combustibles such as wood, paper, cloth, upholstery, trash, some plastics, or any other carbon-based solid materials that are not metals. There is a pictograph that represents a Class A fire. A Class A classification may also be represented by a green triangle with a capital letter *A* in it. Both the pictograph and the triangle can be seen in Figure 1-13.

FIGURE 1-13 Fire classification symbols.

Class B fires are fires that burn flammable liquids or gases such as gasoline, oil, grease paints and thinners, propane, acetone, grease, or any other similar gas or liquid that is in a nonmetal state. The pictograph that represents a Class B fire can be seen in Figure 1-13. A Class B classification may also be represented by a red square with a capital letter *B* in it.

A Class C fire is a fire that burns on any electrical or electrically energized equipment. An example would be an electric motor, a drive cabinet, a junction box, or even an appliance. If the electrical equipment that is burning is not electrically energized, it would be considered a Class A or Class B fire; however, it is important to consider all electrical equipment to be electrically energized and use a Class C fire extinguisher. Most industrial machines have a main disconnect. This is the point at which the machine can be totally removed from its electrical energy source. It is important to remember, if a Class C fire does exist, to pull the main disconnect handle to the off position. Keep in mind, however, that there may be some remaining stored electrical energy in some electrical equipment as you fight the fire. For this reason, it is always important to consider all electrical equipment energized. As with the others, there is a pictograph that represents a Class C fire, which can be seen in Figure 1-13. A blue circle with a capital letter *C* in it may also represent a Class C classification.

A Class D fire is a fire that burns combustible metals, such as magnesium, potassium, powdered aluminum, zinc, sodium, or titanium. Because most combustible metals are highly volatile to water in a high-heat environment, a special dry-powder extinguishing agent or a foam extinguisher is used on this class of fire. A Class D fire is represented by a yellow star containing a capital letter *D*, as seen in Figure 1-13.

Responding to a Fire

Here is a suggested list of the procedures that should be followed in the event of a fire.

- Locate and activate the nearest fire alarm. If no fire alarm is in the immediate area, then yell the word *FIRE* as loudly as possible to get the attention of a coworker or a supervisor.
- Make certain that a call to 911 is placed. It is most important to notify the local fire department of the fire.
- Make sure that the facility's emergency response or first responder team is notified.
- Move all nonessential personnel to a safe location.
- De-energize all electrical sources that are in the immediate vicinity of the fire, if possible.
- Quickly identify the class of the fire, and retrieve the appropriate extinguisher.

- Always make sure that you have an escape route as you are trying to extinguish the fire.
- Use the extinguisher properly to achieve the maximum firefighting capability of the extinguisher. Try to use the P.A.S.S. method.
  - Pull the pin.
  - Aim at the base of the fire.
  - Squeeze the handle or trigger. (Be prepared; some extinguishers are extremely loud when the extinguishing agent is released.)
  - Sweep the extinguisher from side to side as it is used.
- Continue to fight the fire as long as possible, preventing any spreading until the local firefighters arrive.
- If you extinguish the fire, keep a watchful eye until the fire department arrives to ensure that it does not flare up again.
- If a fire becomes too large and gets to a point where it is out of control before the fire department's arrival, evacuate the facility and move to a safe area.

Remember, the safety of all personnel is what is important. These standards exist and are adopted for everyone's safety. If a safety violation is noticed, report it as soon as possible to avoid any unnecessary injury. Safety is everyone's job! Take it seriously.

SAFETY

CAUTION

PERSONAL PROTECTIVE EQUIPMENT

PPE is an integral part of any safety program. In fact, after all the standards, policies, procedures, and protocols are put in place, PPE provides the most intimate safety protection for an individual. PPE literally covers the individual from head to toe. Before learning about PPE, however, let's focus on an individual's general appearance.

SAFETY

Appearance

There are certain aspects about your appearance that you may not give any thought to when it comes to safety. However, certain items need to be seriously considered and dealt with in order to prevent accidents from occurring.

Hair

If you have long hair and are working around machinery, be aware of the danger long hair can present. Some people who have long hair have been pulled into machinery or equipment by their hair. Their hair becomes wrapped around a rotating part, and the powerful machine either tears the hair (along with some of the scalp) from the victim's head or continues to pull the victim into the machine, causing serious injury or death. There is absolutely nothing wrong with having long hair and working around machinery—just be smart about it. Tuck long hair under a hat or inside your shirt, or wear a hair net. This prevents an accident from occurring. Some facilities mandate that a hair net be worn.

CAUTION

Jewelry

Jewelry is another safety issue. Rings can get caught on a moving piece of equipment and cause the loss of a finger. Be sure to remove rings before starting any work. Long necklaces are also dangerous. As you lean over a moving part of a machine, it may get caught in the machine. Be careful with bracelets as well. Be aware of these dangers if jewelry is worn. A safety-conscious person would not wear jewelry in this environment.

CAUTION

Clothing

Long-sleeved shirts should be worn with the sleeves rolled down and buttoned. A long-tailed shirt should be tucked into the pants, and the pants should not be too large for the person who is wearing them. Clothing should be loose enough to be comfortable and nonrestrictive but not baggy so as to risk getting caught in machinery.

An apron, a jumpsuit, or a Tyvek™ suit may have to be worn to protect the clothing from chemicals or grease. Sometimes protective suits are worn to cover everything except the hands and the head. Finally, an entire ensemble may have to be worn, protecting everything, including the hands and head. For information on the type of apparel that must be worn in a particular situation, see your safety officer.

PPE—Arc Flash Category Clothing

NFPA 70E Table 130.7(C)(15)(c) identifies PPE for the various arc flash categories. As per the table, there are four categories—1 through 4. Category 1 requires arc-rated clothing with a minimum rating of 4 cal/cm^2 (16.75 J/cm^2). For Category 2, the rating is increased to a minimum of 8 cal/cm^2 (33.5 J/cm^2). Category 3 requires a minimum rating of 25 cal/cm^2 (104.7 J/cm^2). Finally, Category 4 requires a minimum rating of 40 cal/cm^2 (167.5 J/cm^2).

It should be noted that Categories 1 and 2 also specify specific PPE to be worn. They are arc-rated long-sleeve shirt and pants or arc-rated coveralls, an arc-rated face shield or arc-flash suit hood (Category 2 requires an arc-rated flash suit hood or arc-rated face shield and arc-rated balaclava), and an arc-rated jacket, parka, rainwear, or hard hat liner. In addition, a hard hat, safety glasses or safety goggles, hearing protection (ear canal inserts), heavy-duty leather gloves, and leather footwear must be worn.

Categories 3 and 4 likewise specify the PPE; however, these two categories view the PPE as a system, not individual items. The system consists of arc-rated long-sleeve shirt, arc-rated pants, arc-rated coveralls, arc-rated flash suit jacket, arc-rated flash suit pants, arc-rated flash suit hood, arc-rated gloves, and arc-rated jacket, parka, rainwear, or hard hat liner. In addition, a hard hat, safety glasses or safety goggles, hearing protection (ear canal inserts), and leather footwear must be worn. Figure 1-14 shows an electrician wearing a Category 4 arc-rated suit. Note the hood, tinted face shield, and gloves.

FIGURE 1-14 Category 4 arc-rated suit.
Nutthapat Matphongtavorn/Shutterstock.com

Many facilities have adopted a two-category approach to the arc flash clothing requirements. By following the requirements of Category 2 and Category 4, the facility can meet, and exceed, the requirements of Categories 1 and 3. This simplifies the identification and selection process, lowers cost, and maintains the required level of protection for all categories.

PPE—Head Protection

You have probably heard of hard hats, but what is the story behind the hard hat? According to the E. D. Bullard website (bullard.com/history-of-the-hard-hat),

> Established in San Francisco in 1898, Bullard sold carbide lamps and mining equipment to gold and copper miners. “The miners used to wear a soft derby, similar to a baseball cap. It had a small, hard-leather and shellac brim,” said Edward D. “Jed” Bullard, Chairman of the Board and former President and CEO.
>
> In 1915, my grandfather began work on a helmet that could protect miners from falling objects. He based it on the doughboy, a helmet he’d worn as a soldier in World War I. The ‘Hard Boiled® Hat’, patented in 1919, was so called because of the steam used in the manufacturing process,” said Bullard.
>
> “The original ‘Hard Boiled® hat’ was manufactured out of steamed canvas, glue, a leather brim, and black paint. My grandfather built a suspension device into what became the worlds’ first, commercially available, industrial head-protection device.”

Hard hats protect your head from falling objects. Hard hats also protect your head should you accidentally hit your head against an object. This can happen when someone is climbing or is being lifted into an area that has pipes and ductwork overhead. Sometimes it becomes difficult to see what is above or behind your head that might cause injury. The hard hat protects against these accidental instances.

Wearing the hard hat improperly is as bad as not wearing one at all. A hard hat must be worn according to each manufacturer’s specification. How do you wear a hard hat improperly? Wearing a hard hat on the back of your head with the bill facing toward the back of your feet, as shown in Figure 1-15A, offers very little or no protection to the forehead. Wear the hard hat properly to offer the most protection possible, as shown in Figure 1-15B.

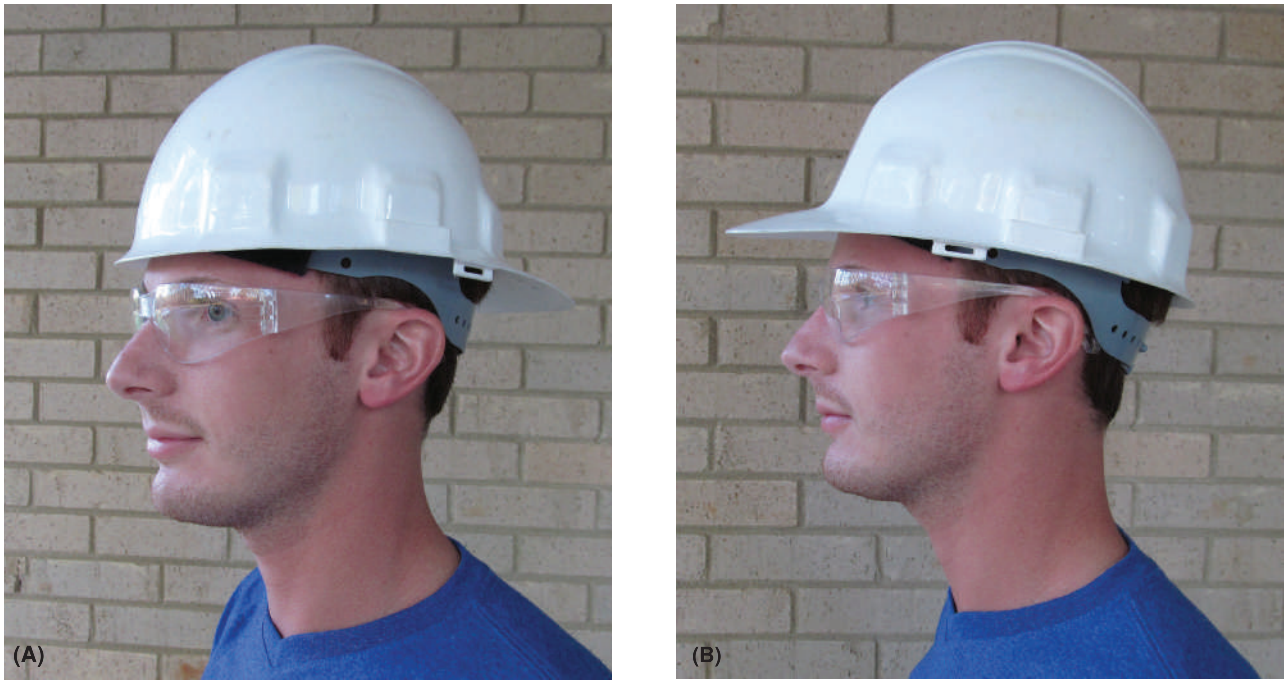

FIGURE 1-15 (A) Improper way to wear a hard hat. (B) Proper way to wear a hard hat. Also notice the safety glasses.

PPE—Eye Protection

Sight is one of the most valuable senses that we have. Many maintenance personnel have lost their vision because of carelessness and/or laziness. Carelessness is not wearing eyewear (safety glasses) when the situation warrants protection. Laziness is not wearing safety glasses because they were left in the shop and it is too far to walk back. Most facilities require the continuous wearing of safety glasses while on company property. Injury can occur by a flying projectile, falling debris, a chemical that has been splashed, or a thousand other ways. An eye injury caused by any of those hazards takes only a fraction of a second to occur, and then it is too late. Protect your eyes *before* you start working by wearing the proper eye protection. Safety glasses can be seen in Figure 1-15. Make sure that your eyewear has side shields to protect the eyes from foreign objects that may enter from the side. If you are already wearing prescription glasses, you can add side shields to your glasses for added protection; the lenses, however, need to be rated for impact resistance. See Figure 1-16.

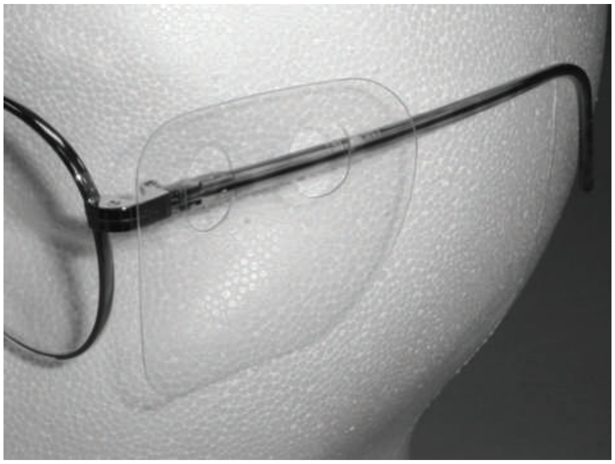

FIGURE 1-16 Disposable side-shields for prescription glasses.

PPE—Hearing Protection

Noise levels are measured in decibels (dB). Exposure to noise levels equal to or greater than 85 dB may cause hearing loss. That is why the NIOSH recommends that hearing protection devices (HPDs) be used whenever the noise level equals or exceeds 85 dB, regardless of the exposure time. To illustrate what 85 dB may sound like, here are some examples of common sounds that a person may be exposed to. A common hand drill runs at approximately 95 dB, an impact wrench is somewhere around 103 dB, a hammer drill operates at approximately 114 dB, and a 12-gauge shotgun fires at 165 dB. As you can see, it is not difficult to

FIGURE 1-17 In-ear canal ear plugs and dispenser.

FIGURE 1-18 Work gloves. Michael Smolkin/Shutterstock.com

be exposed to dangerous noise levels in our normal lives. In industry, there are many noisy machines and moving pieces of equipment. It is easy to see how people can lose their hearing if certain safety measures are not taken. Hearing loss can be prevented with the proper training and the use of HPDs. Dispensers may be mounted in strategic locations throughout the plant where hearing protection is required. These dispensers, as seen in Figure 1-17, contain inexpensive, disposable foam earplugs that can be squeezed and inserted into the ear canals, where they then expand, sealing out dangerous noise levels. Hearing is something that many people take for granted. It is too late to protect hearing once it is gone! Most facilities have mandated the use of HPDs. If your facility does not mandate the use of HPDs, take it upon yourself to preserve your hearing. Become a leader, and set an example for others to follow.

PPE—Hand Protection

Wearing work gloves is necessary to protect your hands from being burned or cut. Work gloves, as seen in Figure 1-18, give an added layer of protection that is needed when a rope slips through your hands, when something hot has to be moved, or when something that has very sharp edges has to be held. Work gloves should be worn whenever there is a threat of injury to the hands. Work gloves should fit comfortably. Do not wear work gloves that are too large or too tight. There are times when work gloves can become a safety hazard themselves. It is a good practice to step back and analyze each situation before you put the work gloves on. Work gloves should not be worn if the work glove, along with your hand, could be pulled into a machine or piece of equipment that is moving. Do not get in close proximity to any moving machinery or equipment if possible. By getting close to moving machinery, you have committed an unsafe act.

In addition to work gloves, electricians wear electrical insulating (rubber) gloves, as seen in Figure 1-19. These gloves come not only in different sizes but different voltage ratings as well. The gloves use a color-coded label to indicate the class and voltage rating for the glove. The color-code is as follows:

- 00—Beige 500 VAC/750 VDC
- 0—Red 1000 VAC/1500 VDC
- 1—White 7500 VAC/11,250 VDC
- 2—Yellow 17,000 VAC/25,500 VDC
- 3—Green 26,500 VAC/39,750 VDC
- 4—Orange 36,000 VAC/54,000 VDC

These gloves are usually constructed of two different colored layers of rubber. In this fashion, should an abrasion or a cut occur, the underlying color will be seen, indicating that the glove should be replaced. To protect the rubber glove, electricians will wear a leather glove, as seen in Figure 1-19, over the rubber glove. The leather glove is called a *leather outer*. Also, because the rubber glove may cause the hand to sweat, some electricians will also wear a thin, lightweight cotton glove on their hand, before putting on the rubber glove. You can imagine that this can make for very bulky and difficult handling of tools and equipment. With practice, you can perfect the techniques that work for you so that you can get the job done and done safely.

PPE—Foot Protection

Hard-toed boots should be used if there is a possibility that something might accidentally fall on the toes, causing them to be injured or even severed. These boots can be slightly heavier than

FIGURE 1-19 Rubber gloves and leather outers. Chalat Photography/Shutterstock.com

conventional work boots, but they are worth wearing if they can save your toes from being injured or severed. Electricians should not use shoes that use nails to fasten the soles to the shoe, nor should they use steel-toed boots. The nails or steel toes can provide a path to conduct electrical current.

PPE—Cold Weather Apparel

People working in extreme cold weather may be exposed to conditions that can cause frostbite and hypothermia. Persons working in these conditions can protect themselves from the elements by wearing protective cold weather PPE. These garments may include, but are not limited to, hooded outerwear or parkas, jackets, and sweatshirts. It is also essential to wear thick wool socks and gloves to protect the digits from frostbite.

PPE—Checklist

Review the following list to ensure you are wearing the proper PPE. Wearing safety equipment may be inconvenient or uncomfortable, but your personal safety is more important than comfort.

- Wear a hard hat.
- Wear safety glasses (with side shields).
- Wear hearing protection.
- Use a safety belt when working in an elevated location.
- Use a lifting belt when lifting a heavy load.
- Have your safety belt inspected and tested by a qualified individual according to your facility's policies and procedures.
- Use approved rubber gloves, leather gloves, rubber blankets, and rubber mats when working on energized circuits or equipment.
- Carefully inspect all PPE each time you use it. Your life depends on it!
- Have all rubber items electrically tested according to your facility's policies and procedures.
- Discard all worn, defective, or otherwise unsafe items.

SAFETY

LADDERS AND SCAFFOLDS

In order to perform some of the work required of an electrician, you will more than likely need to employ the use of a ladder or scaffold to reach inaccessible areas. Ladders and scaffolds present some potential safety hazards, the most obvious of which are falls. However, people are also injured by incidental contact with electrical power lines while moving metal ladders and scaffolds. Here is some important information to know about ladders and scaffolds.

SAFETY

Ladders

So, what is a ladder? A ladder is a structure consisting of two side rails joined at intervals by steps (which are referred to as *rungs*) for climbing up and down. Ladders are manufactured in lengths of 3 to 50 feet (0.9–15.2 m).

OSHA Standard 1926.1051 (General Requirements) states that a stairway or ladder shall be provided at all personnel points of access where there is a break in elevation of 19 inches (48 cm) or more, and no ramp, runway, sloped embankment, or personnel hoist is provided. OSHA Standard 1926.1053 lists the requirements for the manufacturing or construction of a ladder. OSHA Standard 1926.25 covers portable wooden ladders, 1926.26 covers portable metal ladders, 1926.27 covers fixed ladders, and 1926.1053 covers ladders that are used in the construction industry. Regarding American National Standards Institute (ANSI) ratings, different safety codes apply, depending on the type of material and type of ladder.

The ANSI codes are as follows:

Wood ladders	ANSI A14.1
Metal ladders	ANSI A14.2
Fixed ladders	ANSI A14.3
Fiberglass ladders	ANSI A14.5
Steel ladders	ANSI A14.7
Rolling scaffold	ANSI A10.8, 2019 edition, (covered later in this section)

Duty ratings have also been established by ANSI. These ratings identify the ladder's load capacity and its intended use. All ladders must have a rating label.

Rating	Load Capacity	Rated Use
Type IAA	375 lbs (170 kg)	Special duty
Type IA	300 lbs (136 kg)	Extra-heavy duty (industrial)
Type I	250 lbs (113 kg)	Heavy duty (industrial)
Type II	225 lbs (102 kg)	Medium duty (commercial)
Type III	200 lbs (91 kg)	Light duty (household)

LADDER RATING LABEL.

Wood Ladders

Wood ladders have some disadvantages. They deteriorate with age and are extremely susceptible to weather. As the wood dries out, shrinkage can occur, causing loose rungs. The integrity of a wood ladder must be maintained by regularly coating it with clear shellac or linseed oil throughout its working life. Wood ladders should never be painted because it covers the defects that otherwise would be visible and can be caught during inspection of the ladder. Wood ladders tend to splinter if mistreated. Finally, wood ladders tend to be very heavy. Wood ladders are generally considered to be nonconductive. However, dirt, grease, or other contaminants may make them conductive. Also, some wood ladders utilize metal-reinforcing wires to provide stability and strength. These wires can conduct electricity as well. The wood ladder does have some advantages. For example, they do not tend to transfer heat or cold to the worker because of wood's insulating properties. They typically cost less than other ladders and are very durable. Wood ladders must be stored on their edge, away from excessive dampness, dryness, and heat, to reduce the possibility of warping. If possible, the best method of storing a wood ladder is by hanging it horizontally on hooks, by the rails, that are spaced no more than 4 to 6 feet (1.2–1.8 m) apart.

Metal Ladders

Metal ladders are normally constructed from aluminum. Their disadvantage is the tendency to become very cold and very hot. This is transferred to the worker standing on the ladder. Metal ladders cannot be used within 4 feet (1.2 m) of energized electrical circuits or equipment, as they are made from an excellent conductive material. The advantages are that they are lightweight, are extremely tough and durable, and will not splinter or crack when subjected to impact. Also, they are resistive to deterioration with age and require much less maintenance than wood.

Fiberglass Ladders

Fiberglass ladders are the most popular ladders. However, even these have some disadvantages. They are typically heavier than both wood and metal ladders. They have been known to crack and fail when overloaded, and they may crack or chip when severely impacted. They are also extremely susceptible to sun rot. The UV rays from the sun tend to break down the resin compounds that form the shape of the ladder. When this occurs, very small fiberglass splinters are exposed and can become lodged into your skin when lifting or carrying the ladder. The advantages are that they do not conduct electricity when dry, they can withstand considerable abuse while maintaining their integrity, they do not require surface finishing and are typically more comfortable to stand on for long periods of time, and finally, they do not transfer heat or cold to the worker.

Fixed Ladders

The fixed ladder is a ladder that is permanently attached to a structure. It is commonly constructed of steel or aluminum. Fabrication of a fixed ladder, including the design, materials, and welding, must be done under the supervision of a qualified, licensed structural engineer. The width between side rails is normally 16 inches (40.6 cm), and the spacing between rungs is 12 inches (30.4 cm). Any fixed ladder that has a length of 24 to 50 feet (7.3–15.2 m) must have a cage, well, or ladder safety system. If a cage is installed, it must start no less than 2 feet (0.6 m) and no more than 8 feet (2.4 m) from the ground or platform. Fixed ladders must also have a load capacity rating of 250 lb (113 kg), and they must be attached every 10 feet, 7 inches (3.2 m) off the wall or structure.

Extension Ladders

Extension ladders are ladders that have an inner (fly) section that slides up and down in the outer (base or bed) section. It is raised by a rope and is kept on track by an interlocking side rail system. See Figure 1-20 for all the parts on an extension ladder.

When leaning an extension ladder against a building or structure where the fly section does not extend above the structure, it is a common practice to install end covers to protect the end cap on

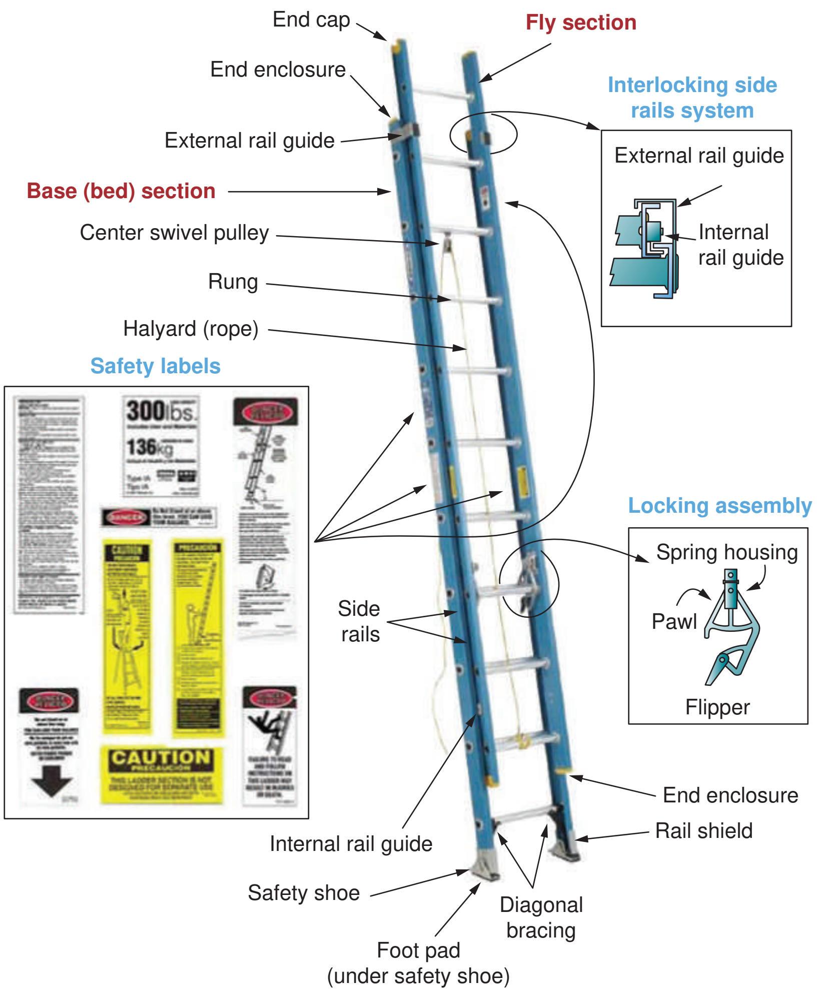

FIGURE 1-20 Extension ladder components.

FIGURE 1-21 Extension ladder end caps.

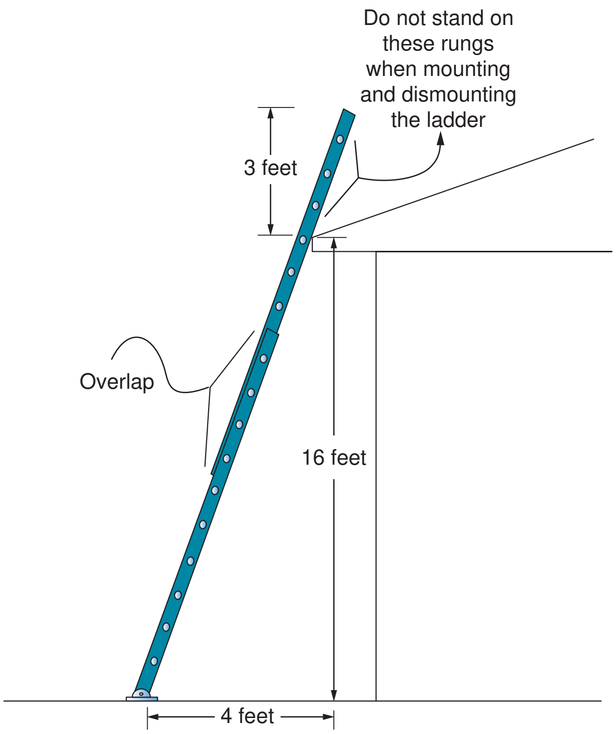

FIGURE 1-22 Proper ladder set-up.

the ladder as well as the structure that it is leaning upon. A set of end cap covers can be seen in Figure 1-21.

When leaning an extension ladder upon a structure where the fly section rises above the top edge of the structure, the ladder must extend above the structure not less than 3 feet (0.9 m), measured from the highest point of contact. Having this additional length provides a means of support as you mount and dismount the ladder. Never stand on the top three rungs when mounting or dismounting the ladder. To prevent the ladder from kicking out from under you or sliding sideways, the ladder should be secure to the structure.

When extending a ladder, it is important that enough overlap remains to prevent the ladder from folding in the middle. The distance of overlap is determined by the ladder length. For ladders that are 8 to 36 feet (2.4–11 m), there must be a minimum of a 3-feet (0.91 m) overlap. For ladders that are 36 to 48 feet (11–14.6 m), there must be a 4-feet (1.2 m) overlap. And for ladders that are 48 to 60 feet (14.6–18.2 m), there must be a minimum of a 5-feet (1.5 m) overlap.

Another thing to be concerned about is angle positioning. If this is not considered, as one climbs higher on the ladder, the shifting center of gravity could cause the ladder to fall over backward, causing severe injury or even death. The rule is that for every 4 feet (1.2 m) of vertical rise, the bottom of the ladder (safety shoes) should be moved away from the structure 1 foot (0.3 m) horizontally. See Figure 1-22.

Ladder Safety

Over 11% of all injuries that require time away from work are related to falling from ladders. Safe climbing employs the three-point contact method. This means that contact must be maintained at all times when you are on the ladder. It is also a good practice to use the rungs instead of the rails while climbing or descending on a ladder. Another cause for ladder injury is that the worker will stand on the top rung or even the table (very top) of the ladder so they can "reach just a little farther." While reaching, the center of gravity is shifted, causing the ladder to tip, resulting in a fall with injury or possibly even death. Every ladder that is manufactured will have safety labels placed on them stating "DO NOT STAND ON OR ABOVE THIS RUNG."

SAFETY

Scaffolds

As mentioned earlier, the ANSI A10.8, 2019 edition, covers the safety codes for rolling scaffolding. Safety requirements for scaffolding are covered in OSHA (Standard) 1910.28, and 1926.451 also pertains to scaffolds and scaffold constructions. Scaffolding should only be assembled by qualified, trained personnel. Be sure to follow all OSHA standards when constructing any scaffolding. A scaffold is a temporary and sometimes movable structure that has platform(s) on which workers stand when working at heights. There are three basic types of scaffolds.

Pole Scaffolds

The pole-type scaffold uses a series of poles and braces that are secured to the top of the structure. A jack is then installed on each pole, after which the scaffolding platform is attached to the jacks. This allows the scaffold platform to be raised or lowered to any desired level by adjusting the jacking system. The pole scaffold could be erected with wooden or aluminum poles. Scaffolding exceeding 25 feet (7.6 m) in height must be securely guyed or tied to the structure or building. See Figure 1-23 to see an example of a pole scaffolding.

Sectional Metal-Framed Scaffold

The most common type of scaffolding is called the *sectional metal-framed scaffold*. This scaffold is assembled on-site and is typically constructed by erecting prefabricated panels and pinning them together. The working platform is then installed on the framing. Many scaffolding systems can be built level by level until the desired height has been achieved. These scaffolds must be level when being assembled. Also, each panel should be inspected for damage, defects, or cracks before installing it into the scaffolding system. A damaged scaffold frame or platform could cause the entire structure to collapse if it is not detected.

Suspension Scaffold

The final type of scaffolding is the suspension scaffold, also referred to as an *aerial lift*. OSHA (Standard) 1926.453 sets the criteria for aerial lifts. This type of scaffold is suspended from the top of a building or structure and is lowered through a cabling system that is fed out by either a motor or a hand crank. It is often installed permanently on high-rise buildings that require window washing.

FIGURE 1-23 Pole scaffolding.

Toe-boards are required as a barrier to guard against the falling of tools or other objects. Guardrails are also required and must be installed in accordance with OSHA standards. They must be installed no less than 36 inches (91 cm) and no more than 42 inches (106.6 cm) high, with mid-rail, measured from the working platform. Guardrail and mid-rail support are to be at intervals not more than 10 feet (3 m).

Here are some general safety considerations when constructing a scaffold.

- Guardrails, mid-rails, and toe-boards must be installed on all open sides and ends of platforms more than 10 feet (3 m) above the ground.
- Platform planks are to be laid with no openings more than 1 inch (2.5 cm) between adjacent planks.
- Overhead protection must be provided for persons on a scaffold who are exposed to overhead hazards.
- Fall protection should be used when working at heights of 10 feet (3 m) or more (harness, shock-absorbing fall lanyard, etc.).
- Safety nets for workers should be used at any level over 25 feet (7.6 m) when the workers are not otherwise protected by personal fall protective equipment or properly guarded scaffolding work surfaces. Safety nets restricting falling objects must be used when persons are permitted to be underneath a work area.
- Work must not be done on scaffolding during high winds or storms.
- Work must not be done on ice-covered or slippery scaffolds.
- Scaffolds with a height-to-base ratio of more than 4:1 must be restrained by the use of guy lines.
- Mobile scaffolds must be locked in position when in use.
- All tools and materials must be secured to or removed from the platform before the scaffold is moved.

Ladder and Scaffold Safety

Accidents from using scaffolds and ladders usually occur because of carelessness and rushing. Take some time to inspect the ladder or scaffold on which you will be working. The life you save may be your own.

SAFETY

- Examine scaffolds and ladders before each use.
- Use only nonconductive ladders when working on electrical circuits.
- Be careful when moving scaffolds and ladders so as to not come into contact with energized circuits.
- Have all scaffolds and ladders inspected and tested by a qualified individual according to your facility's policies and procedures.
- Remove a defective scaffold or ladder from service.

Keep scaffolds and ladders clean and free from dirt or paint, which may conceal defects or provide a path for electrical current to flow.

HAND AND POWER TOOLS

Electricians need hand and power tools to accomplish the everyday tasks demanded of them. The selection of these tools is dependent upon not only the task to be completed but also the environment in which the work is performed. As a result, there are requirements that must be met so that the tool can be used efficiently, effectively, and safely.

SAFETY

Hand Tools

Electricians will use hand tools every day. The tools used are generally the basic hand tools: screwdrivers, pliers, wire cutters, wire strippers, and so forth. However, one major difference between the hand tools used by an electrician and the typical do-it-yourself weekend handyman is that the tools used by an electrician should be voltage rated. This means the hand tools are constructed with additional layers of insulation and are rated for 1000 volts. The layers of insulation, like the rubber gloves, are different colors so that any cuts or abrasions will expose the underlying color, thus indicating that the tool needs to be replaced. Figure 1-24 and Figure 1-25 show two examples of 1000-volt-rated hand tools.

FIGURE 1-24 1000 volt rated screwdriver.
Woody Alec/Shutterstock.com

FIGURE 1-25 1000 volt rated pliers.
Woody Alec/Shutterstock.com

CAUTION

Power Tools

Most handheld portable power tools used today are battery operated. This minimizes the risk of electrical shock to the user. However, it does not minimize the risk of coming into contact with an energized electrical circuit, hydraulic line, or pipe when drilling, cutting, and so forth. If the handheld portable power tool has a cord-and-plug connection for power, be sure that the power tool is of the double-insulated type or has a grounding type (three-prong) power plug. NEVER CUT OFF THE THIRD (GROUNDING) PRONG OF THE POWER PLUG!!

SAFETY

Here are some items that should be considered when working with power tools.

- Use care with all hand and power tools to prevent their coming into contact with energized equipment or circuits.
- Be especially careful when cutting or drilling "blind." Know what is inside the wall or on the

other side of the wall to eliminate the risk of cutting or drilling into energized circuits.

- Inspect all hand and power tools for defects, and remove them from service if unsafe.

CAUTION

- Inspect the power cords of all power tools for cracks, breaks, and proper grounding (if not of the double-insulated type).

ELECTRICAL TEST EQUIPMENT

Electrical test equipment will be discussed in more detail in Chapter 4; however, this is a good place to identify some safety concerns when using electrical test equipment. When using test equipment, many individuals assume that their equipment is working because it worked the last time they used it. This assumption could prove very dangerous. Think about the following items whenever you need to use test equipment on the job:

- Use the right piece of test equipment for the job.
- Wear appropriate PPE when using test equipment on energized equipment.
- Know the proper usage and procedures of the test equipment that you are using. Be certain that you are properly trained in its correct operation and use.

CAUTION

- Do not exceed the design limits of the test equipment that you are using. Be aware of circuit voltages present so that you do not use the test equipment on a circuit of higher voltage. Injuries have occurred to the hands, arms, and face of a worker by inadvertently connecting a 1000-volt-rated multimeter to a circuit energized with 7200 volts.
- Always inspect your test equipment for signs of wear and damage before use. Remove a damaged piece of test equipment from service immediately.

CAUTION

- Always verify that voltage measuring equipment functions properly by checking the operation on a known voltage source before usage on the circuit to be tested.
- Be especially careful when using test equipment on *live* or *energized* circuits.
- Verify that a circuit is *dead* or *de-energized* before measuring circuit resistance with an **ohmmeter** or a **Megger®**.

MACHINERY

Working around machinery presents several areas for safety concerns. The obvious is the moving machinery itself. In addition to the presence of electricity, be alert and aware of the moving parts so that you do not get captured by the machine and injured or killed.

Pinch Points

It is very important that you know about and understand **pinch points**. Pinch points are points on a machine where two or more separate components meet or come together. There are two types of pinch points: rotating and pressing. A rotating pinch point is where two rollers, gears, or anything that is rotating meet. A pressing pinch point is where two separate parts of a machine that are pressed together meet. Whatever goes into a pinch point becomes compressed. If fingers or hands get pulled into a pinch point, the fingers or hand will certainly be mutilated, and the digits or the entire hand itself could be severed.

CAUTION

Motors

Motors may cause injury not only from an electrical shock but also from the mechanical motion. Take steps to minimize the risk of electrical injury and injuries that may occur from the motor starting unexpectedly.

- Follow your facility's lockout/tagout procedures when working on the electrical connections to rotating machinery.
- When making temporary connections to rotating machinery, use sufficient amounts of electrical tape or other insulating material.
- Keep oilcans, wipes, rags, and so on away from rotating machinery. Be mindful of ferrous-type material that may be attracted to the magnetic field created by the motor or generator.
- De-energize rotating machinery when using cleaning solvents and lubrication.

CAUTION

WORKING ON LIVE, ELECTRIFIED EQUIPMENT

Keep your mind on the task at hand. All it takes is a lapse in concentration, or working without thinking, and a shock or an electrocution occurs. Try to remember the following:

- Treat all circuits as *live* or *energized*, even when you know for certain that they are not. Often injury occurs from the surprise reaction of coming into contact with an assumed *dead* circuit. Quite often, the electrical shock does not cause the injury, but the surprised reaction to the electrical current causes you to lose your balance and fall from a ladder or jerk your hand from a conductor only to smash it into a cabinet!
- Familiarize yourself with NFPA 70E. As mentioned previously, NFPA 70E addresses not only the hazards of electrical shock but also the hazards from arc flash. This has resulted in standards for electrical safety including PPE that was not considered in years past. The scope and nature of the requirements, as set forth by NFPA 70E, identify different hazards and risks, the use of rubber gloves and insulated tools, and protective clothing and PPE.
- De-energize, lockout, and tagout all electrical circuits upon which work is to be performed. If it is not practical to de-energize a circuit, follow your facility's policies and procedures for working on energized circuits.
- Upon completing repairs, make a thorough examination of the circuit before reapplying power.
- Verify that all personnel are clear, and it is safe to re-energize the circuit.

SAFETY

CAUTION

Grounding

Proper grounding of equipment is often over looked. This is an accident waiting to happen. Also, unintentional grounding of personnel causes injury and death.

- Verify that all electrical equipment such as motors, generators, conduits, switchgear, transformers, and so forth are properly and adequately grounded. Any defective or missing grounds should be repaired immediately in accordance with your facility's policies and procedures.
- When working on electrical circuits or equipment, take all necessary precautions to prevent yourself from becoming the path for the electrical current to ground. Use proper PPE in accordance with your facility's policies and procedures. Be especially mindful in damp or wet areas.

SAFETY

CAUTION

Switches

Never assume you know when a switch is off. Personally verify the state of all switches and circuits. Do not get offended when coworkers check behind you. They are just being safe, and you should do the same for them.

- To ensure the protection of yourself and coworkers, always verify the condition of the circuit before the opening or closing of any switches that affect that circuit. Verification minimizes the risk of injury in the event a faulty circuit is encountered or should a worker become exposed to a live circuit.
- Always open or close switches in a firm, positive manner. Use sufficient force to cause the switch contacts to make or break fully and quickly.
- Switches should be opened or closed fully and completely. Partially opened or closed switches may produce arcing or flashover, which may damage the switch and burn or injure the operator.

CAUTION

SAFETY

Fuses and Disconnects

Again, the following precautions are often overlooked. Think about these items every time you work around fuses and disconnects. If you keep safety at the forefront of your thoughts, you minimize the chances of an accident occurring.

- Never remove a fuse from a circuit under load. Always open the associated disconnect switch before removing the fuse.
- Use the appropriate and approved fuse puller as specified by your facility.
- When removing fuses, remove the fuse in such a manner so that the *hot* side of the fuse and circuit is broken first.

CAUTION

- When installing fuses, install the fuse in such a manner so that contact with the *hot* side of the fuse and circuit is made last.

CAUTION

Capacitors

Be careful when working around capacitors.

- Capacitors may store a charge for a very long time, even without connection to an electrical circuit. This charge may discharge upon contact with the capacitor terminals.
- Always use an approved discharge device to discharge capacitors before working around, handling, or making connections.

CAUTION

SUMMARY

- Without safety, electrical work would be a very dangerous and deadly occupation. The electrician must be very safety oriented to avoid unnecessary accidents and bodily harm when working around electricity. A culture of safety in the workplace is vital.
- NFPA 70E and OSHA guidelines work in conjunction with each other so that the OSHA guidelines specify what an employer shall do and NFPA 70E specifies how it shall be done.
- Secure the work area.
- The work area must be kept clean and safe.
- Perform an Arc Flash Risk Assessment.
- Lighting must be adequate.
- Hazardous materials must be properly labeled, handled, and stored.
- Use the appropriate PPE.
- Use voltage-rated hand tools.
- Be aware of machinery hazards and pinch points.
- Do not exceed the design ratings of electrical test equipment.
- Use the appropriate ladder and scaffolding safely.
- Perform lockout/tagout procedures when working on electrified equipment.
- Take extra precautions, and demonstrate a heightened awareness when working on energized electrical equipment.

REVIEW QUESTIONS

Multiple Choice

1. With regard to NFPA 70E and OSHA guidelines, which statement is correct?
   a. NFPA 70E states how an employer should meet the safety requirements, and OSHA states what those requirements are.
   b. NFPA 70E states what the safety requirements are, and OSHA states how the employer meets those requirements.
   c. Both NFPA 70E and OSHA state how an employer should meet the safety requirements.
   d. Both NFPA 70E and OSHA state what the safety requirements are.
2. The three steps involved in an Arc Flash Risk Assessment are:
   a. secure the work area, de-energize all circuits and equipment, and assess the risk.
   b. identify the hazards, assess the risk, and develop the required work protocols.
   c. de-energize all circuits and equipment, identify the required PPE, and inform coworkers of work to be performed.
   d. assess the risk, de-energize all circuits and equipment, and contact OSHA for an inspection.
3. The four areas of the Hazardous Materials diamond are:
   a. red/health, blue/hazard, white/instability, and yellow/fire.
   b. red/hazard, blue/instability, white/fire, and yellow/health.
   c. red/instability, blue/fire, white/health, and yellow/hazard.
   d. red/fire, blue/health, white/hazard, and yellow/instability.

4. When using a three-prong, corded portable hand drill, it is permissible to cut off the third prong to enable it to be plugged into a two-prong outlet.
    a. True
    b. False

Give Complete Answers

5. Explain the concept of a *culture of safety*.
6. Identify three areas of safety concern within a given work area.
7. Describe three pieces of Personal Protective Equipment (PPE).
8. Describe the proper placement of a ladder regarding the relationship between the vertical rise versus the horizontal placement.
9. Describe three requirements or precautions when using electrical test equipment.
10. Name two safety concerns when working around machinery.
11. Identify two areas of concern when working on live, electrified equipment.

PUT IT INTO PRACTICE

Working alone, or with a partner or group, have your instructor or supervisor assign you an area (could be a classroom, lab, shop, or area in the plant) where you can perform a safety assessment. Imagine that you need to perform some type of electrical maintenance (as specified by your instructor/supervisor) in this area. Identify any areas of safety concern. Perform a general Arc Flash Risk Assessment. Identify and interpret any hazardous materials and signage. List all the PPE that will be required. List the required ladders, scaffolds, hand and power tools, and electrical test equipment, along with any safety concerns. Identify any machinery that poses a hazard and what those hazards are. Determine if the electrical circuit can be de-energized, and if not, describe the precautions that must be taken to work on an energized circuit.

CHAPTER 2

LANGUAGE OF ELECTRICITY

OBJECTIVES

After studying this chapter, the student will be able to:

- Explain the purpose of electrical symbols and drawings.
- Explain the purpose of pictorial symbols and drawings.
- Describe four basic types of electrical drawings.
- Demonstrate the use of scientific and engineering notation.

KEY TERMS

In this chapter, you will learn the following key terms:

- Power source
- Ground
- Fuse
- Circuit breaker
- Switch
- Relay
- Motor starter
- Motor
- Generator
- Resistor
- Capacitor
- Inductor
- Transformer
- Pictorial symbols
- Single-line drawing
- Pictorial diagram
- Schematic diagram
- Ladder diagram
- Voltage
- Architectural drawings
- Scientific notation
- Engineering notation

INTRODUCTION

One of the greatest accomplishments of humanity is the development of systems of symbols for communication. The modern English alphabet is a set of 26 symbols, called *letters*, which convey information when combined in the proper order. Our number system is a set of 10 symbols, which can be used individually or grouped to represent small quantities or large quantities. Symbols used in arithmetic indicate the operation to be performed. For example, the symbol + indicates addition, and the symbol × indicates multiplication. Another set of symbols known as shorthand enables stenographers to write words at a rapid pace.

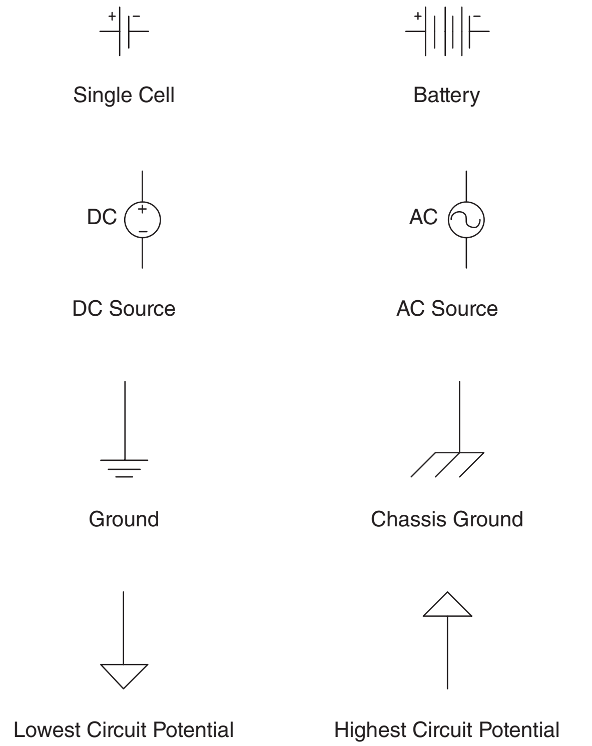

FIGURE 2-1 Power sources and ground symbols.

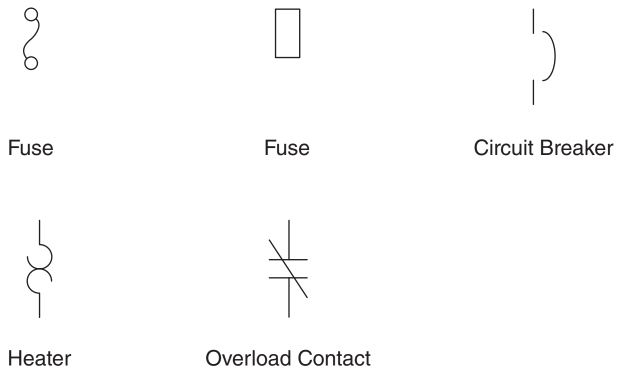

FIGURE 2-2 Overcurrent protective device symbols.

ELECTRICAL SYMBOLS

There are many different types of symbols used in electrical drawings. These symbols are used to convey meaning while conserving drawing space. It is important for you to become familiar with these symbols so that you can read and interpret electrical drawings.

Figure 2-1 shows some of the typical symbols used to represent **power sources** and **grounds**. Figure 2-2 shows the symbols used to represent overcurrent protective devices such as **fuses** and **circuit breakers**. Notice that there are two symbols shown for a fuse. This is one of the challenges that you will face in the electrical industry. There is often more than one recognized symbol for a device. You must become familiar with all forms of symbols in use at your facility. This is especially important when dealing with equipment or machinery manufactured in other countries. The symbols used may be different from the symbols used within the United States.

Various types of **switches** are shown in Figure 2-3, Figure 2-4, and Figure 2-5. When looking at these figures, you will see some abbreviations. The letters *NO* represent "Normally Open." This is the condition of the switch contacts as the switch simply lays on a shelf, so to speak. The contacts would be in their open (nonconducting) state. The abbreviation *NC* signifies "Normally Closed." In this case, the contacts would be closed (conducting) with the switch in its normal, on-the-shelf, state. Other abbreviations are SPST—Single Pole (movable contact) Single Throw (can only be in one of the two positions, open or closed); SPDT—Single Pole Double Throw (can be in one of the two positions, closed between the pole and contact "A" or closed between the pole and contact "B"); and DP—Double Pole (two electrically isolated movable contacts). Figure 2-3 shows various types of switch arrangements. Figure 2-4 shows manually operated switches, while Figure 2-5 shows switches that are operated automatically. Please note that these are not all of the possible switch arrangements in existence today. Often, the symbols are combined so that a more complex switch can be represented. For example, a four-pole, double-throw, normally open switch symbol would resemble two two-pole, double-throw, normally open switch symbols combined.

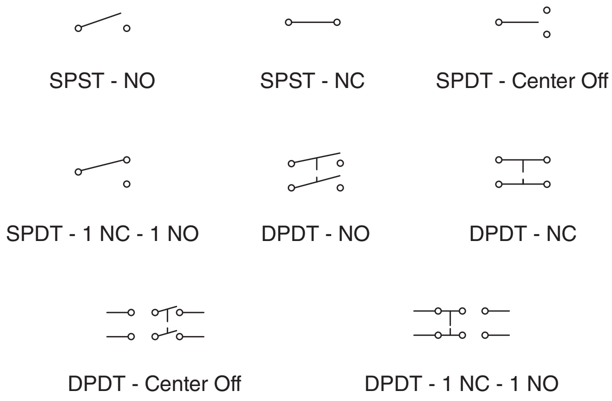

FIGURE 2-3 Symbols of various types of switch arrangements.

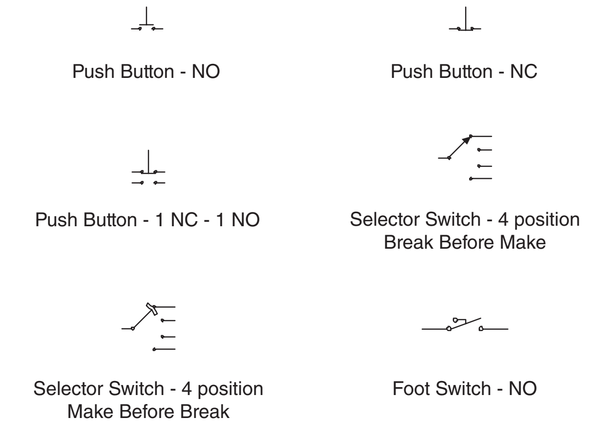

FIGURE 2-4 Manually operated switch symbols.

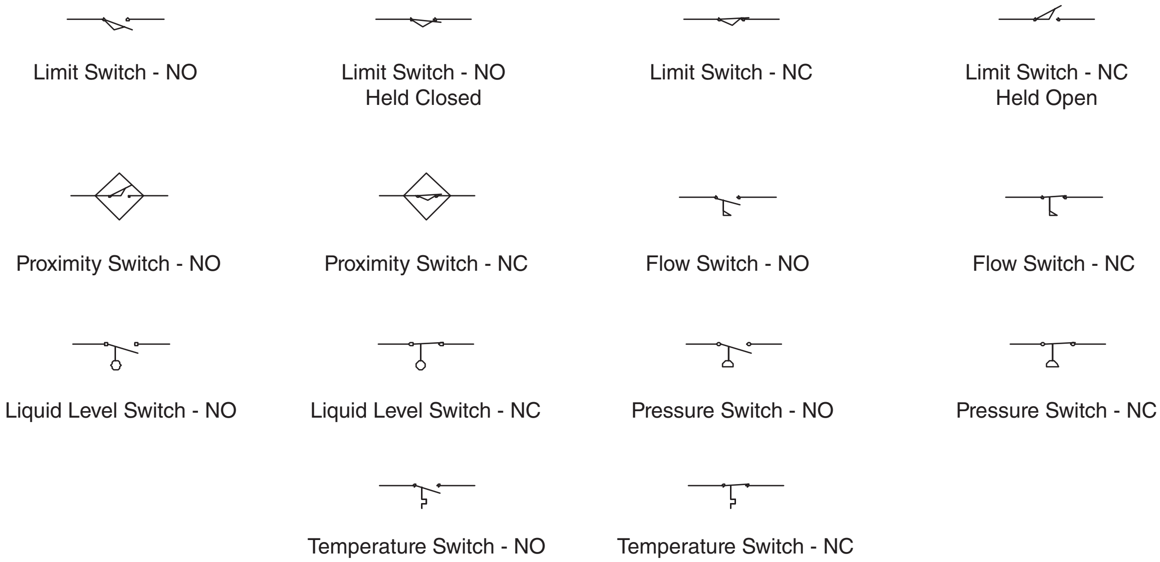

FIGURE 2-5 Automatically operated switch symbols.

Figure 2-6 shows the symbols used to represent various types of contacts, **relays**, **motor starters**, **motors**, and **generators**. Notice that the symbol used to represent motors and generators is the same, the main difference being the qualifier, that is, the flat, horizontal line used to denote DC or the sine wave used to denote AC. The letter *M* is used to represent a motor, a *G* is used to represent a generator, and the letters *MG* are used to represent a motor–generator set.

Various components are shown in Figure 2-7 and Figure 2-8. **Resistors** and **capacitors** are shown in Figure 2-7. Notice the alternate symbols for some of these devices. **Inductors** and **transformers** are shown in Figure 2-8. Again, notice the alternate symbols. Remember, these figures show the essential symbols used in the electrical field. There are many more symbols in use. You will need to become familiar with the symbols used on the machinery and equipment within your facility. Should you have any questions about a particular symbol, ask your facility's supervisor or the equipment manufacturer's representative.

PICTORIAL SYMBOLS

Pictorial symbols use a picture-like representation of the component or item. These symbols are frequently used in panel diagrams (which illustrate the location and connections of electrical and mechanical components within a panel) or floor plans to show the physical location of equipment. Some common pictorial symbols are listed in Figure 2-9.

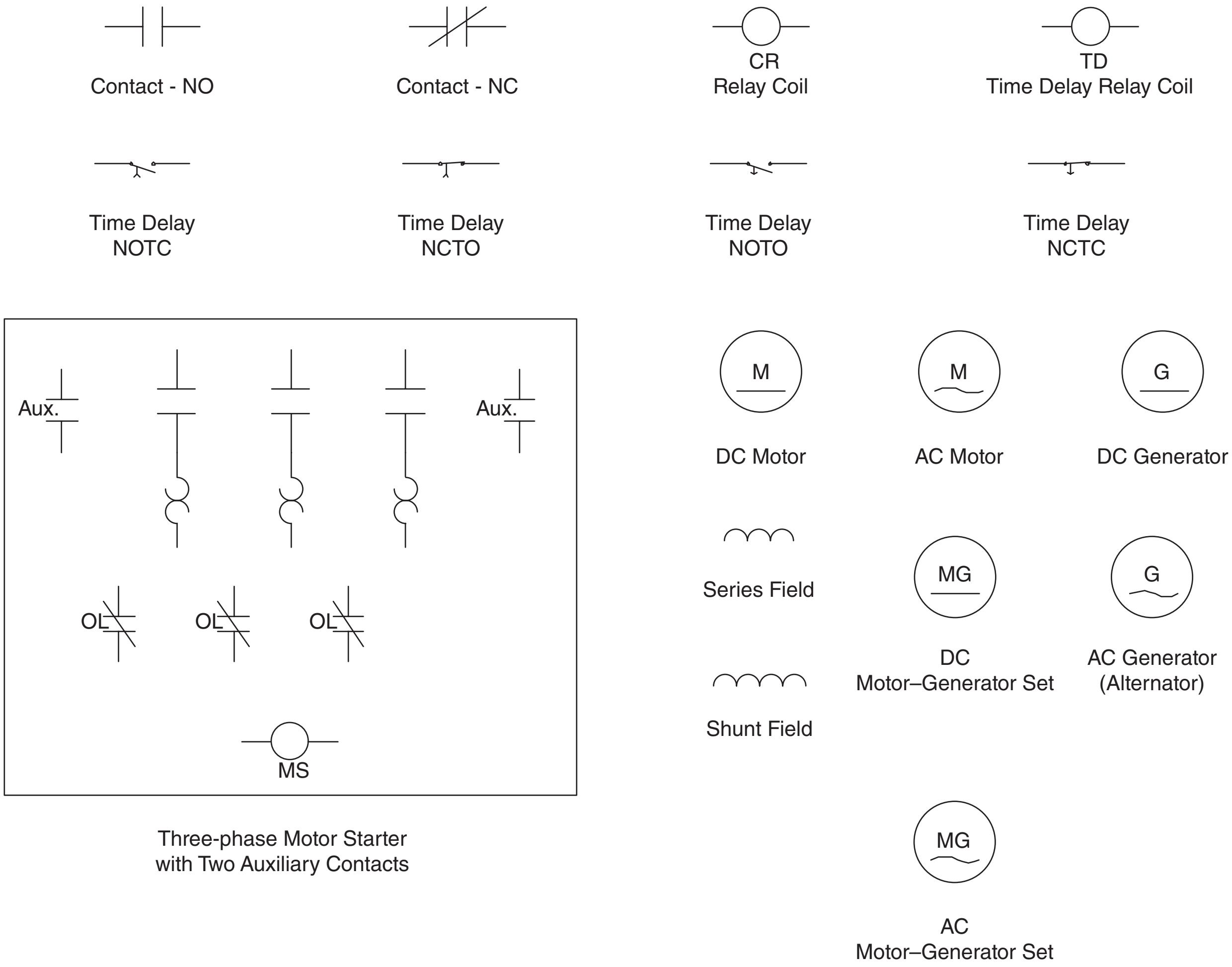

FIGURE 2-6 Contact, relay, motor starter, motor, and generator symbols.

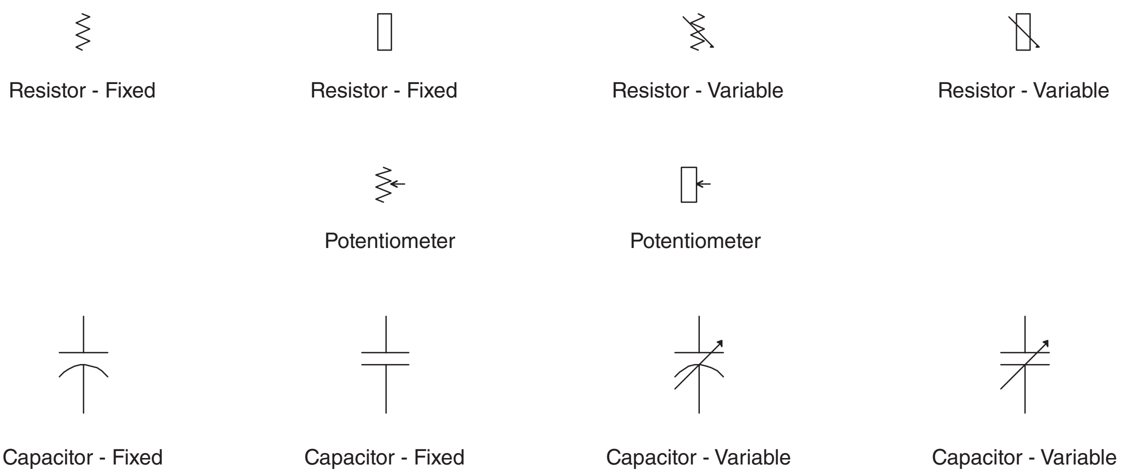

FIGURE 2-7 Resistor and capacitor symbols.

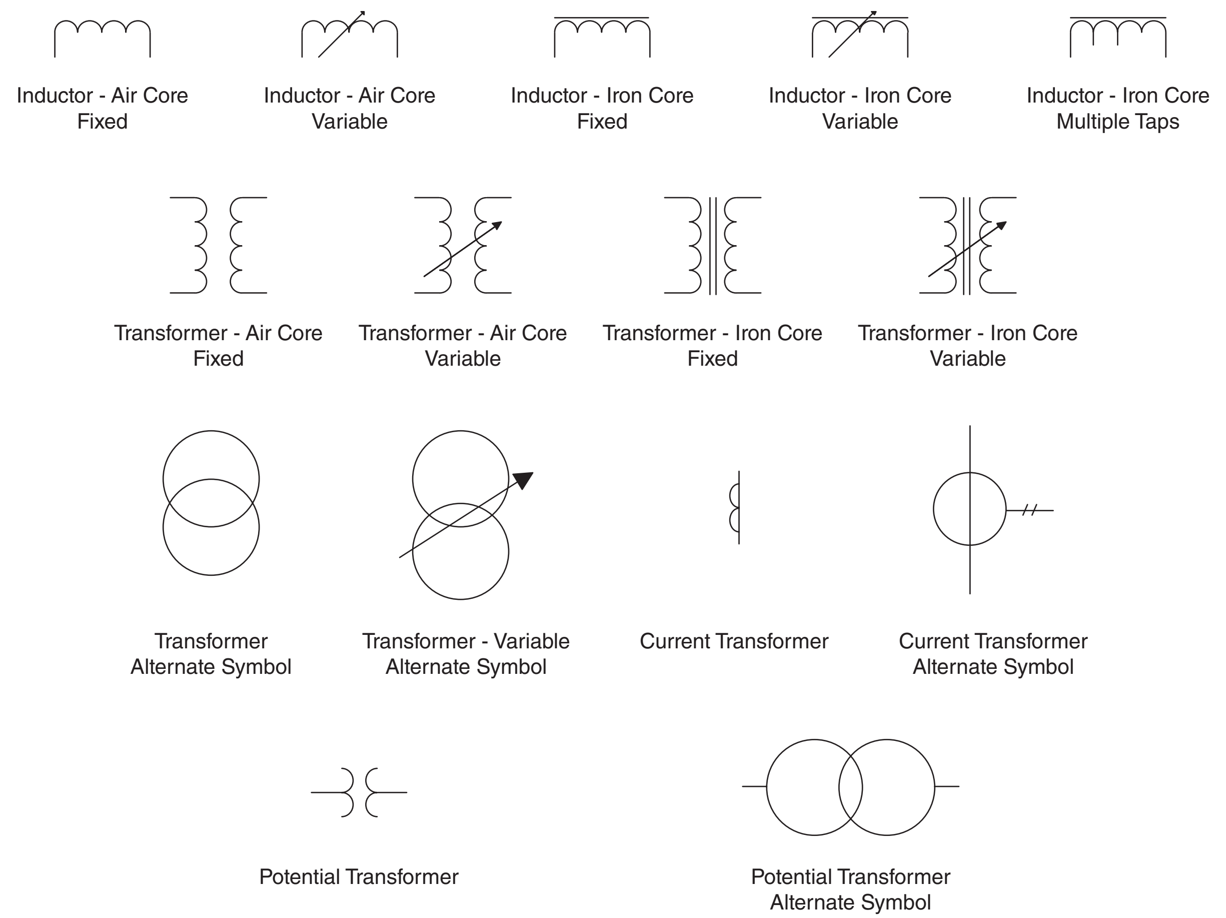

FIGURE 2-8 Inductor and transformer symbols.

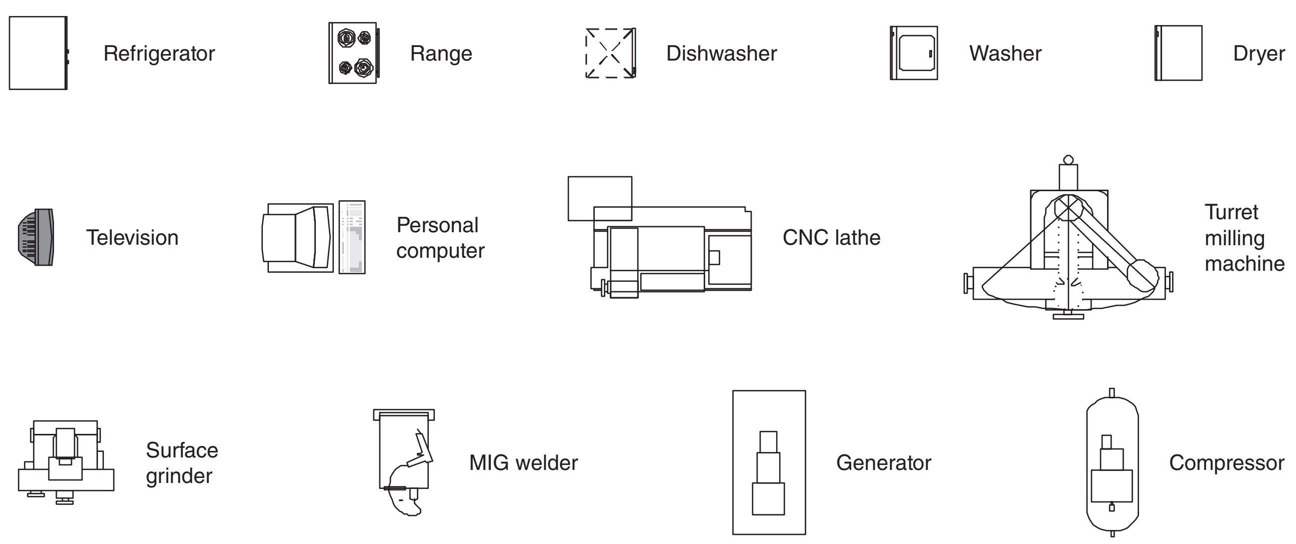

FIGURE 2-9 Pictorial symbols.

ELECTRICAL DRAWINGS

Electrical symbols, by themselves, convey little information. Appropriate symbols are combined to form a drawing. An electrical drawing can provide the following information:

- Circuit operation
- Component location
- Electrical connections
- Component function or purpose
- Manufacturer's information
- Wire gauge or size
- Wire length
- Component specifications
- Circuit specifications
- Motor specifications
- Power specifications

Electrical drawings are typically drawn with all components de-energized. In the electrical field, there are four basic drawings used to convey information. They are the **single-line drawing**, the **pictorial diagram**, the **schematic diagram**, and the **ladder diagram**. We will look at each of these drawings in more detail.

The Single-Line Drawing

The first drawing that we will study is the single-line drawing, as seen in Figure 2-10. This type of drawing is generally used to convey an overview of information but not a lot of detail. A single-line drawing does not show the actual electrical connections or the actual physical location of the devices. Single-line drawings show that some type of connection exists between components.

Probably the most common use for single-line drawings is to show the power distribution within a facility. This is helpful in the event that a particular section of the plant must be isolated for maintenance or repair. Using a single-line drawing, the electrician can determine where to electrically isolate one particular section for maintenance without interrupting other portions of the facility.

The single-line drawing in Figure 2-10 shows the power distribution grid of a manufacturing facility. Notice that all the wires are shown as a single line, hence the name single-line drawing. Notice also that there is not a lot of detail shown on this drawing. The components have been arranged so that the highest **voltage** rating is located at either the top or the left side of the drawing. Lower voltage ratings are then located below or to the right. This means that the highest voltage-rated devices will be at the top or left, and the lowest voltage-rated devices will be at the bottom or right.

The simple nature of a single-line drawing allows you to easily trace the flow of power through the drawing. However, you can also use a single-line drawing in reverse. Imagine that you wish to determine the source of power for a specific component. Begin at that component, and trace upward (or to the left) until you arrive at the

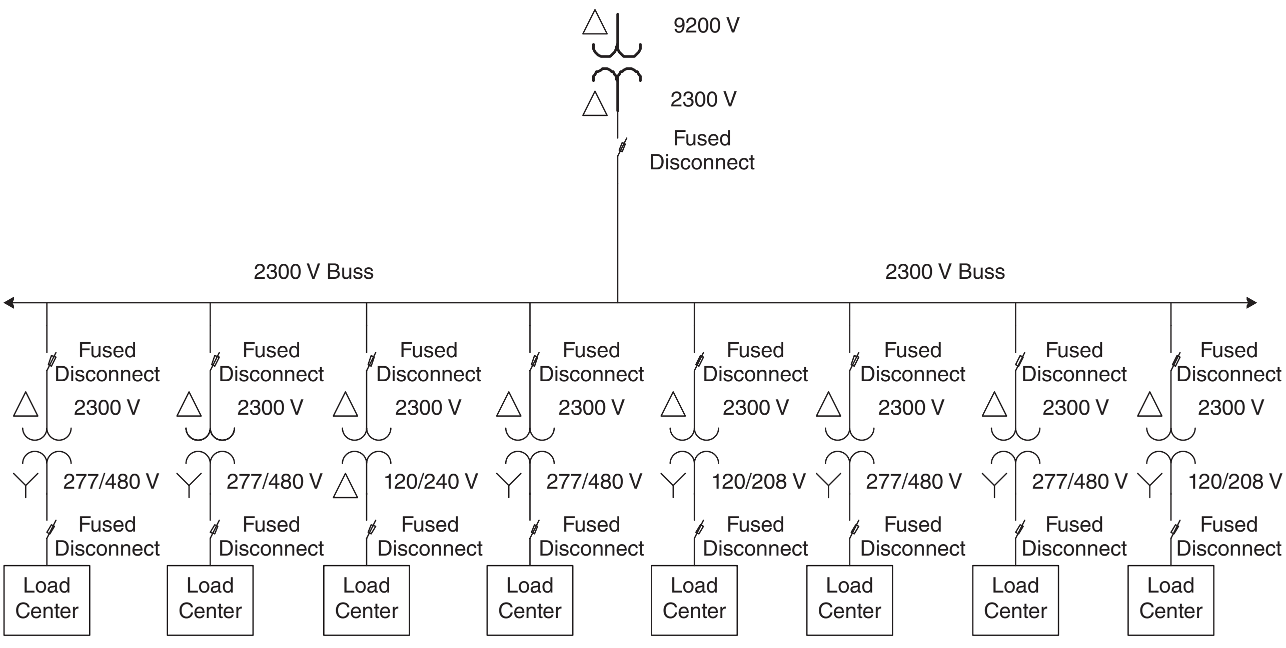

FIGURE 2-10 Single-line drawing.

source of power. This helps you identify the power source and any disconnects that can be used to isolate the component from the remainder of the circuit.

The Pictorial Diagram

The pictorial diagram is also called a *wiring diagram*. A pictorial diagram shows the relative physical location of the components, wires, and termination points. A pictorial diagram will not tell you how the circuit operates.

Pictorial diagrams are valuable because they help you locate the specific component or termination point that you may be looking for. Figure 2-11 and Figure 2-12 show an example of a pictorial diagram. Figure 2-11 shows the front view of the cover of a control box. Figure 2-12 shows the same control box with the cover opened. You can now see the backside of the control box cover as well as the inside of the control box.

The circuit shown in Figure 2-11 and Figure 2-12 is a forward–reverse control with push-button and electrical interlocks. There are also indicator lights to tell you that power is applied to the circuit, the motor is running forward, or the motor is running in reverse. You might have a difficult, if not impossible, time trying to determine the function of this circuit or the components by looking at the pictorial diagram. However, if you wanted to know the physical location of control relay CR1 within the panel, for example, the pictorial diagram would help you locate it.

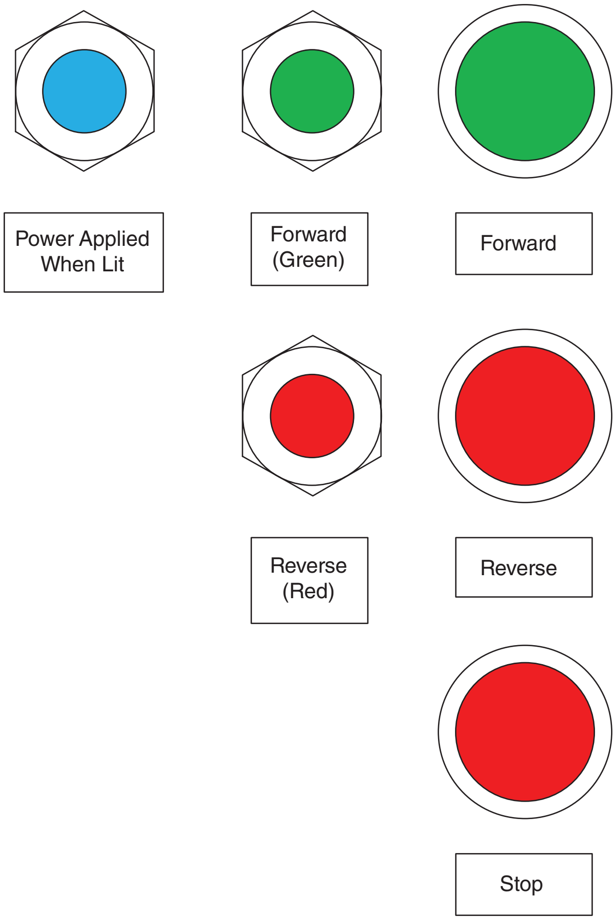

FIGURE 2-11 Pictorial diagram—control box—front view (cover closed).

The Schematic Diagram

Schematic diagrams show the actual electrical connections but not the actual physical location of components. Schematics are useful in determining how a circuit is designed to operate. Components on a schematic are generally arranged in their approximate location, relative to each other. However, the arrangement on a schematic may be very different from reality.

Figure 2-13 shows a schematic diagram of the forward–reverse control circuit seen in Figure 2-11 and Figure 2-12. Notice that the power source is located at the upper-left side of the drawing. (Typically, the power source is located at the top or left side.) Notice also that the motor (load) is located at the bottom of the drawing. (Typically, the load is located at the bottom or right side.) Schematics help you understand the action of the circuit. By reading a schematic, you can gain an understanding of the function of the various components within the circuit. This is useful when troubleshooting, modifying, or performing maintenance on the equipment.

Ladder Diagram

The ladder diagram, shown in Figure 2-14, is a variation of the schematic diagram. Ladder diagrams show the actual electrical connections but not the actual physical location of components. Ladder diagrams are useful in determining how a circuit is designed to operate in a more logical fashion than the traditional schematic diagram. Compare Figure 2-13 with Figure 2-14. Which figure looks simpler and easier to follow?

Refer to Figure 2-14. Two power rails are located on either side of the diagram. The control logic is then placed on rungs between the two power rails. Notice how the drawing resembles a ladder, hence the name ladder diagram. Numbers along the left

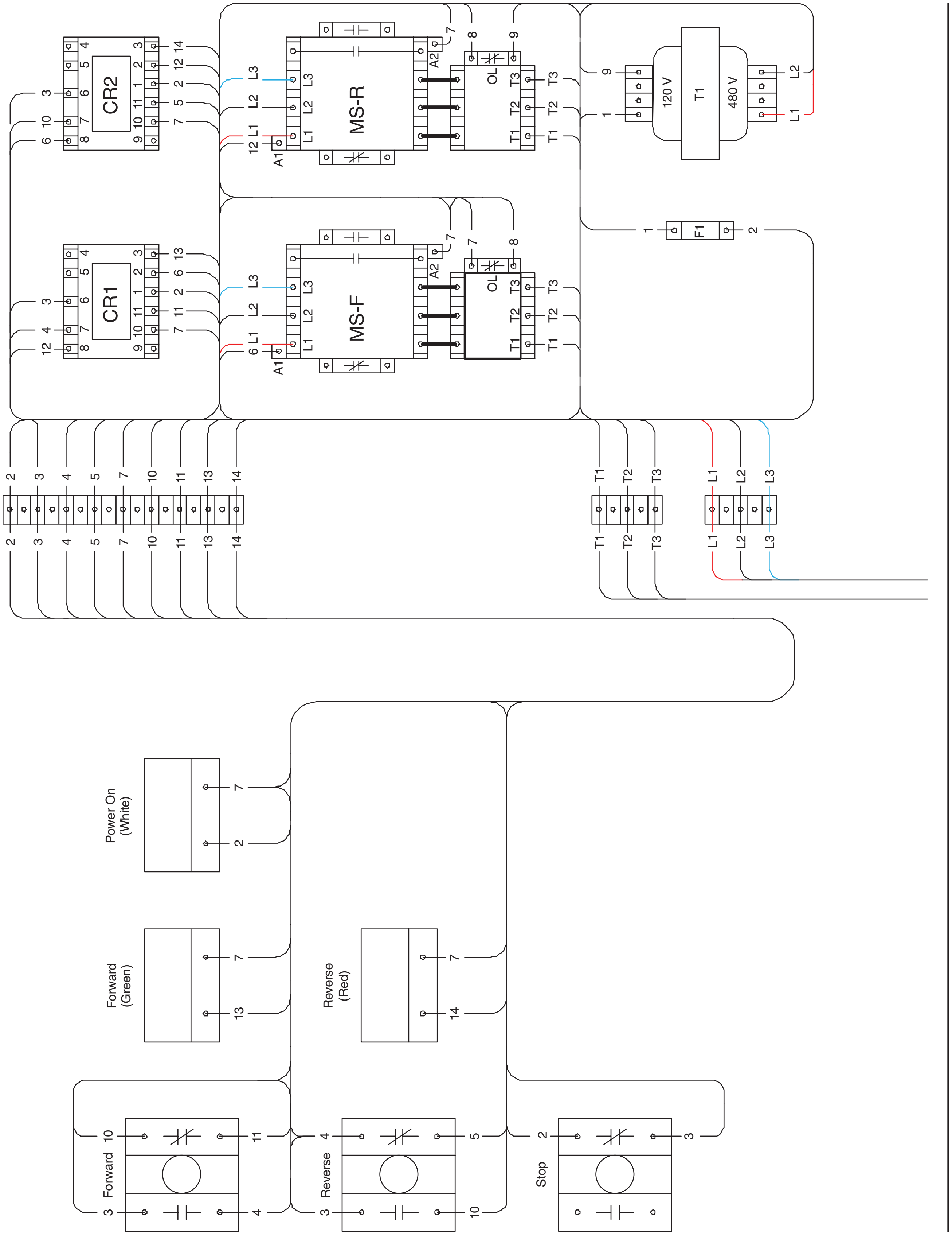

FIGURE 2-12 Pictorial diagram—control box—inside view (cover open).