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Basics in Wiring, Lighting, and Electrical Safety

PDH Credits:

8 PDH

Course No.:

IWL101

Publication Source:

US Navy
Engineering Aid Basics

"Chapter 8 – Interior Wiring and Lighting"

Pub. # NAVEDTRA 14026A

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Chapter 8

Interior Wiring and Lighting

Topics

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Overview

As a Construction Electrician you will be challenged not only with the task of installing interior wiring in new structures, but also rewiring or repairing existing structures. In this chapter you will become familiar with the various code and specification requirements for completing the tasks properly and safely. You will be presented with various techniques for installing, repairing, and maintaining interior wiring systems. Throughout this chapter pay particular attention to the various warning and caution notes. Safety of yourself and your crew is paramount while working with interior wiring.

Objectives

When you have completed this chapter, you will be able to do the following:

1. Describe electrical and fire safety precautions
2. Describe the lockout and tagout procedures associated with interior wiring
3. Describe the contents and use of the National Electrical Code® manual
4. Describe the procedures for balancing different electrical loads
5. Describe the service entrances
6. Describe the different types of interior wiring systems
7. Describe below grade interior wiring systems
8. Describe above grade interior wiring systems
9. Describe the different types of conduit systems
10. Describe the installation methods of conduit support equipment
11. Describe the different types of distribution panels
12. Describe the different procedures for pulling conductors
13. Identify hazardous locations associated with interior wiring systems
14. Describe the different types of electrical devices utilized with interior wiring
15. Describe the usage of electrical test equipment
16. Describe the testing procedures utilized with electrical circuits
17. Describe troubleshooting and repair methods of interior wiring systems
18. Describe the different types of lighting systems
19. Describe the troubleshooting and maintenance of lighting systems
20. Identify the different types of scaffolding

Prerequisites

None

This course map shows all of the chapters in Construction Electrician Basic. The suggested training order begins at the bottom and proceeds up. Skill levels increase as you advance on the course map.

1.0.0 INTRODUCTION

At any Navy or advanced base, the electrical system consists of three parts: the power plant that supplies the electrical power, the distribution system that carries the electrical current from the generating station to the various buildings, and the interior wiring systems that feed the electrical power to the appliances and equipment within a building.

As defined here, interior wiring begins at the point where the distribution system's service leads are connected to the wiring from within the building and extends through each circuit of the interior wiring of the building to the last fixture installation.

In this chapter, we will discuss your responsibilities in meeting various code and specification requirements and a variety of techniques for installing, repairing, and maintaining interior wiring systems.

2.0.0 ELECTRICAL SAFETY

Safety for the electrician is far more complicated today than it was 20 years ago. But with proper use of today's safeguards and safety practices, working on electrical equipment can be safe. Electricity must be respected. With common sense and safe work practices, you can accomplish electrical work safely.

An electrician must know and be able to apply the principles of electricity safely. If you disregard your own safety, you also disregard the safety of your fellow workers. Remember that the time to prevent an accident is before it happens. Respect for electricity comes from understanding electricity. Whenever in doubt, always ask your supervisor. Report any unsafe condition, unsafe equipment, or unsafe work-practices to your supervisor as soon as possible.

2.1.0 Fuses

Before removing any fuse from a circuit, be sure the switch for that circuit is open or disconnected. When removing fuses, use an appropriate type of fuse puller and break contact on the hot side of the circuit first. When replacing fuses, install the fuse first into the load side of the fuse clip, then into the line side.

2.2.0 Electrical Shock

Electrical shock occurs when a person comes in contact with two conductors of a circuit or when his or her body becomes part of the electrical circuit. In either case, a severe shock can cause the heart and lungs to stop functioning. Also, because of the heat produced by current flow, severe burns may occur where the current enters and exits the body.

Prevention is the best medicine for electrical shock. Respect all voltages and follow safe work procedures. Do not take chances. CEs, with the exception of very few personnel with special training, are not qualified to work on live circuits.

2.3.0 Portable Electric Tools

When using portable electric tools, always make sure they are in safe operating condition. Make sure there is a third wire on the plug for grounding in case of shorts. Theoretically, if electric power tools are grounded and if art insulation breakdown occurs, the fault current should flow through the third wire to ground instead of through the operator's body to ground. Always use a ground-fault circuit-interrupter (GFCI) with portable electric tools. New power tools are double insulated, reducing the need for a ground prong; but for safety reasons, they still should be used with a GFCI.

2.4.0 Out-of-Service Protection

Before performing any repair on a piece of electrical equipment, be absolutely certain the source of electricity is open and tagged or locked out of service. Whenever you leave your job for any reason or cannot complete the job the same day, be sure the source of electricity is still open or disconnected when you return to continue the work. Seabees have died because they did not follow proper tag and lockout procedures. These procedures are a must. Following them takes time, but your life is worth doing it.

2.5.0 Safety Color Codes

Federal law (OSHA) has established specific colors to designate certain cautions and dangers. *Table 8-1* shows the accepted usage. Study these colors and become familiar with all of them.

Table 8-1 – OSHA safety color codes.

OSHA SAFETY COLOR CODES	
Red	Fire protection equipment and apparatus; portable containers of flammable liquids; emergency stop buttons; switches
Yellow	Caution and for marking physical hazards, waste containers for explosive or combustible materials; caution against starting, using, or moving equipment under repair; identification of the starting point or power source of machinery
Orange	Dangerous parts of machines; safety start buttons; the exposed parts (edges) of pulleys, gears, rollers, cutting devices, and power jaws
Purple	Radiation hazards
Green	Safety; location of first aid equipment (other than fire fighting equipment)

2.6.0 Clothing and Personal Protective Equipment

As a crew leader, you must be familiar with required safety equipment and the conditions under which your crew must use it to perform assigned tasks safely. The following is a list of common clothing and protective equipment requirements for working around electricity.

- Wear thick-soled work shoes for protection against sharp objects, such as nails. Wear work shoes with safety toes if the job requires.
- Wear electrically insulated gloves when there is the slightest chance that you might come in contact with energized parts.
- Wear rubber boots in damp locations.
- Wear safety goggles for protection against airborne particles, electrical sparks, and acid splashes.
- Wear a hard hat. Wear an approved safety helmet when on a project site. Be careful to avoid placing your head too near rotating machinery.

- Wear Gloves when handling sharp objects.

3.0.0 FIRE SAFETY

Fire safety should always be of great concern to you as a shop supervisor or leader. Furthermore, every member of your crew should be concerned with fire safety. The following fire safety information will help you prevent or combat fires.

The chances of fire may be greatly decreased by following rules of good housekeeping. Keep debris in a designated area away from the building. Report to your supervisor any accumulations of rubbish or unsafe conditions that create a fire hazard.

If a fire should occur, however, the first thing to do is give an alarm. You must alert all workers on the job and call the fire department. In the time before the fire department arrives, a reasonable effort can be made to contain the fire. In the case of some smaller fires, use the portable fire extinguishers available at the site.

The following list gives the four common types, or classes, of fire. Each class is designated by a symbol.

- Class A fires occur in wood, clothing, paper, rubbish, and other such items. This type of fire usually can be handled effectively with water. (Symbol: green triangle.)
- Class B fires occur with flammable liquids, such as gasoline, fuel oil, lube oil, grease, thinners, paints, and so forth. The agents required for extinguishing this type of fire are those that will dilute or eliminate the air by blanketing the surface of the fire. Foam, CO^2, and dry chemicals are used, but not water. (Symbol: red square.)
- Class C fires occur in electrical equipment and facilities. The extinguishing agent for this type of fire must be a nonconductor of electricity and provide a smothering effect. CO^2 and dry chemical extinguishers may be used, but not water. (Symbol: blue circle.)
- Class D fires occur in combustible metals, such as magnesium, potassium, powdered aluminum, zinc, sodium, titanium, zirconium, and lithium. The extinguishing agent for this type of fire must be a dry-powdered compound. The dry-powdered compound must create a smothering effect. (Symbol: yellow star.)

Figures 8-1 through 8-4 show the symbols and fire extinguishers for fighting the four classes of fire. One or more of these symbols should appear on each extinguisher. Because not all fire extinguishers can be used on all types of fires, the electrician must be able to identify the proper fire extinguisher to use for each type.

Always read the operator’s instructions before using an extinguisher. Also, never use water against electrical or chemical fires. Water also should not be used against gasoline, fuel, or paint fires, as it may have little effect and only spread the fire.

Fire extinguishers are normally red. If they are not red, they should have a red background so they are easy to locate.

If you call the fire department, be ready to direct them to the fire. Also, inform them of any special problems or conditions, such as downed electrical wires or leaks in gas lines.

Figure 8-1 – Class A.

Figure 8-2 – Class B.

Figure 8-3 – Class C.

Figure 8-4 – Class D.

4.0.0 LOCKOUT / TAGOUT PROCEDURES

Utilization of proper Lockout / Tagout procedures is required as described in 29 CFR 1926 Subparts K and G, and OPNAVINST 2300.G. These standards cover the servicing and maintenance of machines and equipment in which the unexpected energization or start up of the machines or equipment, or release of stored energy could cause injury. OPNAVINST 2300.G is the governing policy for the US Navy to implement lockout/tagout program.

4.1.0 Energy Control Program

Each unit shall establish a program, consisting of energy control procedures, training, and periodic inspections, to ensure machines or equipment that could cause injury by unexpectedly energizing, starting up or releasing stored energy shall be isolated from the energy source and rendered inoperative before anyone performs servicing or maintenance on them. If an energy isolating device cannot be locked out, the energy control program shall utilize a tagout system. These energy sources include:

- Electrical from any source
- Mechanical
- Hydraulic
- Pneumatic
- Thermal (heat/steam)

Keep in mind that some equipment utilizes two or more types i.e., electrical and hydraulic. All sources of energy must be secure! Lockout / Tagout is not required for routine operation unless:

- Workers are required to remove or bypass a guard or other safety device.
- Workers are required to place **ANY** part of their body into an area where work is actually performed (point of operation).

4.2.0 Equipment

4.2.1 Lockout Device

A ***Lockout Device*** is a positive means to hold an energy-isolating device in a SAFE position in order to prevent a machine or equipment from energizing. Examples are:

- Padlock (key or combination)
- Chain and padlock
- Adapter pins
- Self-locking fasteners

A single padlock may be used for single, individual lockout procedures. Group maintenance requires a lockout device enabling EACH WORKER a place to position an individual lockout device. If the devise will not accept multiple locks or tags, a multiple device WILL BE USED. As each individual no longer needs to maintain his/her lockout/ tagout protection, that individual shall remove his/her own isolating device. An example of a lockout device is below at *Figure 8-5*.

Figure 8-5 – Lockout device.

4.2.2 Tagout Device

A ***tagout device*** is a prominent warning device which can be securely fastened to an energy isolating device. It will indicate that the energy isolating device and equipment being controlled WILL NOT BE OPERATED until its removal. The tagout device will be constructed and printed so that exposure to weather conditions will not cause its deterioration. It shall be substantial enough to prevent inadvertent or accidental removal with the use of excessive force or unusual techniques. Tag attachment, shall be of a non-reusable type, hand self-locking non-releasable with strength of no less than 50 pounds. The tag shall warn about the hazardous conditions if the machine or equipment is energized. The tag shall include a legend such as:

- **DO NOT START**
- **DO NOT OPEN**
- **DO NOT CLOSE**
- **DO NOT ENERGIZE**
- **DO NOT OPERATE**

It shall have the name of the person installing the tagout as well as the date of installation. The tag will be affixed to the individual lockout device. If it cannot be attached directly to the lockout device, it will be placed as close as possible. Lockout and Tagout devices will be standardized within the activity by color, shape and size. Tagout devices will also be standardized in print and format. *Figure 8-6* shows an example of a Tagout Device.

Figure 8-6 – Tagout device.

4.2.3 Lockout / Tagout Log

Departments or spaces will maintain a log for documenting lockout and tagout procedures conducted in their spaces. The log shall include:

- The tag serial number
- The tool or equipment locked/tagged out
- Location (building number, room)
- When the lock was applied and removed
- The lock number (if applicable)
- A remarks section
- A signature block of the person performing the lockout/tagout

4.3.0 Application (prior to maintenance)

Lockout / tagout will be performed by authorized personnel ONLY. They shall be designated and trained and must have a thorough knowledge of the machine or equipment to include:

- Type and magnitude of the energy
- Hazards of the energy to be controlled
- Methods or means of controlling the energy

An orderly shutdown will be established to minimize the danger and inform affected personnel. The lockout device is then affixed ensuring it properly disables the energy supplying device. At that time the tagout device is attached DIRECTLY TO the lockout device. All potentially hazardous stored or residual energy, including capacitors, hydraulics and pneumatic, shall be relieved and rendered safe. ENSURE you secure all energy producing devices

If the potential for re-accumulation of stored energy exists, the system will need to be verified safe on a periodic schedule. Prior to starting work, an authorized person will verify the isolation or de-energizing of the equipment.

4.4.0 Release from Lockout / Tagout

Prior to release from lockout / tagout, the individual who applied the lockout/tagout device shall inspect the work area to ensure the removal of all non-essential items and ensure the machine or equipment components are operationally safe. The individual who applied a particular lockout / tagout device will remove it and notify all affected personnel of the removal. When the authorized employee who applied the lockout / tagout is not available, it may be removed ONLY under the direction of a supervisor familiar with the shutdown. The supervisor will also be familiar with the removal procedures mentioned. The supervisor will first verify the following:

- That the authorized person is no longer at the facility or job site
- That all reasonable efforts have been made to contact the authorized person and inform them of the removal
- That the authorized person has knowledge of the removal PRIOR TO starting work the next day or shift

4.5.0 Tagout

Tagout may be used on equipment that cannot be locked out but only with the Department Head’s or Company Commander’s approval.

4.6.0 Energized Circuits

Installation or maintenance of energized circuits WILL NOT BE PERFORMED without permission of the Commanding Officer.

4.7.0 Training

All personnel authorized to perform work or who are affected by the lockout / tagout procedures will receive training as well as annual refresher training. All training shall be documented in individuals’ training record.

Test your Knowledge (Select the Correct Response)

1. **(True or False)** Always use a ground-fault circuit-interrupter (GFCI) with portable electric tools.

   A. True
   B. False

2. What should be your first action if a fire occurs on your job site?

   A. Run
   B. Attempt to extinguish the fire
   C. Give an alarm
   D. Tell your supervisor

3. **(True or False)** Lockout and tagout devices must be standardized within an activity by color, shape and size.

   A. True
   B. False

5.0.0 NATIONAL ELECTRICAL CODE (NEC)®

The current edition of the National Electrical Code® contains the requirements for installing electrical systems. Those requirements are specific and detailed, and they change somewhat as the complexity of the system to be installed increases. Therefore, check the NEC® for proper installation of all electrical systems.

5.1.0 Standards

The National Fire Protection Association (NFPA) prepares and publishes the National Electrical Code® (NEC®) every 3 years. Use the latest publication and volume reference. The NEC® is an accepted guide for the safe installation of electrical conductors and equipment. Its purpose is to safeguard personnel and buildings and their contents from hazards arising from the use of electricity. Naval Facilities Engineering Command (NAVFACENGCOM) recognizes the NEC® and uses it as its minimum standard.

How does the NEC® minimize the dangers mentioned above? Briefly, the NEC® provides the following:

- Various methods of wiring and descriptions of materials
- Techniques for wiring designs and protection
- Requirements of general and special equipment
- Special conditions and occupancy information
- A variety of tables and examples for calculations

The NEC® provides Construction Electricians (CEs) with a guide, which they must strictly observe, that minimizes electrical hazards to personnel and to buildings and their contents.

At this time we are going to distinguish between 3 important electrical terms. As a CE, you will need to know the difference between the terms ***grounded***, ***grounded conductor***, and ***grounding conductor***. Grounded, as defined by the NEC®, means connected to the earth or to some other conducting body that serves in place of the earth. A grounded conductor is a circuit conductor that is intentionally grounded. A grounding conductor is a conductor used in connecting equipment in the circuit of a wiring system to a grounding electrode or electrodes. As a CE, you should make it a point to learn the difference between these terms, since you will encounter them throughout your career. Use the NEC®; study it, and learn it. A working familiarity with this reference will prove useful to you, and as you advance in rate, teach your junior personnel the importance of this valuable guide.

5.2.0 NEC® Terminology

5.2.1 Mandatory Rules

Mandatory Rules of this code are those that identify actions that are specifically required or prohibited. These rules are characterized by the use of the terms "SHALL" or "SHALL NOT". These are rules with which you **MUST** comply.

5.2.2 Permissive Rules

Permissive rules of this code are those that identify actions that are allowed but not required. These rules normally describe options or alternative methods and use terms such as "SHALL BE PERMITTED" or "SHALL NOT BE REQUIRED". Permissive rules are simply options or alternative methods of achieving equivalent safety; they are not requirements.

5.2.3 Modifications

Local ordinances may amend the NEC® language, changing the term "SHOULD" to "SHALL." You must comply with the regulations for the locality in which you are working.

5.3.0 NEC® Arrangement

The NEC® Code is divided into an introduction (article 90) and nine (9) chapters. Chapters 1, 2, 3, and 4 apply to electricians generally; Chapters 5, 6, and 7 apply to special occupancies, special equipment, or special conditions; Chapter 8 covers communications systems and is not subject to the requirements of Chapters 1 through 7 except where the requirements are specifically referenced in Chapter 8. Chapter 9 consists of tables and examples. Annexes are not part of the Code; they are included in the NEC® for informational purposes only. There is also a table of NEC® Contents at the beginning and an index and annexes A-G at the back.

5.3.1 Chapter Divisions

Articles are subdivided into sections. Sections may contain one sentence or paragraph and can be further subdivided. The following is a general breakdown of the Articles and chapters:

- Article 90, Contents
- Article 90.1, Purpose
- Article 90.2, Scope
- Article 90.3, Code Arrangement
- Article 90.4, Enforcement
- Article 90.5, Mandatory Rules, Permissive Rules, and Explanatory Material
- Article 90.6, Formal Interpretations
- Article 90.7, Examination of Equipment for Safety
- Article 90.8, Wiring Planning

- Article 90.9, Units of Measurement
- Article 100 (Chapter 1), Definitions
- Article 110, Requirements for Electrical Installations
- Article 200 through 285.25 (Chapter 2), Wiring design and protection which includes: grounded conductors, branch circuits, feeders, feeders, calculations, services, over current protection and grounding
- Article 300 through 398.104 (Chapter 3), Rules on wiring methods and materials. It also discusses the type of building, type of occupancy and the location of wiring. This article's rules apply to all wiring installations unless specified otherwise in the NEC® articles and sections.
    - There are Four (4) basic types of wiring methods used in a modern system: Sheathed cables of 2 or more conductors, Raceway wiring systems, Bus ways, and cable trays
    - Chapter 3 gives a complete description of all types of electrical conductors
    - Articles 318 and 384 contain rules for raceways, boxes, cabinets and fittings. It does not describe in detail all types and sizes
    - Article 380 covers switches, push buttons, pilot lamps, receptacles and power outlets
    - Article 384 covers switchboards and panel boards including locations, installation methods, clearances and over current protection
- Article 400 through 490.74 (Chapter 4), Equipment for General Use. Covers use and installation of flexible cords and cables.
    - Article 410 covers lighting fixtures, installation procedures and installations in specific locations. It does not describe fixture illumination requirements.
    - Article 430 covers electric motor information to include mounting motors and electrical connections
    - Article 440 through 460 covers air conditioning and heating equipment
    - Article 480 covers battery operated electrical systems
- Articles 500 through 590.7 (Chapter 5), Special Occupancies. Cover special occupancy spaces, areas where sparks generated by electrical equipment may cause a fire or explosion.
    - Articles 500 through 501 cover different types of special occupancy atmospheres which are considered to be a hazard.
    - Articles 501.4, 502.4, and 503.3 cover the installation or wiring in hazardous locations.
    - Articles 511 and 514 regulate garages and similar locations where volatile or flammable liquids are used.
    - Article 520 covers theaters, audience areas of motion picture and television studios, performance area, and similar locations.
    - Chapter 5 also covers residential storage garages.
- Articles 600 through 695.14 (Chapter 6), Special Equipment
    - Article 600 covers electric signs and outline lighting.

- Article 610 covers cranes and hoists.
- Article 620 covers electrical work involved with elevators, escalators, and moving walks.
- Article 630 covers electric welding equipment.
- Article 640 covers wiring for sound recording and similar equipment. This is normally low voltage wiring.
- Article 660 covers X-ray equipment.
- Article 665 covers induction and heat generating equipment.
- Article 670 covers industrial machinery.

- Article 700 through 780.7 (Chapter 7), Special Conditions. Covers the installation of emergency lighting systems.
- Article 800 through 830.179 (Chapter 8), Communications Systems. Covers wiring associated with electronic communications systems to include telephone, radio, TV, community antenna systems and fire/burglar alarm.
- Chapter 9 contains tables and examples
- Annex A, Product Safety Standards. This annex provides a list of product safety standards used for product listing where that listing is required by the Code.
- Annex B, Application Information for ***Ampacity*** Calculation. This annex provides application information for ampacity calculated under engineering supervision.
- Annex C, Conduit and Tubing Fill Tables for Conductors and Fixture Wires of the Same Size
- Annex D, Examples. This annex provides sample calculations
- Annex E, Types of Construction. This annex briefly describes the five different types of construction.
- Annex F, Cross-Reference Tables. This annex is provided to cross reference between the 2005, 2002, and 1999 editions of the NEC® as well as an alphabetical cross-index.
- Annex G, Administration and Enforcement. This annex briefly defines authority and jurisdiction.

Test your Knowledge (Select the Correct Response)

4. How often is the National Electrical Code® prepared and published?

A. Every year
B. Every 2 years
C. Every 3 years
D. Never

5. Chapter 8 of the NEC® covers what specific wiring subject?

A. Bus ways and cable trays
B. Lighting fixtures
C. Installation of flexible cords and cables
D. Communications systems

6.0.0 BALANCE ELECTRICAL LOADS

6.1.0 Purpose

The purpose of load balancing is to reduce the voltage drop that results from overloading one side of the incoming service. It also prevents the possibility of overloading the neutral. A perfectly balanced load between the supply conductors reduces current flow in the neutral to zero.

6.2.0 Bus Bar Arrangements

Conductors cannot be connected to a panelboard by attaching each one as you come to it. Several factors determine the arrangement or sequence of attaching conductors to the panelboard: the arrangement of the bus bars in the panelboard, whether the circuits are 240 volts or 120 volts, and the need to balance the load on the phase conductors. Bus bars are installed into panelboards in one of several ways. Most of the time, the bus bars are run in a vertical configuration. One arrangement uses a split-bus panelboard that has all the 240-volt circuits in the upper section and the 120-volt circuits in a lower section. Another type of split-bus panelboard uses one main circuit breaker to feed one set of branch circuits and a second main circuit breaker to feed a second set. In many cases, panelboards are designed so that any two adjacent terminals can be used to provide 240-volt service. This arrangement also means that two 120-volt circuits attached to adjacent terminals are connected to different phase conductors. Since there are so many panelboard layouts, you must look at the panelboard to see how it is set up for 240-volt service, and you must be sure you get the conductors for 240-volt circuits connected to the proper terminals.

6.3.0 Connections

Loads connected to a panelboard should be divided as evenly as possible between the supply conductors. This process of equalizing the load is commonly referred to as load balancing. Its purpose is to reduce the voltage drop that results from overloading one side of the incoming service. It also prevents the possibility of overloading the neutral. A perfectly balanced load between the supply conductors reduces current flow in the neutral to zero. Load balancing is no problem for the 240-volt circuits on a three-wire, single-phase system since the load has to be equal on each phase conductor. However, the 120-volt circuits are a different matter. These must be connected in such a way that the loads tend to equalize. Generally speaking, the simplest way to balance the load on a panelboard is to connect an equal number of branch circuits to each phase conductor. This method does not necessarily give you a balanced load, as is evident at the top of *Figure 8-7*. As you can see, the indiscriminate connection of branch circuits without consideration of their loads can cause an unbalanced condition. On the other hand, you can connect the circuits so that one with a heavy load is offset by one with a light load, which does result in the balanced condition shown in the bottom of *Figure 8-7*. Most of the time, you should be able to connect half of the lighting circuits and half of the appliance circuits to each phase conductor to give you a reasonably well-balanced load. Spare circuits should also be equalized. There is one more thing to consider: Appliance circuits where the loads are known to be heavy must be divided between the phase conductors.

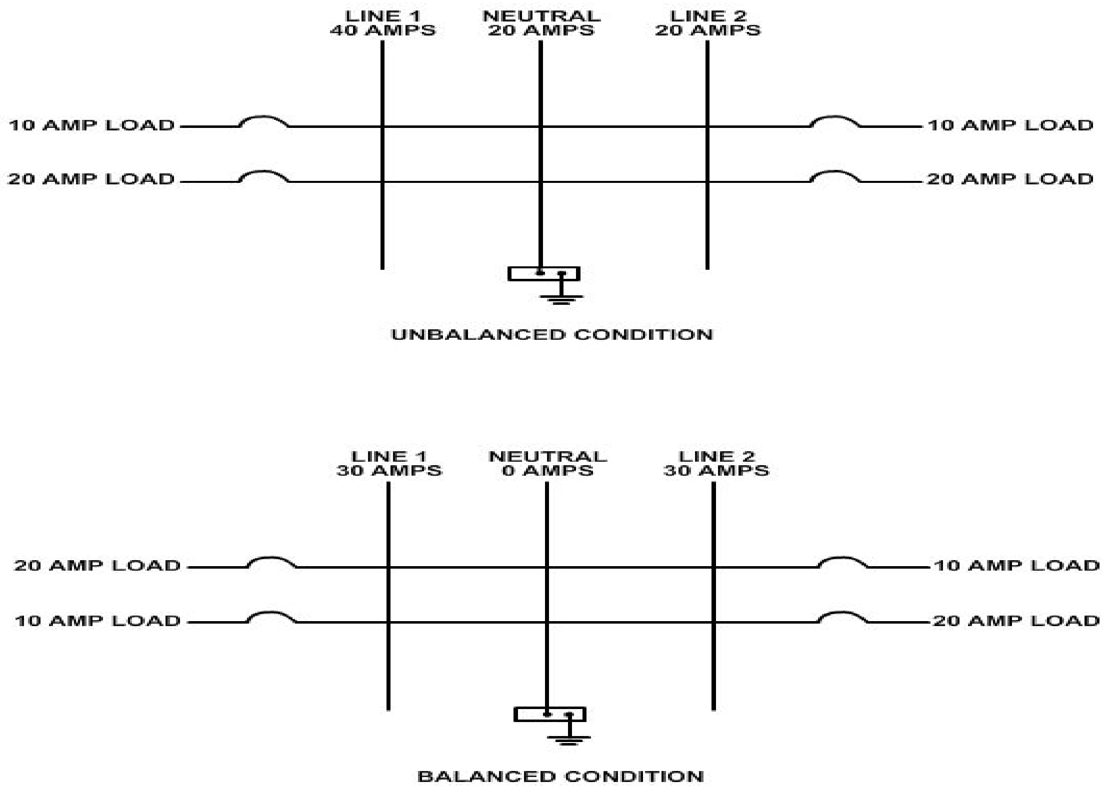

Figure 8-7 – Load balancing.

Test your Knowledge (Select the Correct Response)

6. **(True of False)** The process of equalizing the load is commonly referred to as load balancing.

   A. True
   B. False

7.0.0 SERVICE ENTRANCE SYSTEM

The starting point for interior wiring is the ***service entrance***. It is connected to the service drop. The service entrance is made up of several components, but before we get into the specifics concerning the service entrance, let us look briefly at the wiring system used to supply a building. The types of electrical systems that are to be installed are determined mostly by what the building is to be used for and the type of equipment that is to be used. Generally speaking, electrical loads are divided into four categories: two-wire, single-phase; three-wire, single-phase; three-wire, three-phase; and four-wire, three-phase.

7.1.0 Wiring Systems

7.1.1 Two-wire, single-phase system

The simplest wiring system is a two-wire, single-phase type, shown in *Figure 8-8*. This system is used in small buildings where the primary requirement is lighting. It can also be used to operate 120-volt appliances and motors. The two-wire system consists of one underground, insulated conductor and one identified (grounded) conductor, which is called the neutral. This system is limited to the operation of 120-volt equipment and relatively light loads of 50 amperes or less. Larger Loads can be better served by another type of wiring system. The two-wire systems requires the use of an equipment-grounding conductor that may be a separate conductor, conduit, or other recognized means of grounding.

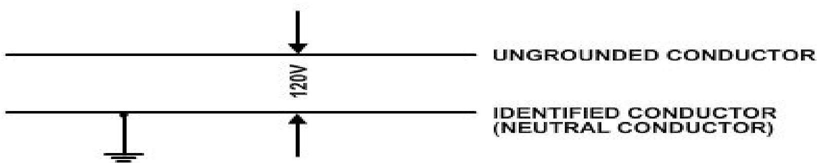

Figure 8-8 – Two-wire, single-phase system.

7.1.2 Three-wire, single-phase system

Figure 8-9 shows the three-wire, single-phase wiring system, used for both lighting and power. This system, commonly known as “220,” “110,” (single phase), uses two ungrounded conductors and a neutral conductor, which is grounded. It provides 110 volts between each ungrounded conductor and the neutral. It also provides 220 volts between the two ungrounded conductors. This system is used for lighting and power loads, such as air conditioners and heating equipment. The three-wire, single-phase system provides up to twice the power available from a two-wire system with conductors of the same size provided the load is balanced between the two underground conductors. The 110 three-wire, 220 volts is the most common system used in residences today. This system also requires an equipment-grounding conductor.

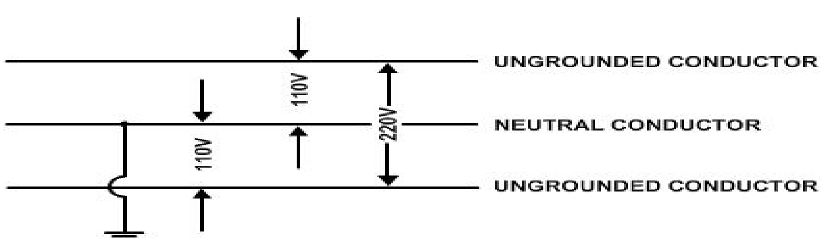

Figure 8-9 – Three-wire, single-phase system.

7.1.3 Three-wire, three-phase system

A second type of three-wire system is the three-wire, three-phase system shown in *Figure 8-10*. This system furnishes power, usually 220 volts, to installed equipment. If some lighting is needed, 220-volt fixtures and bulbs can be installed, but be aware that there are certain restrictions on lighting circuits exceeding 120 volts.

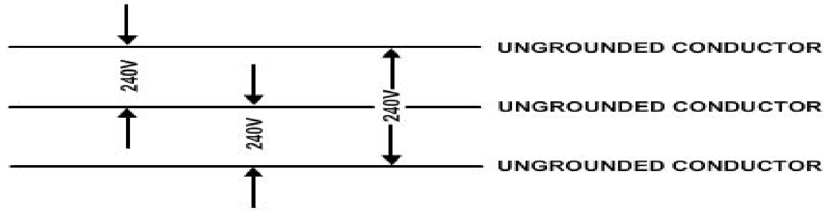

Figure 8-10 – Three-wire, three-phase system.

When substantial amounts of power are required, this type of system may provide higher voltages, such as 480 volts AC.

7.1.4 Four-wire, three-phase system.

The last type of wiring system in common use is the four-wire, three-phase system illustrated in *Figure 8-11*. This system has three ungrounded phase conductors plus a grounded neutral. This system is a combination of light and power and offers quite a cost reduction over a three-wire, single-phase system for the same amount of power. The usual voltages are 120/208 or 120/240 VAC, depending on the type of transformer connections used.

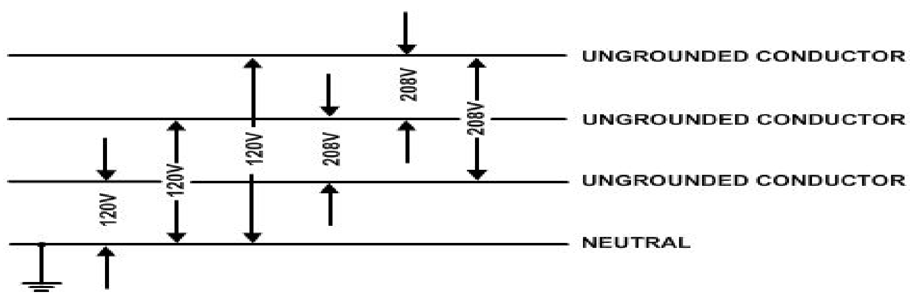

Figure 8-11 – Four-wire, three phase system.

7.2.0 Service Entrance

The service entrance brings power from the service drop to the panelboard inside the building. One component of the service entrance is the conductors through which the current flows. The conductors may consist of individual wires run through a protective raceway, such as rigid metal conduit, electrical metallic tubing, or rigid non-metallic conduit. The raceway provides the conductors with protection from both physical and weather damage. Power may also be brought into the building by means of service entrance cable. This cable does not need raceway protection unless it is

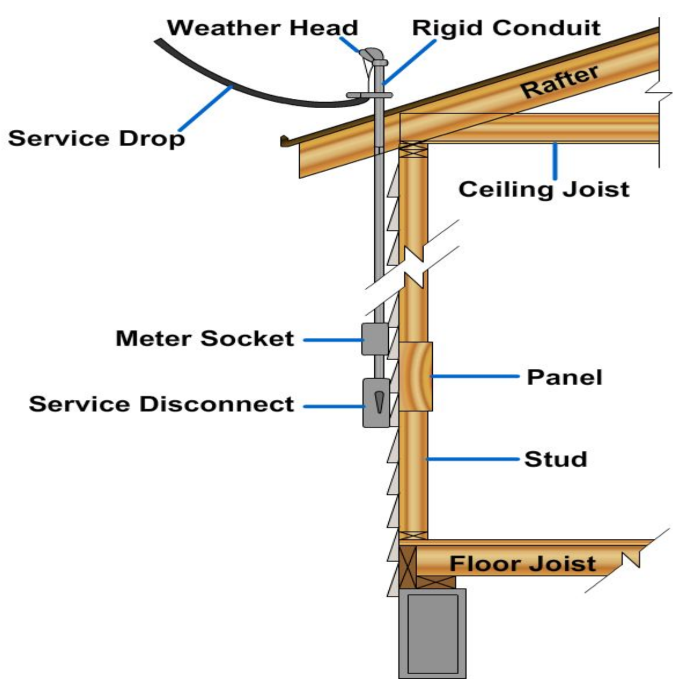

Figure 8-12 – Service mast service entrance.

likely to be physically damaged by abrasions or by being struck by passing equipment. A weather head, also called a service head, shown in *Figure 8-12*, is used with a raceway to provide an exit for the conductors from the raceway. The weather head is designed to prevent the entrance of rain into the raceway. The conductor holes in the service head are designed to reduce abrasion to the insulation. You may need to measure power delivered to the building to determine how much power it uses. When this measurement is necessary, install a watt-hour meter socket (*Figure 8-13*) in the service entrance circuit in order to include a wattmeter to record power consumption. Article 230 of the NEC® covers the service conductors and equipment for control and protection of services and their installation requirements.

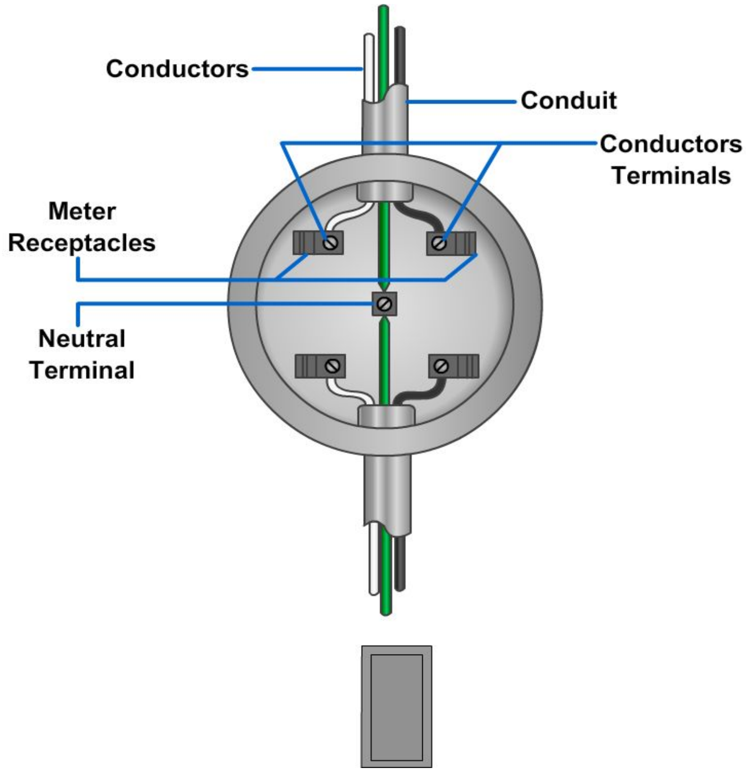

Figure 8-13 – Meter socket and wiring.

7.3.0 Service Disconnects

The service entrance must provide a means of disconnecting the service entrance conductors from the interior building circuits. Install the service disconnecting means at a readily accessible location either outside of a building or structure, or inside nearest the service conductors' point of entrance. Use a service disconnect, or main switch, to turn off all interior power in case of a fire or other emergency conditions. A disconnect switch is also useful when you perform work on the panelboard or on two or more circuits at the same time. Disconnecting service conductors requires overcurrent protective devices. You may use several types of service entrance. One of these is the knife-blade switch with one, two, or three blades, as needed, to open the circuit. *Figure 8-14* shows a two-pole knife-blade disconnect. As you can see, this switch has two fuses directly beneath the movable blades.

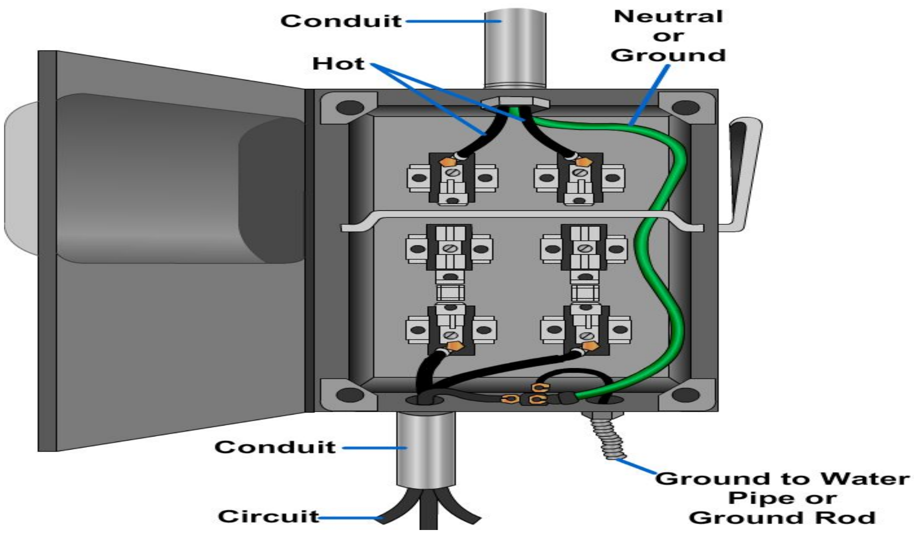

Figure 8-14 – Service entrance disconnect and overcurrent protection.

Another type of disconnect is the fuse block. The fuse block contains a fuse for each underground conductor. Removal of the fuse block has the same effect as opening a switch to interrupt current flow. A third method of providing for service disconnect and overcurrent protection is the circuit breaker. These may be installed as a multiple assembly with a single-switch handle. You must permanently mark the service disconnect to identify it as a service disconnecting means. The grounded conductor is not normally attached to the disconnect switch, but when it is, the switch must be in the form of a circuit breaker, and all the ungrounded conductors must open simultaneously with the grounded conductor. Regardless of whether it is switched, the grounded conductor must be fixed so it can be disconnected. A terminal or bus bar to which all grounded conductors can be attached by means of pressure connectors meets this requirement. The service entrance must be grounded to a low-resistance ground (refer to section 250 of the NEC®). Normally, a ground rod is driven into the ground for this purpose, but you may use a metal underground water pipe in direct contact with the earth for 10 feet or more and electrically continuous to the points of connection of the grounding electrode conductor and the bonding conductors. Another way to ground the service entrance is to use the nearest available effectively grounded structural metal member of the building for grounding. Once you have identified a suitable grounding electrode, attach the grounded or neutral conductor to it. Install the grounding electrode conductor as a continuous conductor from the neutral bus bar to the grounding electrode. Small grounding conductors are enclosed in a protective metal covering that should be electrically continuous from the panelboard cabinet to the grounding electrode. Metal raceways, meter sockets, panelboard cabinets, and the grounding electrode conductor enclosure must all be electrically bonded together and to the grounding electrode conductor so as to be electrically continuous. This arrangement results in all metal parts and enclosures in the service entrance and the grounded conductor having the same potential electrically.

Test your Knowledge (Select the Correct Response)

7. Generally speaking, how many categories are electrical loads divided into?

   A. Two
   B. Three
   C. Four
   D. Five

8. **(True or False)** The simplest wiring system is a three-wire, single-phase system.

A. True
B. False

9. **(True of False)** The service entrance serves to bring power from the service drop to the panelboard inside the building.

A. True
B. False

8.0.0 INTERIOR WIRING SYSTEMS

The requirements for installing electrical systems are found in the current edition of the National Electrical Code® (NEC®). The requirements are specific, detailed, and change somewhat as the complexity of the system increases. Therefore, check the Code for proper installation of electrical systems. Every interior wiring job you will be assigned will have its own particulars, depending upon what type of building or structure you are assigned to wire. One of these particulars is whether to use rigid, flexible, or thin-wall conduits. Another is the type of conductors you will use, whether single or a cable with multiconductors, such as Romex or flexible cord. These particulars, as mentioned above, depend on what type of job you are assigned, temporary or hard-wired, block, or drywall construction. Use the information provided here to become familiar with installation requirements. Learn to use the proper cable, conductors, and conduit in the correct place. Make sure you are familiar with the various methods of bending, joining, and installing the various materials, and learn to select the proper fittings and accessories to install those materials. Look up the NEC® articles the chapter indicates. This action will help you get acquainted with the NEC®. A good CE takes pride in doing a neat, safe, and proper job.

8.1.0 Types of Wiring

8.1.1 Rigid Metal Conduit

Rigid metal conduit (RMC) is a threadable raceway of circular cross section designed for the physical protection and routing of conductors and cables and for use as an equipment grounding conductor when installed with its integral or associated coupling and appropriate fittings. RMC is generally made of steel (ferrous) with protective coatings or aluminum (nonferrous). Special use types are silicon bronze and stainless steel. The number of conductors shall not exceed that permitted by the percentage fill specified in Table 1, Chapter 9 of the NEC®.

8.1.2 Intermediate Metal Conduit

Intermediate metal conduit (IMC) is a steel threadable raceway of circular cross section designed for the physical protection and routing of conductors and cables and as an equipment grounding conductor when installed with its integral or associated coupling and appropriate fittings. IMC is a thinner-walled rigid metal conduit (RMC) that is satisfactory for uses in all locations where RMC use is permitted. Table 1, Chapter 9 of the NEC® specifies the maximum fill percentage for IMC.

8.1.3 Rigid Nonmetallic Conduit

Rigid nonmetallic conduit (RNC) is a nonmetallic raceway of circular cross section, with integral or associated couplings, connectors, and fittings for the installation of electrical conductors and cables. The 2005 UL General Information for Electrical Equipment Directory (White Book) describes two types of RNC recognized for use in accordance with the NEC®. They are Rigid Nonmetallic Schedule 40 and Schedule 80 PVC Conduit (DZYR) and Reinforced Thermosetting Resin Conduit (DZKT). Do not exceed the number of conductors permitted by the percentage fill specified in Table 1, Chapter 9 of the NEC®.

8.1.4 Electrical Metallic Conduit

Electrical metallic conduit (EMC), usually fabricated of steel, encloses electrical wiring, thereby protecting the wiring from outside damage. The difference between electrical metallic conduit and electrical metallic tubing is that conduit is heavy-walled and usually has threaded ends; in contrast, tubing is thinner and is not threaded.

8.1.5 Flexible Metallic Tubing

Flexible metallic Tubing (FMT) is a raceway that is circular in cross section, flexible, metallic, and liquidtight without a nonmetallic jacket. A common application of FMT is as a branch-circuit wiring method for equipment or luminaries mounted on or above suspended ceilings. The number of conductors depends on size and will not exceed the allowable percentage fill specified in Table 1, Chapter 9 of the NEC®.

8.1.6 Flexible Metal Conduit

Flexible metal conduit (FMC) is a raceway with a circular cross section; it is made of helically wound, formed, interlocked metal strip. The number of conductors shall not exceed that permitted by the percentage fill specified in Table 1, Chapter 9 of the NEC®, or as permitted in Table 348.22 of the NEC®.

8.1.7 Liquidtight Flexible Metal Conduit

Liquidtight flexible metal conduit (LFMC) is a raceway of circular cross section; it has an outer liquidtight, nonmetallic, sunlight-resistant jacket over an inner flexible metal core with associated couplings, connectors, and fittings for the installation of electric conductors. The number of conductors shall not exceed that permitted by the percentage fill specified in Table 1, Chapter 9 of the NEC®.

8.1.8 Surface Metal Raceway

A surface metal raceway is a metallic raceway that is mounted to the surface of a structure, with associated couplings, connectors, boxes, and fittings for the installation of electrical conductors. The number of conductors or cables installed in a surface metal raceway shall not be greater than the number for which the raceway is designed. The number, type, and size of conductors permitted to be installed in a surface metal raceway are marked on the raceway or on the package in which it is shipped.

8.1.9 Electrical Nonmetallic Tubing

Electrical nonmetallic tubing (ENT) is a nonmetallic pliable corrugated raceway of circular cross section; it has integral or associated couplings, connectors, and fittings for the installation of electric conductors. ENT is composed of a material resistant to moisture and chemical atmospheres and is flame retardant. A pliable raceway is a raceway that can be bent by hand with a reasonable force but without other assistance. The number of conductors shall not exceed that permitted by the percentage fill in Table 1, Chapter 9 of the NEC®.

8.1.10 Armored Cable

Armored cable (Type AC) is a fabricated assembly of insulated conductors in a flexible metallic enclosure. Underwriters Laboratories lists Type AC armored cable in sizes 14 AWG through 1 AWG copper and 12 AWG through 1 AWG aluminum or copper-clad aluminum and rates it at 600 volts or less. Some examples of where Type AC armored cable are permitted are as follows:

- In both exposed and concealed work
- In cable trays
- In dry locations
- Embedded in plaster finish on brick or other masonry, except in damp or wet locations
- To be run or fished in the air voids of masonry block or tile walls where such walls are not exposed or subject to excessive moisture or dampness

8.1.11 Metal-Clad Cable

Metal-clad cable, Type MC is a factory assembly of one or more insulated circuit conductors, with or without optical fiber members, enclosed in an armor or interlocking metal tape or a smooth or corrugated metallic sheath. Some examples of where Type MC cable shall be permitted follows:

- For services, feeders, and branch circuits
- For power, lighting, control, and signal circuits
- As aerial cable on a messenger
- In a raceway
- In hazardous (classified) locations as permitted

8.1.12 Nonmetallic Sheathed Cable

Nonmetallic sheathed cable is a factory assembly of two or more insulated conductors enclosed within an overall nonmetallic jacket. There are three types of this cable. They are:

- Type NM, which has insulated conductors enclosed within an overall nonmetallic jacket
- Type NMC, which has insulated conductors enclosed within an overall, corrosion resistant, nonmetallic jacket
- Type NMS, which has insulated power or control conductors with signaling, data, and communications conductors within an overall nonmetallic jacket

8.2.0 Conductors and Cable Systems

Electrical conductors generally consist of drawn copper or aluminum formed into a wire. They provide paths for the flow of electric current and usually have insulating material encasing the metal. The insulation material minimizes short circuits and protects personnel. Atmospheric conditions, voltage requirements, and environmental and operating temperatures are factors to consider in selecting the type of insulating material for a particular job.

8.2.1 Single Conductors

A conductor may consist of a single solid wire or a combination of a number of solid wires (stranded) that are not insulated from each other and share in carrying the total current. A stranded conductor has the advantage of being more flexible than a solid conductor, making it more adaptable for pulling through bends in the conduit. Conductors vary in diameter. Wire manufacturers have established a numerical system called the American Wire Gauge (AWG) standard. Table 8 of the NEC® shows how this numerical system eliminates the necessity for cumbersome, circular mil or fractional inch diameters in the description of wire sizes. Notice that the wire gauge numbers increase from 4/0 through 18 as the diameter of the wire decreases.

8.2.2 Size, Number, and Ampacity

The wire size most frequently used for interior wiring is Number 12 AWG, used as a solid or stranded copper conductor. Table 310.17, column 2, of the NEC® shows the allowable ampacity of a single conductor in free air. Number 12 AWG (for types FEPW, RH, RHW, THW, THWN, XHHW, and ZW insulation) has an allowable ampacity of 35 amperes. However, the minute that same conductor is not alone in free air and is placed in a raceway, cable, or direct burial, its ampacity, as table 310.16, NEC® shows, is reduced to 25 amperes, provided that not more than three conductors are in the raceway or cable. *Table 8-2* of this chapter indicates the reduced ampacity, according to the NEC®, for a variety of conductors in such a situation.

Table 8-2 – Percentage of current-carrying capacity of conductors.

Number of Conductors	Percent of Normal Current-Carrying Capacity
4 through 6	80
7 through 24	70
25 through 42	60
43 and above	50

Suppose now that you have four to six Number 12 AWG wires in a conduit. The allowable current-carrying capacity would be only 80 percent of the normal, or 20 amperes. To ensure a current-carrying capacity of 25 amperes, you would have to use Number 10 wire with a normal current-carrying capacity of 35 amperes, 80 percent of which is 28 amperes.

8.2.3 Cables

A cable is an assembly of two or more conductors insulated from each other with an additional insulating or protective shield formed or wound around the group of conductors.

8.2.4 Nonmetallic Sheathed Cable

Nonmetallic sheathed cable is more commonly called nonmetallic cable, NM cable, or Romex. Nonmetallic cable consists of two or three insulated conductors in an outer sheath. It may have an added insulated or bare conductor to be used as an equipment ground. The outer sheath is made of a moisture-resistant, flame-retardant, nonmetallic material either of thermoplastic or treated braid. Nonmetallic cable has copper, aluminum, or copper-clad aluminum conductors. Copper conductors used in cable range in size from Number 14 to Number 2 AWG, aluminum conductors from Number 12 to Number 2 AWG. Specific descriptive information must be marked on the exterior of nonmetallic cable, repeating at intervals of at least every 24 inches. This information includes the manufacturer’s name or trademark, maximum working voltage, wire size, and cable type. Most cable is also marked to show the number of conductors and whether it has a ground, as shown in *Figure 8-15*.

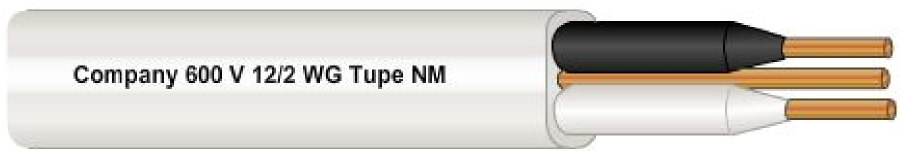

Figure 8-15 – Markings on nonmetallic cable.

The ground wire is used to ensure the grounding of all metal boxes in the circuit, and it also furnishes the ground for the grounded type of convenience outlets. Nonmetallic cable comes in two types: NM and NMC. Type NM cable has a flame-retardant and moisture-resistant cover. Type NMC cable is corrosion-resistant. Its covering is flame-retardant, moisture-resistant, fungus-resistant, and corrosion-resistant. Refer to the NEC®, Article 336, for Types NM and NMC uses permitted and not permitted. In naval installations, Romex is used primarily for temporary structures, such as on Quonset huts. Civilian contractors, however use it extensively for residential wiring. All connections in Romex must be at the junction or outlet boxes. Saddle, straight clamps, or cable connectors must secure the cable to the boxes. In installations where Romex is permitted, fasten the ground wire securely to create a good mechanical and electrical ground. When a bend is made in Romex, the radius of the bend should be not less than five times the diameter of the cable.

8.3.0 Box Selection

There is no firm requirement that a certain type of box be installed for a specific purpose. The usual practice is to install octagonal boxes for lighting outlets and rectangular and square boxes for switches and receptacle outlets. Round boxes are normally installed overhead for lighting purposes especially where the fixture canopy must cover the box. However, when the need arises because of inside space requirements, wall-surfacing materials, number of electrical devices to be mounted, or availability of boxes, almost any box can be used for any purpose. The size and number of conductors to be installed in a box have a definite impact on the selection of a box. Each conductor in a box must have some free air space to prevent a buildup of heat. As a result, the more conductors, or the larger their size, the bigger the box in which they are installed must be. The cubic inch capacity of a box is determined by its length, width, and depth. An increase in one or more of these dimensions increases box capacity.

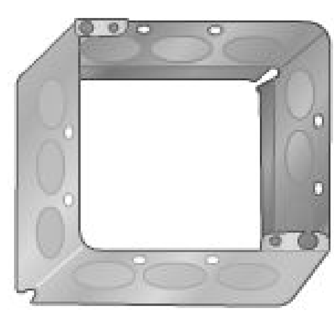

Figure 8-16 – Extension ring.

When gangable boxes are assembled together, box volume is the total of all sections assembled together. Also, when a raised cover or a box extension with volume markings is added to a box, as shown in *Figure 8-16*, its capacity is added to the volume.

Select the box to be mounted in each location after you know the number and size of conductors it will contain. In many cases, the usual box for the intended purpose is not adequate. To ensure proper air space for a conductor in a box, consult Table 314.16(A) for metal boxes in the NEC®. This table lists dimensions for common boxes, their capacity in cubic inches, and the maximum permitted number of conductors in wire sizes Number 18 through Number 6. The number of conductors listed does not make allowance for fixture studs, cable clamps, grounding conductors, switches, or receptacles, or straps for mounting these devices. Deduct one conductor from those listed when the box contains one or more fixture studs or cable clamps. Each strap containing one or more devices requires deduction of one conductor. Also, deduct one conductor for one or more grounding conductors that enter the box. Count a conductor that runs through the box as one conductor. Each conductor that terminates in the box counts as one. Fixture wires and conductors that do not leave the box, such as an internal grounding wire, are not counted. Let us use an example to see how the table works. Two receptacle outlets are to be installed using Number 12 nonmetallic cable. One is to be an extension to the other. Device boxes with cable clamps are to be used if possible. The first step is to determine the number of conductors that will be wired through the box. Two conductors plus a grounding conductor enter this box. Also, if a second outlet is to be connected to this one, then two conductors plus a grounding conductor must leave the box. If the preceding rules are followed, we have four conductors plus one for the grounding conductors, the equivalent of one conductor for the cable clamps, and the equivalent of one conductor for the receptacle outlet. This method gives us an equivalent of seven conductors. The table for metal boxes in the NEC®, has no listing given for seven Number 12 conductors in a device box. There are a couple of listings for eight conductors; one indicates a device box (3 X 2 X 31/2 inches) is required. Since there will be an equivalent of just five conductors in the device box for the second outlet, the table shows a (3 X 2 X 2 1/2 inch) box to be adequate. The table does not cover all the requirements for conductor space in boxes. Boxes of 100 cubic inches or less are not covered by the table, and nonmetallic boxes are marked with their cubic inch capacity. When these boxes are used or when conductors of different sizes are installed in the same box, the number of conductors allowed in a box is based on the free air space requirement for each conductor. The free air space needed is given in Table 314.16(B) in the NEC®. According to the table, the volume of space needed in cubic inches per conductor is 2 for Number 14, 2¼ for Number 12, 2½for Number 10, and so on. As an example, if a box is to contain four Number 10 conductors and two Number 12 conductors, multiply 4 times 2 1/2 and 2 times 2 1/4. This equals 14 1/2 cubic inches, the minimum sized box that can be installed. Outlet and junction boxes are installed in a number of ways in either new construction or an old building. Article 314 of the NEC® gives the installation rules for outlet, switch, and junction boxes. In most cases, boxes in new construction are fastened with nails or screws. Usually, nails are better because they are cheaper and quicker to use. Unless the box has a bracket on it, the side of the box must be removed to use screws for mounting. Some of the newer box mounting brackets have prepunched and preformed devices that are driven into wood framing to support the box in the place of nails.

8.3.1 Nail Through Box Mounting

One of the simpler boxes to mount is a device box. Boxes without brackets are mounted by putting two sixteen penny nails (3 1/2 inches long) through the holes in both sides of the box and then driving them into the wood framing member (stud). Nails that pass through the inside of a box must not be more than a quarter inch from the bottom (or back) of the box, as shown in *Figure 8-17*. Also, note the markings on the side of the box. These are depth markings which let you easily install the box to project the proper distance from the edge of the stud to offset the thickness of the wall material that will be installed.

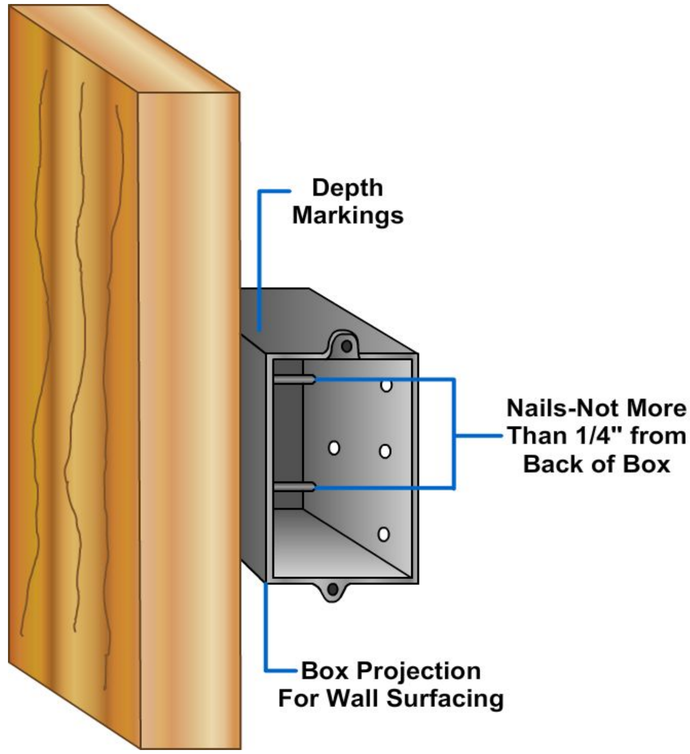

Figure 8-17 – Box installed with nails.

Another way to mount device boxes with sixteen penny nails is shown in *Figure 8-18*. In this case, the nails are outside the box, eliminating the possibility of wiring interference inside. The extension of the box sides, as is done here to provide for nailing, is often referred to as an S bracket mount. The bracket is made so that the nails can be driven straight or on a slant, depending on whichever is easier. Being able to drive the nails at a slant is especially useful when stud spacing is less than normal. The notches on the front outer ends of the bracket serve as a depth guide for mounting, the same as the markings mentioned before.

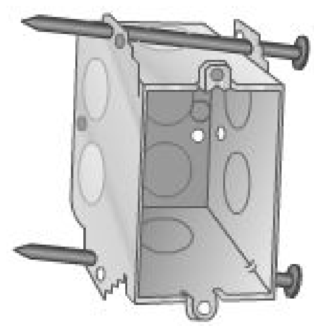

Figure 8-18 – S bracket box.

Many boxes come with attached brackets of various designs. Several of these brackets are shown in *Figure 8-19*. The D bracket is the simplest of the group and is simply an extended box side. It is nailed or screwed to the stud and has notches to serve as an installation guide. The next bracket is the A bracket. As you can see, it is a straight bracket with a turned-over upper edge that fits over the edge (face) of the stud. When nailed from both the front and side, this bracket makes an extremely strong mounting. The A brackets come attached to the boxes at varying distances from their edges to allow for use with different thicknesses of wall material.

The B bracket is made to fasten the box to the face of the stud.

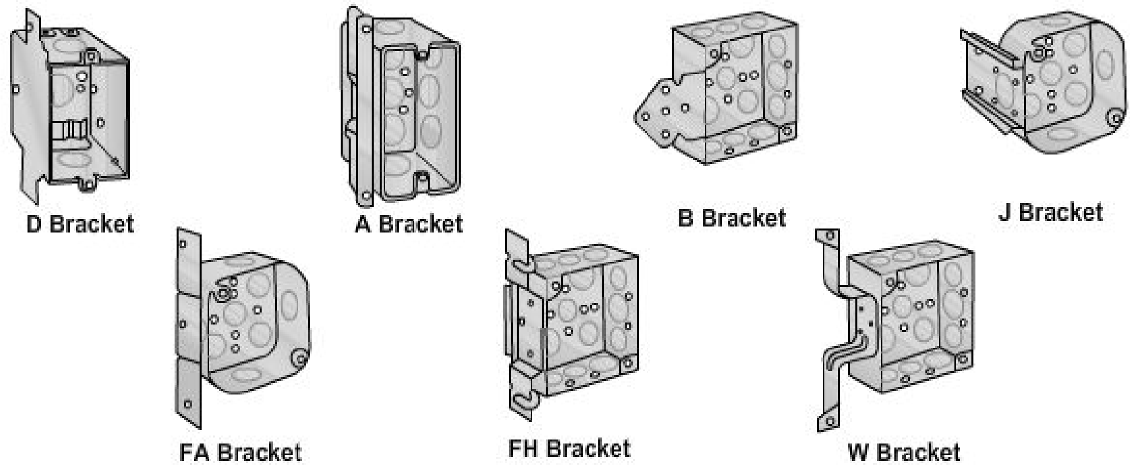

Figure 8-19 – Assorted box mounting brackets.

It has spurs that, when driven into the stud, hold the box in place while you nail it. The bracket may be attached to the box so it projects slightly above the edge, as shown in the illustration. This bracket prevents the device cover and its holding screws from causing a bulge in sheetrock used for the wall surface. B brackets on device boxes are located at various depths to coincide with the thickness of the finished wall. Some B brackets are about twice as long as the one shown. These brackets are suitable for mounting on doorway framing studs to place switches and their cover plates beyond the edge of the door trim. This same bracket may be attached to the end of a device box for the horizontal mounting of a switch or receptacle.

The J bracket is used the in the same way as any other bracket fastened directly to the side of a stud. The holes are slotted to permit the box to be toe nailed. The bracket is flush with the edge of the box and has gauging notches for positioning. This bracket has a knockout that allows installation of conduit through the stud into the box.

The FA bracket is similar to the D bracket, except it is welded to the side of the box. It also has a positioning spur to assist in holding the box in place for nailing. The bracket is offset from the edge of the box one-half inch or five-eighths inch to allow for wall material thickness.

The FH bracket is similar to the FA bracket, except it has two barbed hooks that drive into the face of the stud. The bracket is welded flush on square boxes and offset one-half inch on device boxes. Driving the barbed hooks into the stud face and nailing the side makes a very rigid mount. The W bracket is fastened to both the face and side of the stud to provide a rigid mount. Since it stands the box off to the side of the stud, it is used to provide clearance between switches and switch plates and doorway trim, as does the long B bracket.

8.3.2 Box Mounting on Metal Framing

Much modern construction makes use of metal framing members. The ones with which you are concerned most are studs and doorframes. Boxes can be attached to metal framing members with sheet metal screws or machine bolts and nuts. However, special attaching devices are available.

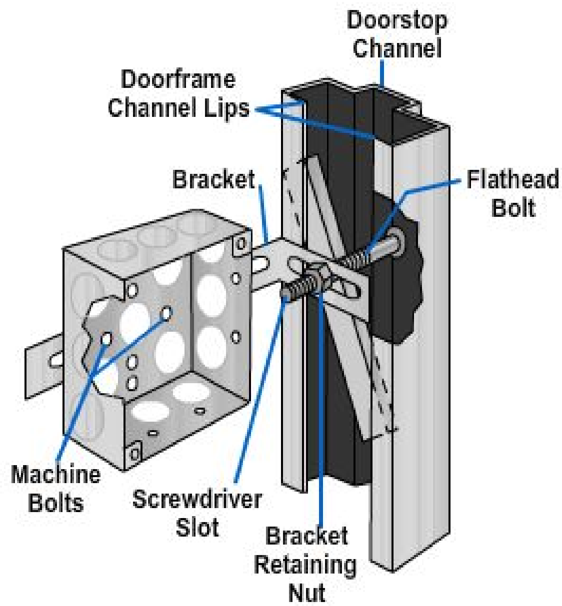

Figure 8-20 – Box mounting on metal doorframe.

A special anchor, shown in *Figure 8-20*, provides a quick, simple method of installing a box on a doorframe. This anchor allows the box to be adjusted in all directions; that is, toward or away from the frame, the depth from the outside wall surface, and up or down as needed. The nut on the bolt shown in the figure holds the bracket to the anchor and must be loose while the anchor is installed. The anchor itself consists of a flathead bolt with a screwdriver slot and a threaded channel. The channel comes in two sizes; one for narrow doorframes not over 4 inches wide and a second for doorframes up to 7 inches wide. The anchor is set in place by inserting it in the frame channel with the flathead of the bolt toward the doorstop channel and the threaded channel under the lips of the doorframe. The anchor is locked in place by inserting a screwdriver in the slot of the bolt and turning it clockwise until the bolt is tight. As you can see in the figure, the bracket is adjustable and held in position by the tightened nut on the bolt. The box is adjustable toward or away from the doorframe and is attached to the bracket with two machine bolts and nuts.

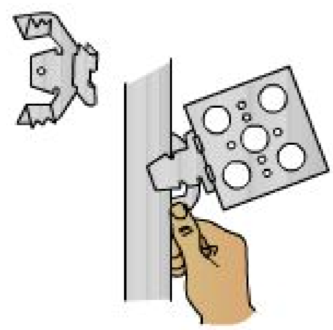

Figure 8-21 – Box mounting on metal stud with spring clip.

Metal spring clips provide a quick and easy way of mounting boxes onto metal studs. The same clip will work on studs of more than one design and size, such as the 1 5/8 to 3 5/8-inch C channel and truss types of studs. They are designed to mount square boxes with cover plates and to permit mounting device boxes flush with various thicknesses of wall surfacing. A metal spring clip is shown above in *Figure 8-21*. To mount a box, tap the clip over the open edge of the box, then tip the box so the upper prong slips behind the face of the stud, as you can see in the figure. Press the lower prong back with your thumb until it slips behind the stud face and locks the box in place. You can move easily move the box up or down on the stud by releasing the spring tension. You can also attach boxes to metal framing members with sheet metal screws or machine bolts and nuts.

8.3.3 Box Mounting Between Framing

At times, boxes must be mounted between the wall supports instead of directly on them. This positioning is particularly true of ceiling lights where the joists do not coincide with the spot at which the light is to be placed. In such cases, boxes must be mounted on a separate support attached to the structure. These supports may be purchased in the form of bar hangers or metal straps, or they may be constructed from metal straps or wooden strips. *Figure 8-22* shows two typical bar hangers and two metal strap supports.

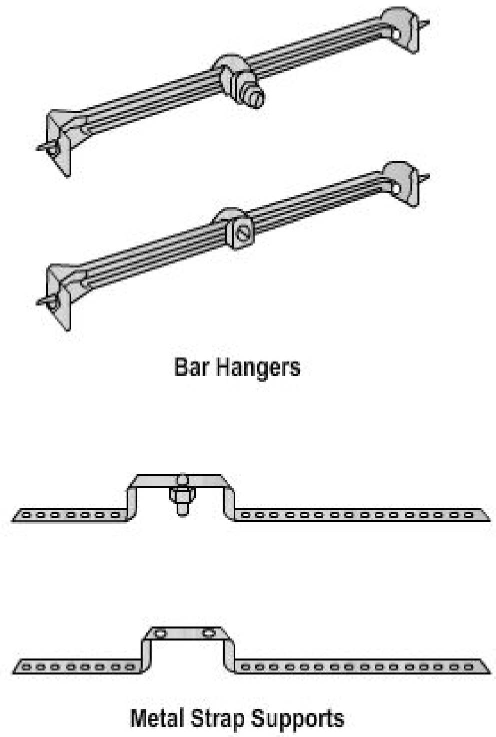

Figure 8-22 – Box supports.

You can see that one of the bar hangers includes a fixture stud that also serves to support the box when it is installed through the knockout in the box bottom. The other bar hanger supports the box by means of a clamp installed through the bottom knockout. Bar hangers with boxes already attached are available. Bar hangers come in different lengths; each has a range of adjustment to fit spaces of varying widths. Bar hangers are fastened in place by nails driven into the side of the joist or stud. Attach bar hangers with sheet metal screws or machine bolts and nuts instead of nails when metal framing is involved.

Metal straps may have fixture studs or slotted mounting holes for attaching the box with machine bolts and nets. Strap supports come in different lengths with several nail holes in each end to fit various width spaces. Strap supports are nailed to the face of the joist or stud. They have different offsets to fit different box depths or installation needs. Metal strap supports can be made similar to the manufactured one shown in the lower part of *Figure 8-22*. Determine hole locations and drill holes as needed for the specific installation being made.

Wood supports can be made in a number of ways. The simplest is shown in *Figure 8-23*. It consists of a piece of 1 X 4-inch lumber cut to length to fit between the joists and nailed in place. Allow for the depth of the box plus the thickness of the ceiling material when positioning the board for nailing. In some cases, two 1 X 4s may be nailed up with the wide dimension perpendicular to the joist or stud faces and the box mounted between them. Sometimes the ends of the 1 X 4 X 4-inch support is nailed to 1 X 4 X 4-inch blocks which, in turn, are nailed to the joists.

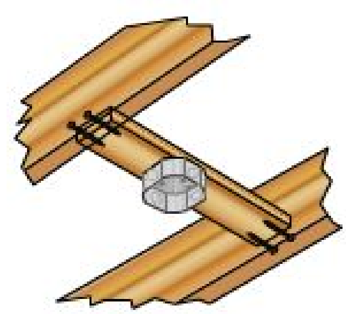

Figure 8-23 – Wood box support.

8.3.4 Box Mounting in Existing Structures

A completely different method of box mounting is required when making a concealed extension to an existing circuit or adding a new concealed circuit in an existing structure. The procedures discussed here pertain to mounting boxes in hollow walls, that is, walls such as sheetrock or plaster on studs. Boxes must be equipped with plaster ears to help anchor them in place.

One method of hollow wall mounting is shown in *Figure 8-24*. This method uses two sheet metal brackets to hold the box in place.

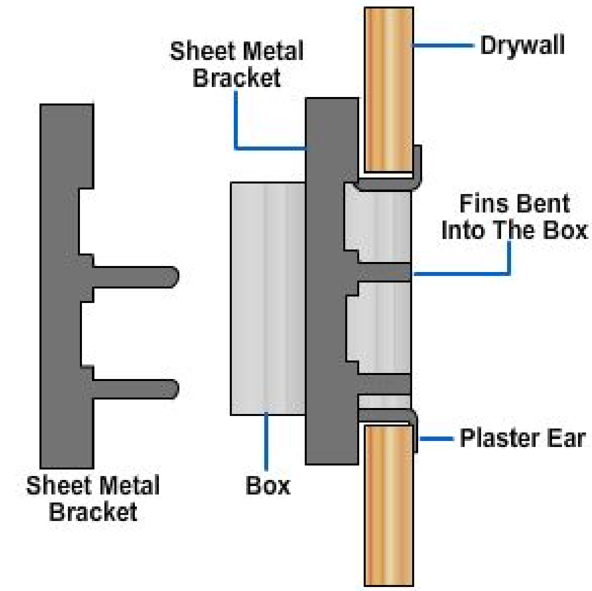

Figure 8-24 – Bracket support of box in hollow wall.

The first step for this type of mounting is to locate and cut the mounting hole. After the hole is cut, hold the box in place in the hole with the plaster ears against the wall. Slip a bracket with the fins pointing out, long end first, between the box and the wall. Slide the bracket up until the short end clears the hole. Push the short end into the hole and slide the bracket downward to center the fins with the box. Bend the fins tightly over the box edge and down against the inside. Repeat these steps for the second bracket. The box should now be held firmly in place.

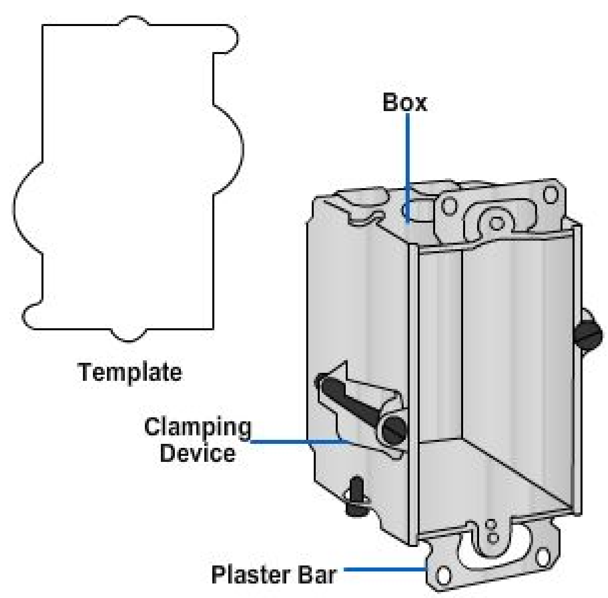

Figure 8-25 – Box with hollow wall clamps.

A second method of mounting a box in a hollow wall makes use of clamping devices attached to the box sides, as shown in *Figure 8-25*. These boxes usually come with a stiff paper template to outline the hole you must cut into the wall. If you do not have a template, put the box against the wall and draw around it. Be sure you do not include the plaster ears in your drawing. Cut the hole as indicated. Then slip the box into the hole and tighten the clamping screws until the box is firmly anchored. One variation of this method works quite well with a lath and plaster wall. On the side of the box are cleats that unfold when the screws are tightened and clamped behind the lath. In this way, they support the ends that were cut when the hole was made.

A third means of fastening a box in a hollow wall uses a support added to the box through the knockout in the back. The application of this support is shown in *Figure 8-26.*

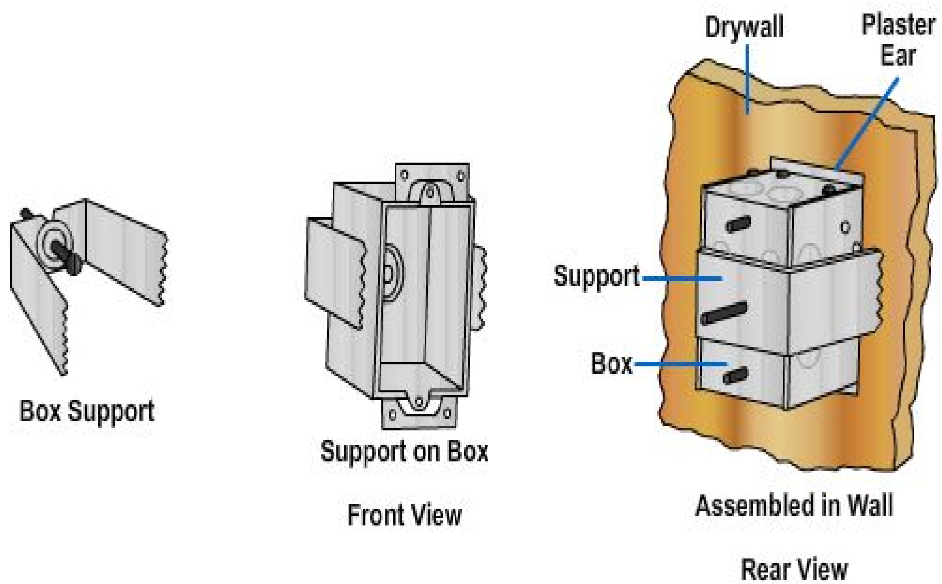

Figure 8-26 – Box support for hollow wall.

After removing the knockout, assemble the support to the box by inserting the bolt with the retaining washer through the knockout hole. Thread the bolt into the support; push the box into the prepared hole, and press on the bolt head until the ends of the support spring clear on the inside. Tighten the bolt with a screwdriver until the box is held securely in place.

8.3.5 Box Mounting Height and Location

There are no specific height requirements for mounting boxes. Seabees use NECA-1 standard for mounting height. Though it is not enforceable, uniformity needs to be established, if the height is not specified in the specifications, prints, or drawings. Mounting may be at any convenient height that meets the need for which the box is being installed. All boxes for the same purpose should be mounted at the same height. In some extreme cases, receptacle outlet boxes have been mounted in the wall parallel to the floor and just high enough to permit the cover plate to be installed. This type of installation requires you to make allowance for the base finishing material as well as for the wall material when you set box depth. Receptacles set against the floor are hard to use and hazardous in places where floors require mopping.

Listed below are the heights to be used when not specified:

1. Wall switches: 48 inches
2. Receptacle outlet: 18 inches
3. Telephone outlet: 18 inches
4. Intercom: 48 inches
5. Wall lighting outlet: 84 inches
6. Thermostat: 48 inches
7. Bed lights: 72 inches

Plans for a structure usually give heights for receptacle outlets and switches. The measurement may be from either the subfloor or the finished floor and may be to the bottom of the box; the center of the box (probably the most common), or the top of the box. The most common height for receptacle outlet boxes in the living areas of a house is 12 inches from the floor line to the center of the box. Many electricians mark their hammer handles to use as a guide for installing outlet boxes at the proper height, as shown in *Figure 8-27*. You can use any number of other guides, such as a rule or a notched stick.

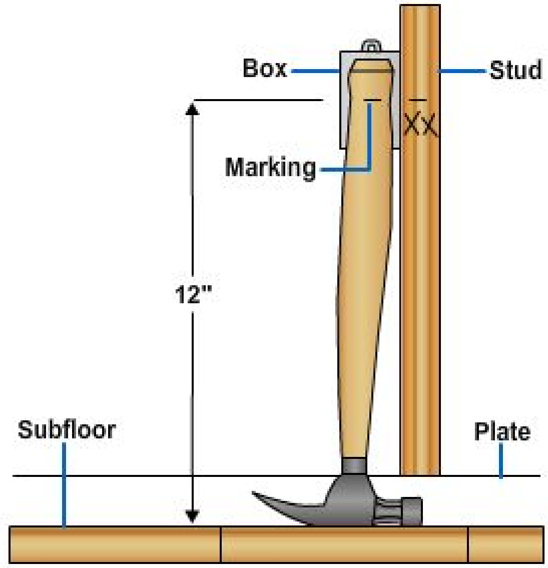

Figure 8-27 – Measuring box mounting height.

It is fairly common practice to mark the exact location of each wall-mounted box on the studs throughout the building before beginning mounting. Use a lumber crayon, carpenter's pencil, or felt-tip pen that makes an easily seen mark. Use an arrowhead (←), like that shown in *Figure 8-27*, to show where to place the center of the box. The arrowhead also points to the side of the stud on which the box will be placed. As an added convenience, mark symbols near the arrow to indicate the types of device to be installed. Some examples might be XX for a duplex outlet, SS for two single-pole switches, S3 for a three-way switch, or XR for a range outlet.

Switch boxes and outlet boxes for laundry and utility rooms and garages are normally set 4 feet above the floor. This height often increases by 4 to 6 inches when wainscoting or paneling 4 feet high is included as part of the wall. Boxes for outlets over countertops are usually installed about 18 inches above the countertop (see NEC® Article 210.52(C)(5)). This measurement can vary a few inches up or down, depending on the height of the backsplash panel. Installing boxes without considering the splash panel could cause boxes to overlap different wall surface levels.

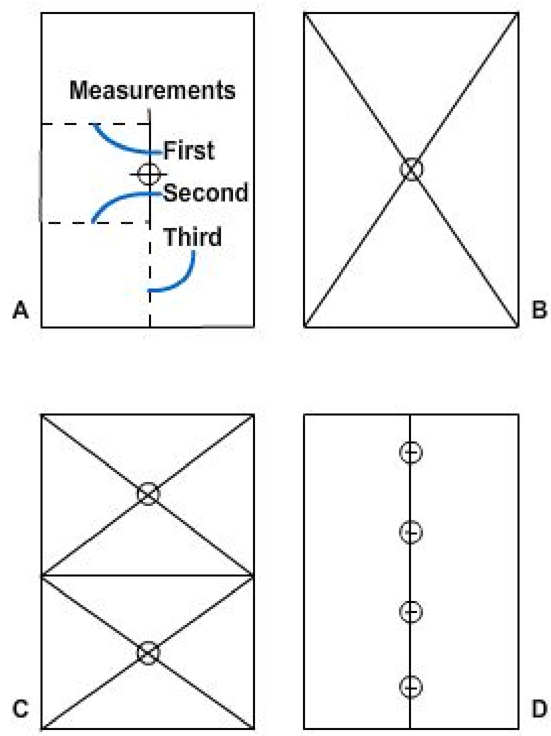

Figure 8-28 – Location of ceiling lights.

Ceiling boxes are located by a completely different method of measurement. Most rooms have at least one ceiling light located in the center of the room. You can use a number of ways to find the spot to mount a light box. One way is to use a rule or tape to find the halfway point across one dimension of the room and mark it, as shown in *Figure 8-28*, view A. Make a second measurement across the same room dimension and mark the halfway point. Connect the two marks.

Measure the other room dimension to find the center and mark it on the preceding line. This point is the place for the ceiling light box.

Figure 8-28, view B, shows another way to spot the ceiling box. Run diagonals with string from opposite corners of the room. The point where the diagonals cross is the room center. Sometimes the position of the box is laid out on the subfloor. If so, transfer the point to the ceiling using a plumb bob (a pointed weight on a string). When you suspend the plumb bob by a string held at the level of the ceiling joists with the point of the weight over the desired location, the top of the string will be at the spot to mount the box.

Many rooms require multiple ceiling lights. If only two lights are involved, measure half the length of the room and then run diagonals for each half, as shown in *Figure 8-28*, view C. This measurement procedure gives you the location for each light. A room to be lit with a row of lights will have them installed along the center line.

The lights should be spaced so that the lighting is as uniform as possible. Determine the spacing by dividing the length of the room by the number of lights. This figure is the space to be left between any two adjacent lights. Place the light at each end of the row at half the preceding distance from the wall. This spacing is shown in *Figure 8-28*, view D. If you take another look a view C, you will see that the space from the end walls to the lights is also half that of the space between the lights.

Test your Knowledge (Select the Correct Response)

10. What must each conductor in a box have to prevent a buildup of heat?

    A. More than three conductors
    B. More than four conductors
    C. Free air space
    D. Nothing

11. Nails that pass through the inside of a box must not be more than what distance from the bottom (or back) of the box?

    A. ¼ inch
    B. ½ inch
    C. ¾ inch
    D. 1 inch

12. What is the most popular height for receptacle outlet boxes in the living areas of a house?

    A. Six inches from the floor line to center of box
    B. Eighteen inches from the floor line to center of box
    C. Twelve inches from the floor line to center of box
    D. Twenty-four inches from the floor line to center of box

9.0.0 INTERIOR SYSTEMS BELOW GRADE

An electrical system installed in concrete or in direct contact with the earth is considered to be a system below grade. You must install below grade conduit layout and direct buried cable or other raceways to meet the minimum cover requirements of *Table 8-3*.

Under buildings, underground cables must be in a raceway that is extended beyond the outside walk of the building. Direct buried cables emerging from the ground will be in protected enclosures or raceways extending from the minimum cover distance, required by *Table 8-3*, below grade, to a point at least 8 feet above finished grade. There is no requirement for the protection of direct buried cables more than 18 inches below the finished grade.

Install conduit in concrete buildings while the building is being erected. Attach the outlets to the forms and the conduits between outlets to reinforced steel with metal tie wires so that the concrete can be poured around them. When several conduits pass through a wall, partition, or floor, set a plugged sheet-metal tube in the forms to provide a hole for them in the concrete. When a single conduit passes through a wall, partition or floor, you can set a nipple or plugged sheet-metal tube in the forms.

Ferrous or nonferrous metal raceways, cable armor, boxes, cable sheathing, cabinets, elbows, couplings, fittings, supports, and support hardware may be installed below grade. You may also install these materials in areas subject to severe corrosive influences when they are judged suitable for the condition or provided with corrosion protection approved for the condition.

Table 8-3 – Minimum cover requirements for 0 to 600 volts (Burial in Inches).

Minimum Cover Requirements, 0 to 600 Volts, Burial in Inches Cover is defined as the shortest distance measured between a point on the top surface of any direct-buried conductor, cable, conduit or other raceway and the top surface of finished grade, concrete, or similar cover.					
	Type of Wiring Method or Circuit				
Location of Wiring Method Or Circuit	Direct Burial Cables or Conductors **NOTE 1:** For SI units; one inch = 25.4 millimeters.	RMC or IMC **NOTE 2:** Raceways approved for burial only where concrete encased will require concrete envelope not less than 2 inches thick.	RNC Approved for Direct Burial Without Concrete Encasement or Other Approved Raceways **NOTE 3:** Lesser depths are permitted where cables and conductors rise for terminations or splices or where access is otherwise required.	RBC Rated 120V or Less With GFCI Protection and Max Overcurrent Protection of 20 Amps **NOTE 4:** Where conduit types listed in columns 1 through 3 are combined with circuit types in columns 4 and 5, the shallower depth of burial is permitted.	Circuits for Control of Irrigation and Landscape Lighting Limited to Not More than 30V and Installed with Type UF or in Other Identified Cable or Raceway
All other locations	24	6	18	12	6
In trench below 2-Inch thick concrete	18	6	12	6	6
Under building	In raceway only	Not used	Not used	In raceway only	In raceway only
Under 4-Inch concrete slab with vehicle traffic and slab extends not less than 6 inches beyond the underground installation	18	4	4	4 inches for raceway and 6 inches for direct burial	4 inches for raceway and 6 inches for direct burial
Under streets, highways, roads, alleys, driveways, and parking lots	24	24	24	24	24
One and two family dwelling driveways, parking areas	18	18	18	12	18
In or under airport runways including adjacent areas where trespassing prohibited	18	18	18	18	18
In solid rock when covered by 2inches of concrete extending down to rock	2 inches, raceway only	2	2	2 inches, raceway only	2 inches raceway only

9.1.0 Wet and Corrosive Installations

Underground-feeder cable and branch-circuit cable provide an economical wiring system for wet and corrosive installations. Type UF two-conductor cable resembles type USE service-entrance cable in general appearance. The insulation is a plastic compound. NEC® states the following with respect to its use: "Underground-feeder and branch-circuit cable may be used underground, including direct burial in the earth, as feeder or branch-circuit cable when provided with overcurrent protection not in excess of the rated current-carrying capacity of the individual conductors. If single-conductor cables are installed, all cables of the feeder circuit, sub-feeder circuit, or branch circuit, including the neutral and equipment grounding conductor, if any, will be run together in the same trench or raceway. If the cable is buried directly in the earth, the minimum burial depth permitted is 24 inches if the cable is unprotected and 18 inches when a supplemental covering, such as a 2-inch concrete pad, metal raceway, pipe, or other suitable protection, is provided. Type UF cable may be used for interior wiring in wet, dry, or corrosive locations under the recognized wiring methods of the Code, and when installed as a nonmetallic-sheathed cable, it will conform with the provisions of the Code and be of a multi-conductor type. Type UF cable also must be of a multi-conductor type if installed in a cable tray. Type UF cable will not be used (1) as service-entrance cable, (2) in commercial garages, (3) in theaters, (4) in motion picture studios, (5) in battery storage rooms, (6) in hoist ways, (7) in any hazardous location, (8) embedded in poured cement, concrete, or aggregate except as provided in the Code, and (9) where exposed to direct rays of the sun unless identified as sunlight-resistant."

9.2.0 Markings

Ungrounded conductors are available as single or multi-conductor cables. These cables are clearly marked to identify them as grounded and grounding conductors. Ungrounded conductors will be distinguished by colors other than white, natural gray, or green, or by a combination of color plus a distinguishing marking. Distinguishing markings also will be in a color other than white, natural gray, or green and will consist of one or more stripes or a regularly spaced series of identical marks. Distinguishing markings will not conflict in any manner with the surface marking requirements in the NEC®.

9.3.0 Under floor Raceway Systems

Office buildings use under floor raceway systems for installation of telephone and signal system wiring and for convenience outlets for electrically operated office machinery. Under floor raceway systems provide a flexible system by which you may easily change the location of outlets to accommodate the rearrangement of furniture and partitions. The NEC® allows their use when embedded in concrete or in the concrete fill of floors. Their installation is allowed only in locations that are free from corrosive or hazardous conditions. DO NOT install wires larger than the maximum size approved for the particular raceway. The voltage of the system must not exceed 600 volts.

An under floor raceway system consists of ducts, made of either fiber or steel, laid below the surface of the floor and interconnected by means of special cast-iron floor junction boxes. The total cross-sectional area of all conductors in a duct must be greater than 40 percent of the interior cross-sectional area of the duct.

There are two types of fiber ducts – the open-bottom type and the completely enclosing type. Steel ducts are always of the completely enclosing type and usually have a rectangular cross section. In the under floor raceway system, make provision for outlets by means of specially designed floor-outlet fittings screwed into the walls of the ducts. When using fiber ducts, lay the duct system in the floor with or without openings or inserts for outlets. After the floor has been poured and finished as desired, install the outlet fittings inserts or at any points along the ducts which require outlets. The method of installing outlet fittings is described later in this section.

When you use steel ducts, you must make provision for the outlet fittings at the time the ducts are laid before pouring the floor fill. The steel ducts are manufactured with threaded openings for outlet connections at regularly spaced intervals along the duct. During the installation of the raceway and the floor, these outlet openings are closed with specially constructed plugs the height of which you can adjust to suit the floor level.

For telephone and similar circuits, you can obtain much wider ducts. In general, under floor raceways should be installed so that there is a least 3/4 inch of concrete or wood over the highest point of the ducts. However, in office-approved raceways, they may be laid flush with the concrete if covered with linoleum or equivalent floor covering. When two or three raceways are installed flush with the concrete, they must be contiguous with each other and joined to form a rigid assembly.

Flat-top ducts over 4 inches wide but not over 8 inches, spaced less than one inch apart, must be covered with at least 1/2 inch of concrete. Standard practice is to allow 3/4-inch clearance between ducts run side by side. The center line of the ducts should form a straight line between junction boxes. If the spacing between raceways is one inch or more, the raceway may be covered with only one inch of concrete. Make all the joints in the raceway between sections of ducts and at junction boxes waterproof and have good electrical contact so that the raceways will be electrically continuous. You must properly ground metal raceways.

To establish outlets in a preset system after the finish is in place, you must determine the location of the insert. Inserts can be located by using an insert finder. Once you have located the inserts, chip the flooring down to expose the insert cap. Remove the cap and cut a hole in the duct so the wires can be fished through and connected to the receptacle. Use the following procedures to install an outlet fitting at any point in a completely enclosed under floor fiber raceway:

- Locate the duct line
- Cut a hole in linoleum or other floor covering
- Chip a hole down to duct
- Cut a hole in the duct
- Screw insert into the duct
- Anchor the insert with grouting compound
- Screw the outlet into the insert

Use the special tools, provided by the manufacturer, for this purpose to ensure satisfactory workmanship.

You may use combination junction boxes accommodating the two or three ducts of multiple-duct systems provided you furnish separate compartments in the boxes for each system. It is best to keep the same relative location of compartments for the respective systems throughout the installation. Make all joints in or taps to the conductors in the junction boxes. Make no joints or taps in the ducts of the raceway or at outlet insert points.

9.4.0 Conduit Layout

Follow the construction blueprints and specification when laying out conduit runs. Remember, most prints will not show the direction of the conduit run. They only direct you to install a circuit from the distribution panel to a location where an electrical apparatus will be serviced. When you install any circuit, complete the service installation with the shortest route possible.

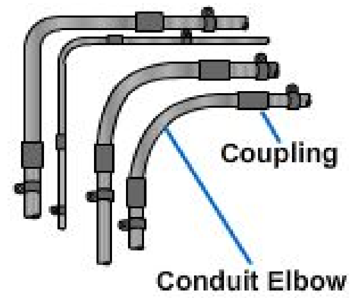

Figure 8-29 – Right angle turns with elbows.

Properly bent conduit turns look better than elbows and, therefore, are preferable for exposed work (*Figure 8-29*). If bends are formed to a chalk line, draw the chalk line as suggested in *Figure 8-30*. The conduits can be placed parallel at a turn in a multiple run, as shown in *Figure 8-31*. If you use standard elbows, it is impossible to place them parallel at the turns. They will have an appearance similar to the one shown in *Figure 8-29*. Except as discussed in the NEC®, join together metal raceways, cable armor, and other metal enclosures for conductors into a continuous electric conductor and connect it to all the boxes, fittings, and cabinets to provide effective electrical continuity. Be sure to mechanically secure raceways and cable assemblies to boxes, fittings, cabinets, and other enclosures. This action ensures electrical continuity of metal raceways and enclosures.

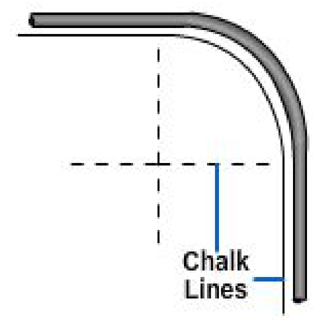

Figure 8-30 – Forming a conduit to chalk lines.

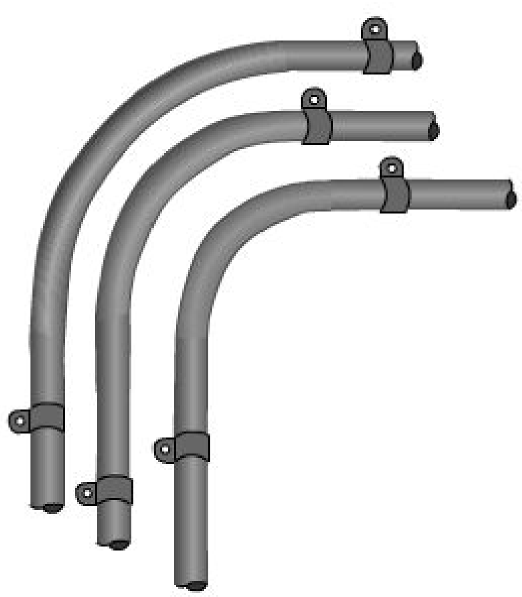

Figure 8-31 – Right-angle turns with bent conduit.

Test your Knowledge (Select the Correct Response)

13. **(True or False)** There is no requirement for the protection of direct buried cables in excess of 18 inches below the finished grade.

    A. True
    B. False

14. Concerning wet and corrosive installations, if the cable is unprotected and buried directly in the earth, what is the minimum depth permitted?

    A. 6 inches
    B. 12 inches
    C. 18 inches
    D. 24 inches

15. Ungrounded conductors will be distinguished by which of the following colors?

    A. Green
    B. Red
    C. White
    D. Natural Gray

16. What is the maximum voltage allowed by the NEC® for under floor raceway systems?

    A. 400 volts
    B. 500 volts
    C. 600 volts
    D. 800 volts

10.0.0 INTERIOR SYSTEMS ABOVE GRADE

An interior system above grade starts at the service drop and covers all conduit layouts (excluding in-the-slab), communication, power, and lighting circuits. You must be aware of the NEC® rules that govern industrial and residential interior electrical systems. To gain additional knowledge, read the following: Standard Handbook for Electrical Engineers and the American Electrician's Handbook.

10.1.0 Wiring of Buildings

An insulator bracket normally secures the power-distribution feeder from the power pole to a building. Mount brackets high enough so the power feeders are never suspended lower than 18 feet over driveways and 10 feet over walkways.

Insulator bracket service-entrance conductors run down the side of the building to a point at which they enter the building and connect to the service-entrance panel. The greatest percentage of commercial and industrial wiring is installed in a conduit or a raceway. Use service-entrance cable for this purpose.

Use armored cable or nonmetallic-sheathed cable for the interior wiring of the building.

10.2.0 Grounding

At each building, the wiring system must be grounded. This provision is in addition to the ground at the power pole. Establish grounds at each point of entrance to each building; and, if possible, tie all these grounds together on driven grounds. Also, for added safety, tie the water system at each building to the driven ground for that building. A well-grounded wiring system adds to the safety of the entire installation.

10.3.0 Wiring System General Provisions

The following discussion applies to the types of wiring used for voltages up to 600V, unless otherwise indicated. Each type of insulated conductor is approved for certain uses and has a maximum operating temperature. If the operating temperature exceeds this maximum, the insulation is subject to deterioration. In recent years, modified ethylene tetrafluoroethylene (2 and ZW) and perfluoroalkoxy (PFA and PFAH) cables have been allowed for high-temperature operations. Each conductor size has a maximum current-carrying capacity, depending on the type of insulation and conditions of use.

Do not place conductors of more than 600 volts in the same enclosure as conductors carrying less than 600 volts, but you can group together conductors of different light and power systems of less than 600 volts in one enclosure if all are insulated for the maximum voltage encountered. Do not place communication circuits in the same enclosure as light and power wiring.

Install boxes or fittings at all outlets, at switch or junction points of raceway or cable systems, and at each outlet and switch point of concealed knob-and-tube work.

10.4.0 Provisions Applying to All Raceway Systems

The number of conductors permitted in each size and type of raceway is definitely limited to provide ready installation and withdrawal. For conduit and electrical metallic tubing, refer to the NEC®. Install raceways, except surface-metal molding, as complete empty systems; draw in the conductors later. Conductors must be continuous from outlet to outlet without splice, except in auxiliary gutters and wire ways.

Conductors of Number 8 AWG and larger must be stranded. Raceways must be continuous from outlet to outlet and from fitting to fitting and securely fastened in place.

Run all conductors of a circuit operating on alternating current, if in a metallic raceway, in one enclosure to avoid inductive overheating. If, owing to capacity, you cannot install all conductors in one enclosure, each raceway used should contain a complete circuit (one conductor from each phase).

Rigid-metal conduit, intermediate metal conduit, and electrical metallic tubing are the systems generally used to install wires in raceways. Both conduit and tubing may be buried in concrete fills or may be installed exposed. Wiring installed in conduit is approved for all classes of buildings and for voltages both above and below 600V. Certain restrictions are placed on the use of tubing; refer to the NEC® for those restrictions.

10.5.0 Lighting and Power Systems

Lighting and power systems start at the panelboards. Refer to the NEC® during the installation of the lighting and power circuits for further guidance. The wiring layout in each of the illustrations contained in the NEC® determines how the component parts in the circuit connect to one another and where to route the wires. Careful planning in the wiring layout can result in substantial savings by eliminating long runs of excess wire. It should be pointed out that the wire runs shown in the actual construction illustration may not be the most economical use of wire. These wire runs are laid out in a very smooth and definite pattern to make the drawing easier to follow. In many cases, wire runs shown at right angles should be run diagonally to conserve wire. When cable runs are routed on the jobsite, shortening the runs will result in lower installation costs.

10.6.0 Service Feeders

No limit is placed on the electrical capacity of service conductors and service protection used in bringing the electric supply into a building, since only one supply should be introduced whenever possible. Near the point of entrance of the supply, the heavy-service conductors are tapped by feeders that conduct the electricity to panelboards at various load centers in the building where the final branch circuits which supply individual lighting, heating, and power outlets originate. No limits are placed on the electrical capacity of feeders; but, for practical purposes, they are limited in size by the difficulty of handling large conductors and raceways in restricted building spaces, by voltage drop, and by economic considerations.

Each lighting fixture, motor, heating device, or other item of equipment must be supplied by either a branch circuit for grouped loads, by an individual branch circuit, or by a motor branch circuit.

10.7.0 Lighting and Appliance Branch-Circuit Panelboards

In solving all installation problems with panelboards, the first consideration is to determine whether the panelboard will be a lighting and appliance branch-circuit type. The NEC® rules are much stricter for lighting and appliance branch-circuit panelboards than for other types.

The Code defines a lighting and appliance branch-circuit panelboard as one having more than 10 percent of its overcurrent devices for which neutral connections are provided are rated 30 Amps or less For example, if any panelboard with less than 10 overcurrent devices contains one overcurrent device rated at 30 Amps for which neutral connections are provided, it would be considered a lighting and appliance branch-circuit panelboard (1 ÷ 9 = 11%).

Panelboards that supply loads without any neutral connections are not considered lighting and appliance branch-circuit types whether or not the overcurrent devices are 30 Amps or less.

When a panelboard is a lighting and appliance branch-circuit type, the following NEC® rules apply:

1. Individual protection, consisting of not more than two main circuit breakers or sets of fuses having a combined rating not greater than that of the panelboard, is required on the supply side. This main protection may be contained within the panelboard or in a separate enclosure ahead of it. The following are two exceptions to the Code rule:
    a. Individual protection is not required when the panelboard feeder has overcurrent protection not greater than that of the panelboard. For example, two 400 Amp panelboards can be connected to the same feeder if the feeder overcurrent device is rated or set at 400 Amps or less.
    b. Individual protection is not required where such existing panelboards are used as service equipment in supplying an individual residential occupancy. One example is a split-bus panelboard in which the line section contains three to six circuit breakers or fuses, none of which are rated 20 Amps or less. In such an arrangement, one of the main overcurrent devices supplies the second part of the panel that contains 15 or 20 Amp branch-circuit devices. The other main overcurrent devices (over 20 Amps) supply feeders or major appliances, such as cooking equipment, clothes dryers, water heaters, or air- conditioning equipment

(*Figure 8-32*). This arrangement is permitted only for existing panelboards in existing individual residential occupancies.

2. A lighting and appliance branch-circuit panelboard is limited to no more than 42 overcurrent devices (excluding the main overcurrent devices) in any one cabinet or cutout box (*Figure 8-33*). When such devices are numbered, a single-pole circuit breaker counts as one overcurrent device, a two-pole circuit breaker as two overcurrent devices, and a three-pole circuit breaker as three overcurrent devices.

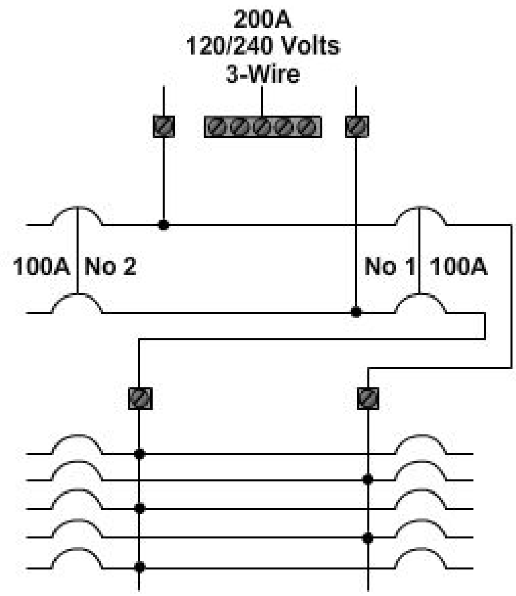

Figure 8-32 – Typical arrangement of a split-bus lighting panelboard.

In addition, the panelboards will be provided with physical means to prevent the installation of more overcurrent devices than the panelboard was designed, rated, and approved to handle. *Figure 8-34* shows a suitable arrangement for overcurrent devices.

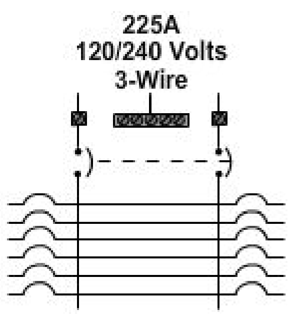

Figure 8-33 – Typical arrangement that shows NEC® rules for lighting panelboards.

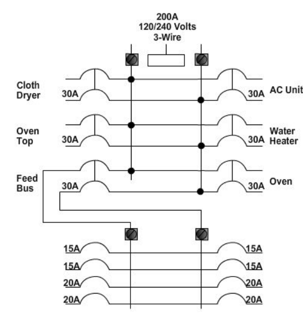

Figure 8-34 – Suitable arrangement for an existing 200 ampere lighting panelboard used as service

A typical lighting panelboard is a circuit-breaker type with a main 200 Amp circuit breaker and thirty-two 20 Amp single-pole breakers. Use this type of panel for a four-wire, three-phase, grounded neutral system. The main breaker is three-pole. The following NEC® provisions apply to all types of panelboards:

1. Panelboards equipped with snap switches rated 30 amperes or less will have overcurrent protection not in excess of 200 amperes. Circuit breakers are not snap switches.
2. Do NOT install panelboards that have switches on the load side of any type of fuse except for use as service equipment. Panelboard equipment with a snap switch is on the line side of the plug fuses and satisfies the Code.

3. The total load on any overcurrent device located in a panelboard will not exceed 80 percent of its rating. If in normal operation, the load will be continuous (3 hours or more) unless the assembly including the overcurrent device is approved for continuous duty at 100 percent of its rating.

Power distribution panels are similar to the feeder-distribution type. They have bus bars normally rated up to 1,200 amperes at 600 volts or less and contain control and overcurrent devices sized to match connected motor or other power circuit loads. Generally, the devices are three-phase.

Special panelboards containing relays and contactors can be obtained and installed for remote control of specific equipment. A thorough knowledge of all the available types of panelboards aids in the selection and installation of the proper unit.

Service-equipment panelboards for loads up to 800 amperes, containing six or fewer main fused switches, fused pullouts, or circuit breakers are available. These panels constitute service equipment and frequently contain split buses that supply branch circuit or feeder overcurrent devices installed in the same enclosure (*Figures 8-32 and 8-34*).

Feeder distribution panels generally contain circuit overcurrent devices rated at more than 30 amperes to protect subfeeders that extend to smaller branch-circuit panelboards.

10.8.0 Branch Circuits for Grouped Loads

The Summary of Branch-Circuit Requirements (NEC® Table 210.24) outlines the uses and limitations of the common types of branch circuits. Lighting branch circuits may carry loads as high as 50 amperes, although florescent lighting is limited to use on circuits of 15-ampere or 20-ampere rating. Commercial and industrial occupancies use such circuits extensively. Branch circuits supplying convenience outlets for general use in other than manufacturing areas are usually limited to a maximum of 20 amperes. The type of outlet required for heavier capacity circuits usually will not accommodate the connection plug found on portable cords, lamps, motor-driven office machinery, and so forth.

10.9.0 Individual Branch Circuits

Any individual piece of equipment (except motors) also may be connected to a branch circuit meeting the following requirements: Conductors must be large enough for the individual load supplied. Overcurrent protection must not exceed the capacity of the conductors or 150 percent of the rating of the individual load if the single-load device is a non-motor operated appliance rated at 10 amperes or more. Only a single outlet or piece of equipment may be supplied.

10.10.0 Motor Branch Circuits

Because of the peculiar conditions obtained during the starting period of a motor, and because it may be subjected to severe overloads at frequent intervals; motors, except for very small sizes, are connected to branch circuits of a somewhat different design from that previously discussed.

10.11.0 Conductors

The Code covers general requirements for conductors and their type designations, insulations, markings, mechanical strengths, ampacity ratings, and uses. These requirements do not apply to conductors that form an integral part of equipment such as motors, motor controllers, and similar equipment, or to conductors specifically provided for elsewhere in the Code.

Conductors must be insulated except where covered or where the NEC® specifically permits bare conductors. The Code covers the insulation of neutral conductors of a solidly grounded high voltage system. The Code states that stranded conductors installed in raceways must be a size Number 8 or larger with the following exceptions:

Exception No. 1: When used as bus bars or in mineral-insulated, metal-sheathed cable

Exception No. 2: When bonding conductors are required

10.11.1 Conductors in Parallel

Aluminum, copper-clad aluminum, or copper conductors of size 1/0 and larger, in each phase of the current; neutral; and grounded circuit conductors may be connected in parallel (electrically joined at both ends to form a single conductor).

Exception No. 1: Conductors in sizes smaller than Number 1/0 AWG will be permitted to run in parallel to supply control power to indicating instruments, contactors, relays, solenoids, and similar control devices provided:

1. They are contained within the same raceway or cable
2. The ampacity of each individual conductor is sufficient to carry the entire load current shared by the parallel conductors
3. The overcurrent protection is such that the ampacity of each individual conductor will not be exceeded if one or more of the parallel conductors become inadvertently disconnected

10.11.2 Equipment Grounding Conductors

Bare, covered, or insulated grounding conductors will be permitted. Individually covered or insulated grounding conductors will have a continuous outer finish that is either green or green with one or more yellow stripes.

Exception No. 1: An insulated or covered conductor larger than Number 6 will be permitted, at the time of installation, to be permanently identified as a grounding conductor at each end and at every point where the conductor is accessible. These conductors are identified by one of the following means:

1. Stripping the insulation or covering from the entire exposed length
2. Coloring the exposed insulation or covering green
3. Marking the exposed insulation or covering with green tape or green adhesive labels

Exception No. 2: Where the conditions of maintenance and supervision assure that only qualified persons will service the installation, an insulated conductor in a multi-conductor cable will be permitted, at the time of installation, to be permanently identified as a grounding conductor at each end and at every point where the conductor is accessible by one of the following means:

1. Stripping the insulation from the entire exposed length
2. Coloring the exposed insulation green
3. Marking the exposed insulation with green tape or green adhesive labels

The following paragraphs discuss conductors in vertical conduits. You may not work very much with multistory buildings but the knowledge is still very important. Conductors in vertical conduits must be supported within the conduit system as shown in *Table 8-4*.

Table 8-4 – Spacing of Vertical Conductors Support.

CONDUCTOR SIZE	CONDUCTORS (IN FEET)	
	Aluminum or Copper-Clad Aluminum	Copper
	Not greater than	Not greater than
No. 18 through No. 8	100	100
No. 6 through No. 0	200	100
No. 00 through No. 0000	180	80
211,601 through 350,000 cmil	135	60
350,001 through 500,000 cmil	120	50
500,001 through 750,000 cmil	95	40
Above 750,000 cmil	85	35

The following methods of supporting cables satisfy NEC® requirements:

1. Approved clamping devices are constructed of, or use, insulated wedges inserted in the ends of the conduits (*Figure 8-35*). With cables having varnished-cambric insulation, clamping the conductor may also be necessary.
2. Insert junction boxes in the conduit system at required intervals. You must install insulated supports of an approved type in the junction boxes and secure them in a satisfactory manner to withstand the weight of the attached conductors. Provide the boxes with proper covers.
3. Support the cables in junction boxes by deflecting them (*Figure 8-36*) not less than 90 degrees and carrying them horizontally to a distance not less than twice the diameter of the cable. You may carry the cables on two or more insulating supports and additionally secure them by tie wires. When you use this method, support the cables at intervals not greater than 20 percent of those mentioned in the preceding table.

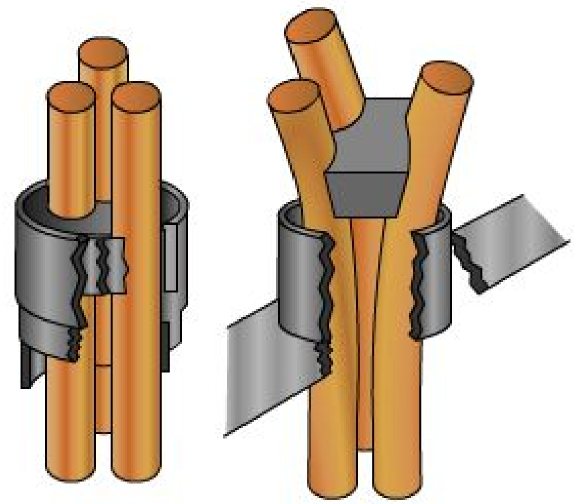

Figure 8-35 – Gable support screwed on the end of a conduit and the one piece plug type.

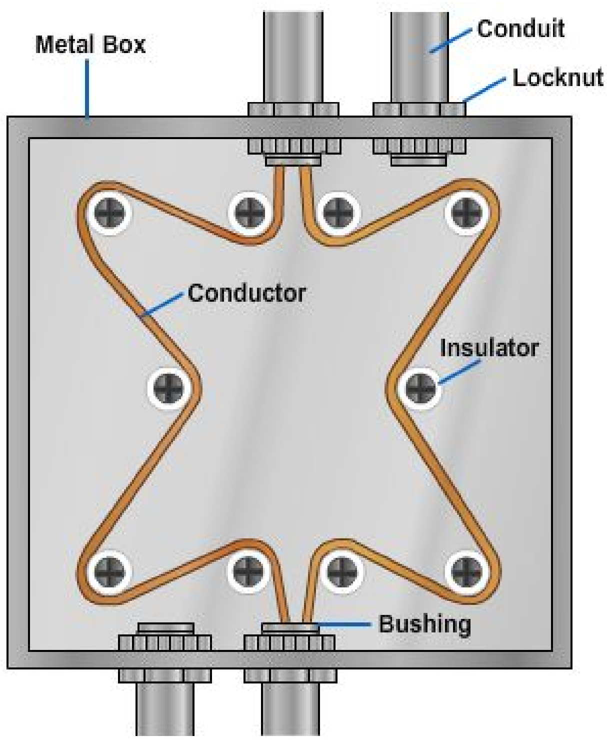

Figure 8-36 – Supporting conductors in a vertical conductor run.

Test your Knowledge (Select the Correct Response)

17. Conductors of what size AWG must be stranded?

    A. Number 4 AWG and larger
    B. Number 5 AWG and larger
    C. Number 7 AWG and larger
    D. Number 8 AWG and larger

18. **(True or False)** There is no limit placed on the electrical capacity of service conductors and service protection used in bringing the electric supply into a building, since only one supply should be introduced whenever possible.

    A. True
    B. False

19. **(True or False)** The NEC® rules are the same for lighting and appliance branch-circuit panelboards as for other branch-circuit panelboards.

    A. True
    B. False

20. On individual branch circuits, overcurrent protection must not exceed the capacity of the conductors or what percentage of the rating of the individual load if the single-load device is a non-motor operated appliance rated at 10 amperes or more?

    A. 300 percent
    B. 275 percent
    C. 200 percent
    D. 150 percent

11.0.0 INSTALLATION of NON-METALLIC CABLE

Installation of electrical circuits with non-metallic cable is fairly simple. It is usually done in two stages. The two stages are called roughing in and finish work. Roughing in is the work done before the walls and ceilings are put in place, and finish work is just what it implies, the finishing up. You splice wires as needed and install the receptacle outlets, switches, and lighting fixtures.

11.1.0 Roughing In

The main objectives in roughing in are to get circuits routed properly, to reduce the chance of damage to the cable during installation, and to reduce the chance of damage while the structure is being finished or during later modifications. Refer to Article 300 of the NEC® for wiring methods.

When roughing in your circuits, study your electrical blueprints. They will show the general location of the outlets and switches and how to route the cable. Unless you receive specific directions otherwise, the NEC® and your experience as an electrician determine the exact spot to put each outlet and switch.

A straight line is the shortest distance between two points. Electricians use this principle a great deal when routing cables. Run cable from box to box by the shortest route unless there is a good reason not to. Such routing does not always look neat, but it keeps the cost of material and labor down, and since most wiring is concealed, it is not often visible.

Cable must be fastened in place to support it and to prevent strain at boxes and connections. Cable must be anchored within 12 inches of a box, cabinet, or fitting and at points no more than 4 1/2 feet apart between boxes. NM cable is usually attached to wooden framing studs by staples (*Figure 8-37*). Take care not to drive the staples in tight enough to damage the cable. Another method for securing Romex is by using straps. *Figure 8-38* shows four types of straps used to secure cables.

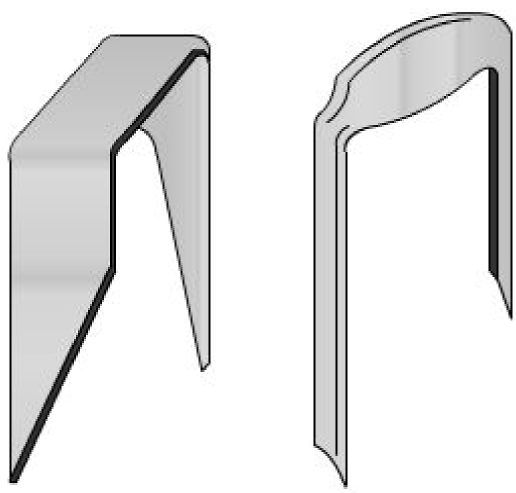

Figure 8-37 – Nonmetallic cable staples.

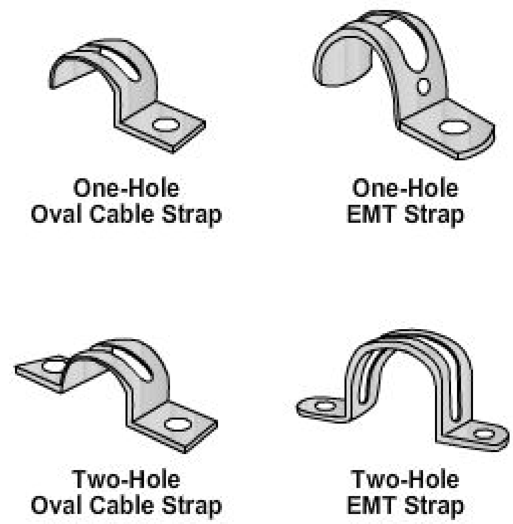

Figure 8-38 – Straps for fastening cable.

Install concealed cable either through holes bored in wooden framing studs or into notches cut in their edges. Holes can be bored with various sizes of bits, depending upon the size of the hole needed. Drill holes in the center of framing studs, in a straight line, and at the least possible angle either vertically or horizontally, as shown in *Figure 8-39*. Holes that are drilled in a crooked line or at much of an angle to the line of pull, as shown at the bottom of *Figure 8-39*, make the cable harder to thread through the holes and pull into position.

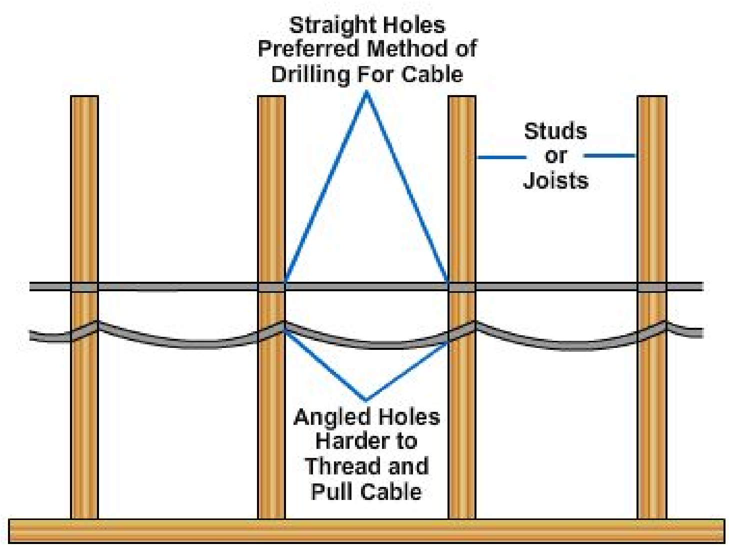

Figure 8-39 – Drilling holes for nonmetallic cable.

Place cable into notches cut in the edge of the framing members and studs, as shown in *Figure 8-40*, if the notches will not weaken the building structure. Make the notches as small as possible. Their depth must not exceed one fifth of the width of the wood. Cable placed in notches or through studs is protected from nails and screws by a thin metal plate at least one-sixteenth inch thick, like those in *Figure 8-40*, according to the NEC®, Article 300.4.

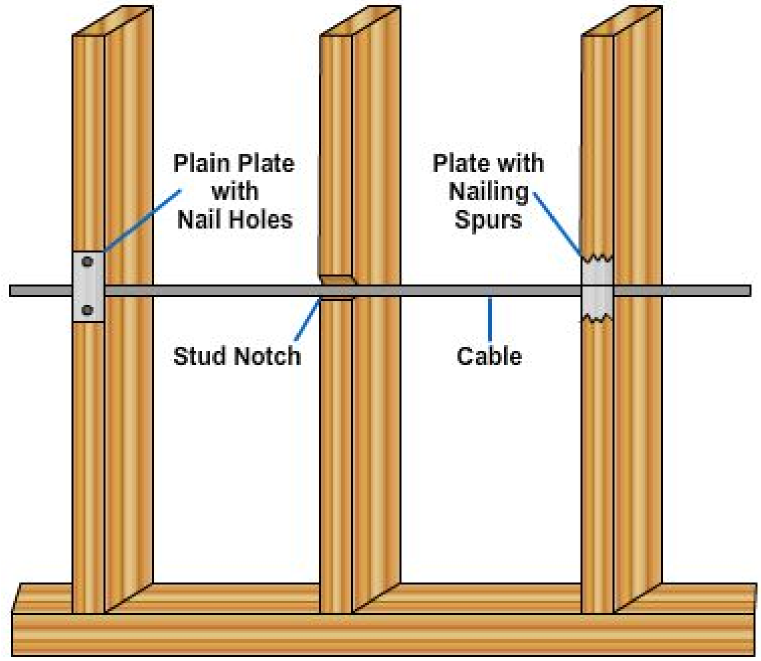

Figure 8-40 – Non metallic cable installed in notches.

Cable is installed through metal framing members in a similar way as it is in wooden ones. Use either holes or slots. Those holes or slots must be cut, punched, or drilled at the factory or in the field. Normally, holes in metal members must have bushings or grommets inserted securely to prevent damage to the cable covering. If holes or slots are formed so that no metal edge can cut or tear the cable insulation, bushings and grommets are unnecessary. Install a steel sleeve, plate, or clip for protection wherever a nail or screw might puncture or cut a cable.

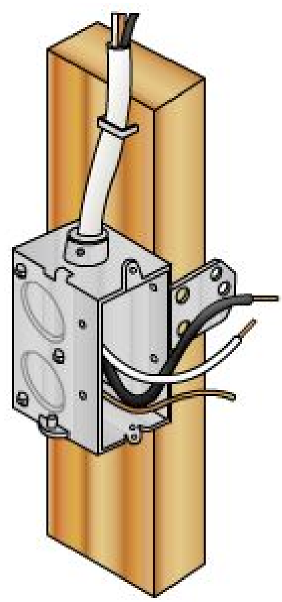

Figure 8-41 – Cable termination at box.

The first step in wiring a building after the distribution panel or panels have been installed is, in most cases, to mark the location of the outlet boxes. After marking those locations, mount the boxes in place unless the mounting of a box might interfere with boring hole or cable anchoring. Once the boxes are in place, make the needed holes or notches for the installation of the cable. Install the cable by starting at the free end. Strip, at minimum, 6 inches of the outside covering from the cable end. If the box has cable clamps, remove one of the knockouts and insert the stripped cable end through the hole under the clamp until one-fourth inch of the cable cover extends beyond the clamp. Tighten the clamp to hold the cable firmly in place, but be careful not to over tighten, which could cause a short. This procedure will give you conductor ends 6 inches long in the box, as shown in *Figure 8-41*. You need these ends so you can make splices or attach devices or fixtures easily. Remember to anchor the cable within 12 inches of the box as shown in *Figure 8-41*.

Boxes without cable clamps require a little different procedure. After stripping the cable end, remove one of the box knockouts. You then install a cable connector, similar to the ones shown in *Figure 8-42*, in the knockout hole. Install the locknut so that it points inward to dig firmly into the metal box as shown in *Figure 8-42*. Put the cable end through the connector to expose one-fourth inch of the outer cover, and then fasten it in place, as shown in *Figure 8-41*.

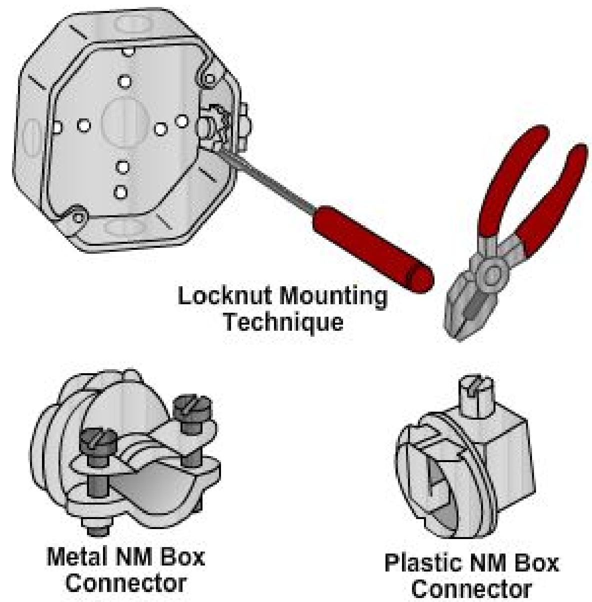

Figure 8-42 – Non metallic cable box connectors and mounting techniques.

After the free end of the cable is in the box, work the cable back toward the other box. Run the cable along the framing members, fastening it at points no more than 4 1/2 feet apart. When you get to the other box, cut the cable to length, allowing for 6 inches of free conductor in the box. Strip the outside covering, insert the cable end, fasten it to the box, and anchor it within 12 inches of the box. To help avoid damage to the wires as wall coverings are placed and other construction is done, make sure you tuck the wires back into the outlet box.

Look at *Figure 8-43*. As you can see, most of these cables are run through holes in the framing members. When holes are involved, you must plan ahead for easiest installation and the least waste. Running the cable between the two duplex receptacle boxes in the figure is a little easier if you put a carton of cable near the box on the right and thread it through the holes to the box on the left. For the circuits that run from the left duplex receptacle box and the switch box to the ceiling outlet, place the carton of cable under the boxes. Then thread the cable up through the holes to the ceiling outlet. From these examples, you can see that you need to look at what is involved before you start to run the cable for a circuit. After you have completed the roughing-in phase of a project, your job comes to a halt for a time. In most cases, you should not start the finish work until the walls and ceilings are completed, after which you can splice wires as needed and install the receptacles, outlets, switches, lighting fixtures, and covers.

Figure 8-43 – Non metallic cable installation.

11.2.0 Finish Work

Once you begin the finish work, the first thing you need to do is to make all ground connections. Equipment grounding is the grounding of all exposed noncurrent-carrying metal parts of an electrical system to the earth. Grounding protects anyone who might come in contact with these parts from shock and protects equipment from damage. Grounding is accomplished when all noncurrent-carrying parts are connected to a grounding conductor (or grounding has been achieved by other means, as approved by the NEC®), and the grounding conductor has been connected to earth at the service equipment or panelboard, as shown in *Figure 8-44*. The equipment ground does not normally carry current. The only time it does is when there is a fault in the circuit.

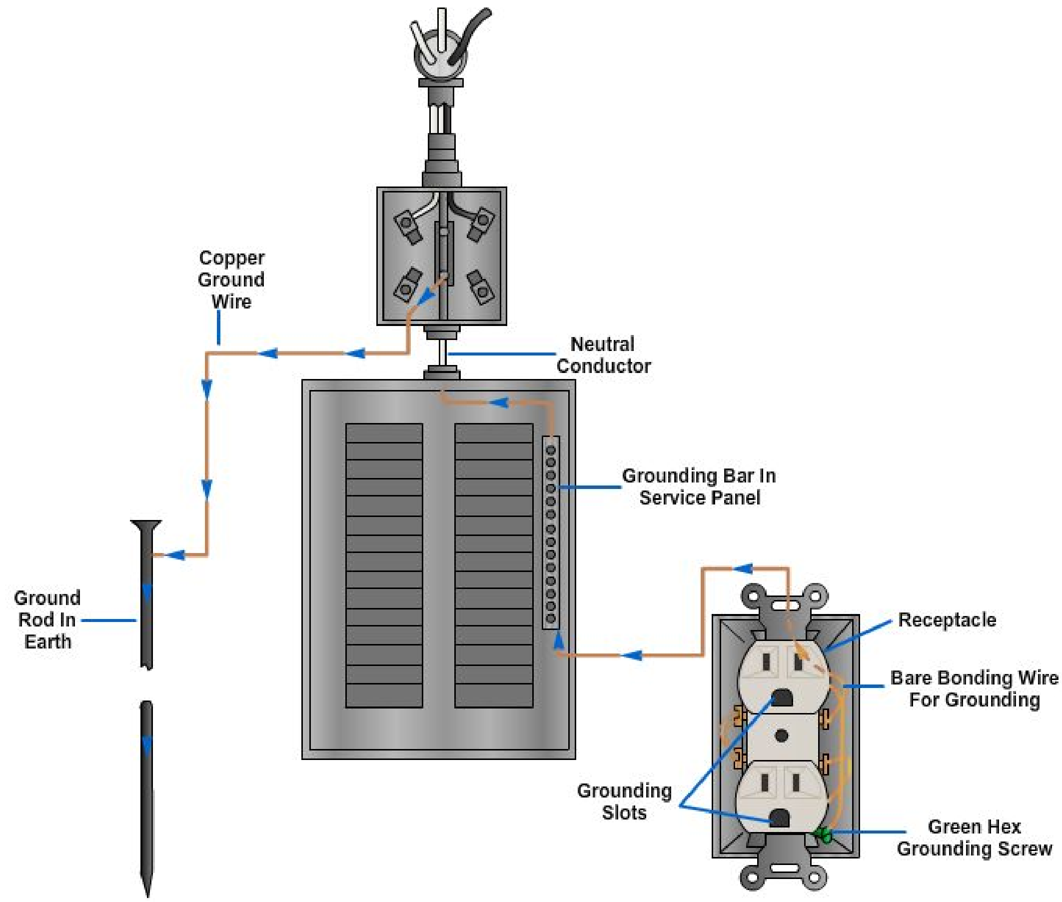

Figure 8-44 – Duplex receptacle electrical connection with the grounding system.

At all outlet boxes that require grounding, according to the NEC®, the equipment-grounding conductor must be fastened to the box with either a grounding clip or a grounding screw, as shown in *Figure 8-45*.

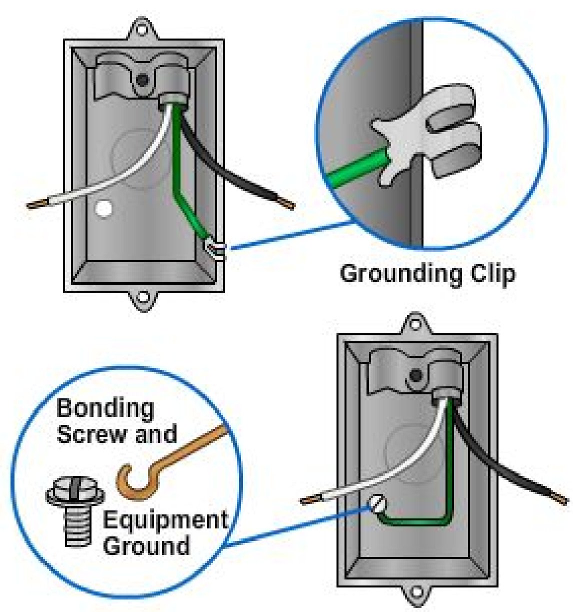

Figure 8-45 – Grounding clip and grounding screw.

When we speak of installing a device, we should be aware that, according to the NEC®, a device is the part of an electrical system carries, but does not use, electrical energy; for example, switches and receptacles. The grounded duplex receptacle comes equipped with a green hex-head screw for connecting the ground wire. When more than one receptacle is connected in a circuit, the NEC® requires that these receptacles be connected to the grounding wire in such a way that removing the receptacle does not break the continuity of the circuit equipment ground. This grounding method is accomplished as shown in *Figure 8-46*, view A.

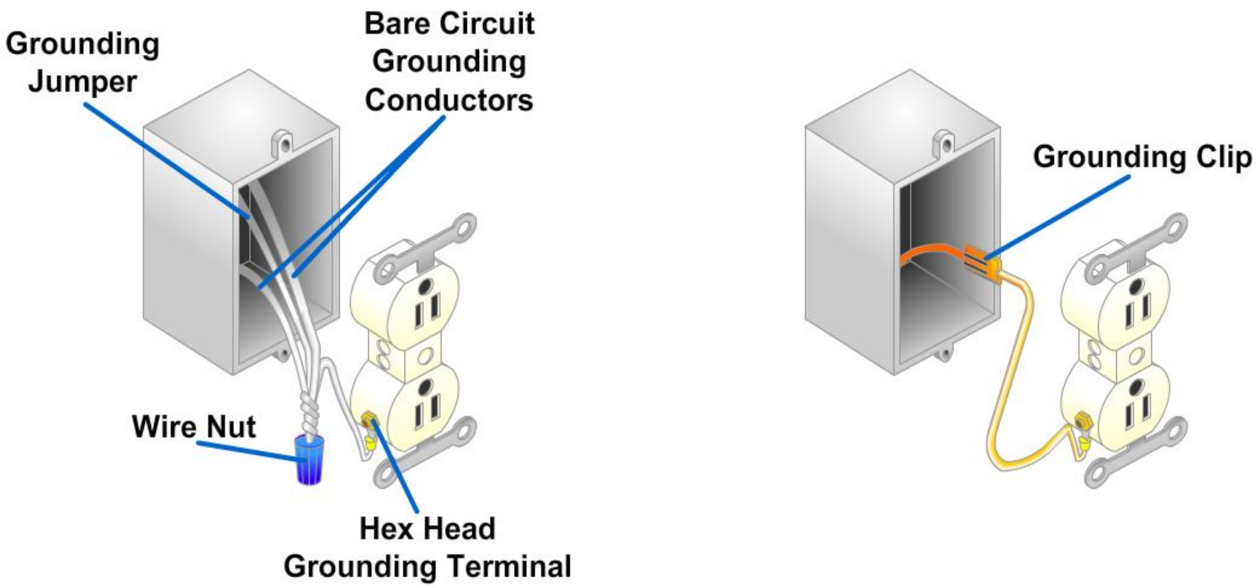

Figure 8-46 – Grounding methods:

(A) More than one receptacle in line and (B) a single receptacle in a circuit

Figure 8-46, view B, shows an example of how to ground a single receptacle in a circuit using a grounding clip. Grounding the receptacle in this way bonds the box, grounding wire, and receptacle, and precludes use of an additional jumper wire.

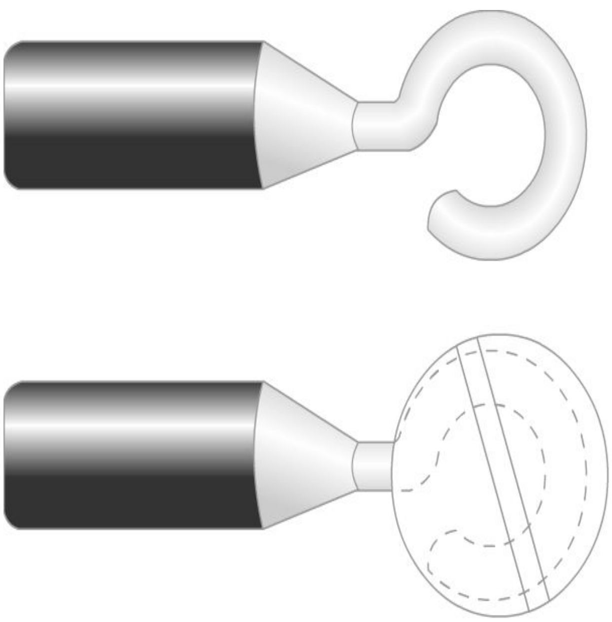

Figure 8-47 – Wire terminal loop.

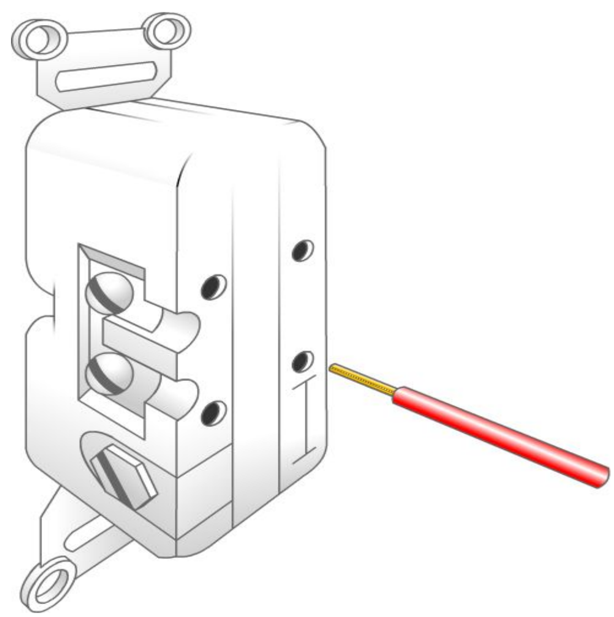

Figure 8-48 – Back-wired receptacle.

Now that we have made the ground connections, the next step of the finish work is to make the terminal connections. Properly made terminal connections are important for several reasons. The operation of the circuit, prevention of fire, and safety of personnel all depend on good electrical connections. Electrical connections must be electrically and mechanically secure. There are two ways to make connections to devices, with or without using a terminal loop. The method using the terminal loop and screw is shown in *Figure 8-47*. Some receptacles and switches are made so that they can be wired from the back without using a terminal loop. This method is shown in *Figure 8-48*. Now that you have made your terminal connections, install the device into its box and secure it with the screws provided. The next step is to install the receptacle cover plates. Install cover plates plumb, ensuring they completely cover the opening and are seated against the mounting surface.

When installing switches for interior wiring, use single-pole, three-way, or four-way toggle switches. Most of the switches you use will be single-pole, but occasionally you will have to install a three-way system, and on rare occasions, a four-way system. Still another system of switching, called the low-voltage system, is coming into use.

A single-pole switch is a one-blade, on-and-off switch that may be installed singly or in multiples of two or more in the same metal box. In wiring a single-pole switch, a general rule is a neutral conductor (white wire) should not be switched or used as one leg in a switch loop. This rule is easily followed in conduit systems but does not apply to armored and non-metallic sheathed cable. Article 200.7 of the NEC® contains the exception to this rule. *Figure 8-49* shows a single-pole switch circuit using nonmetallic sheathed cable.

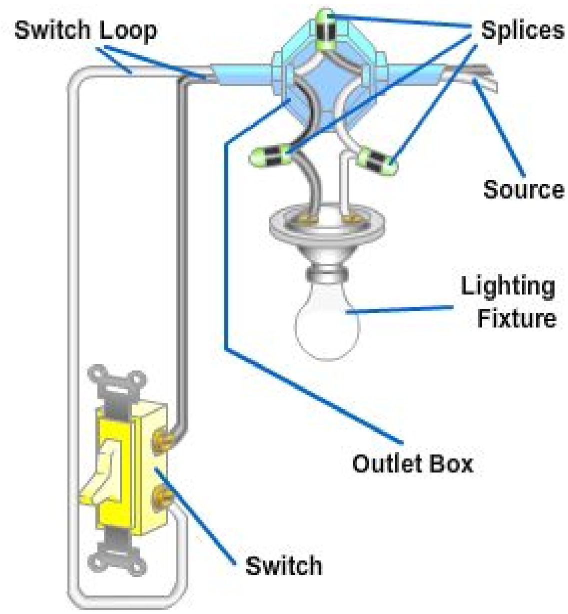

Figure 8-49 – Single-pole switch circuit.

In a three-way switch circuit, you may turn a light on or off from either of two positions. The typical situation is one in which one switch is at the head of a stairway and the other at the foot. *Figure 8-50* shows how the circuit functions.

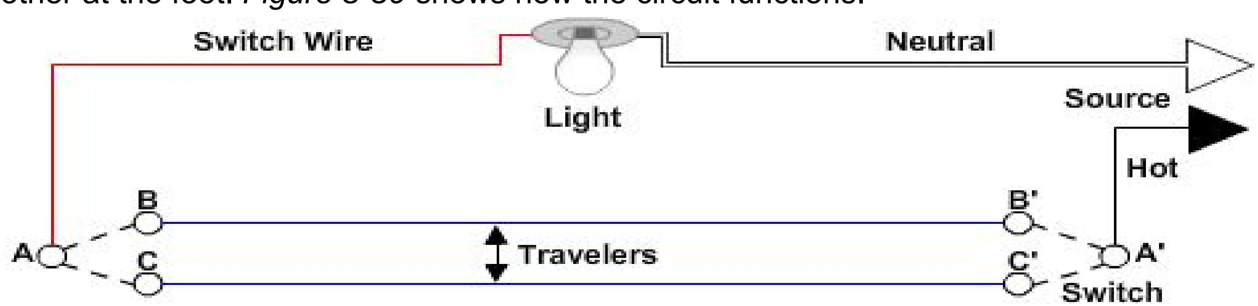

Figure 8-50 – Three-way switch circuit.

Terminals A and A' are the common terminals, and switch operation connects them either to B or C and B' or C', respectively. Either switch will operate to close or open the circuit, turning the lights on or off.

By tracing the circuit in *Figure 8-50* from the source, you can see that the hot wire goes to the first switch, through the closed switch blade to the other switch by way of the traveler, and through the closed switch blade to the other switch by way of the traveler, and through this switch to the light. Changing the position of either of the switches breaks the circuit.

One or more four-way switches may be used with two three-way switches to provide control of a lamp from three or more different points. A four-way switch is an extension of a three-way circuit by the addition of a four-way switch in series with the two traveler wires. *Figure 8-51*, view A, shows how a four-way switch is used in combination with two three-way switches to control a lamp from three locations. By tracing this circuit from the source, you observe the hot wire connected to Switch C passing through Position 1, which is closed. The hot wire continues to Point 4 on the four-way switch (B). At this time the toggle on Switch B is in the UP position, and contact is made from Point 4 to Point 3. The hot wire continues on through the traveler to Switch A, and through Position 2 (which is closed) to the light.

Suppose, now, that you want to turn the light off at the four-way switch (B). By putting the toggle in the OFF (down) position, you change the switch blades from Points 1 to 2 and 3 to 4 to Points 1 to 4 and 2 to 3. (See *Figure 8-51*, view B.) If you now retrace the circuit from Switch B to Switch A, you will find that it goes from Point 4 to Point 1 on Switch B and through the traveler to Switch A to Point 1 where the blade being in the open position breaks the circuit.

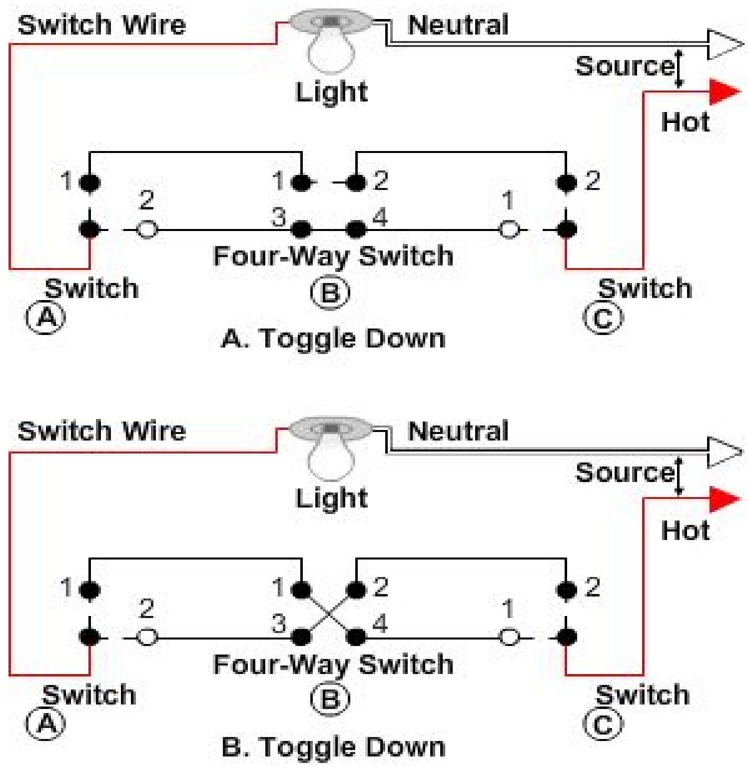

Figure 8-51 – Four-way switch circuit.

Note that three- and four-way switches may be used as single-pole switches, and four-way switches may be used as three-way switches. However, three- and four-way switches are usually larger than single-pole switches and take up more box room. The size of a switch depends on its ampacity (rated maximum amperage). The ampacity and maximum allowable voltage are stamped on the switch and you must consider them when ordering equipment for the job.

11.3.0 Remote Control Wiring

Remote control wiring provides a method of controlling standard voltage devices through the use of low voltage. It consists of relays, low-voltage switches, and transformers and uses a low-voltage conductor cable instead of conduit or Romex. Low-voltage wire is available as three, four, and multiple conductor cables. Multiple conductors are color-coded to identify them. Roughing in a remote control wiring system uses many of the wiring techniques used with nonmetallic cables.

Remote control relays have two coils (on or off) with a common center tap. The use of two coils allows the relay plunger move positively in either direction without the use of springs. When a push button (switch) is turned ON, current will pass through the ON coil and cause the movable core to shift into the ON position. The contacts are closed in the load circuit and the light goes on. The same happens when the OFF button is depressed. The current is passed through the OFF coil and the core moves. The contacts open and power to the light is turned off. The relay will maintain this position until the push button again energizes the ON coil. These relays are capable of controlling 20 amperes of lighting or inductive loads at 110 or 277 volts AC. Relays can be mounted individually in junction boxes as shown in *Figure 8-52*, or several may be mounted in a centrally located cabinet.

Transformers in a remote control system reduce 12V line voltage to 24 volts to provide power in the switching/relay circuit. Wherever transformers are located, they must be accessible and kept from excessive heat. They are sized according to the number of relays they will power.

In the low-voltage system, you can install as many switches as required for any given light, or install a master switch to turn on as many as eight lights simultaneously. There is no necessity for three-way or four way switches because the switches are connected in parallel.

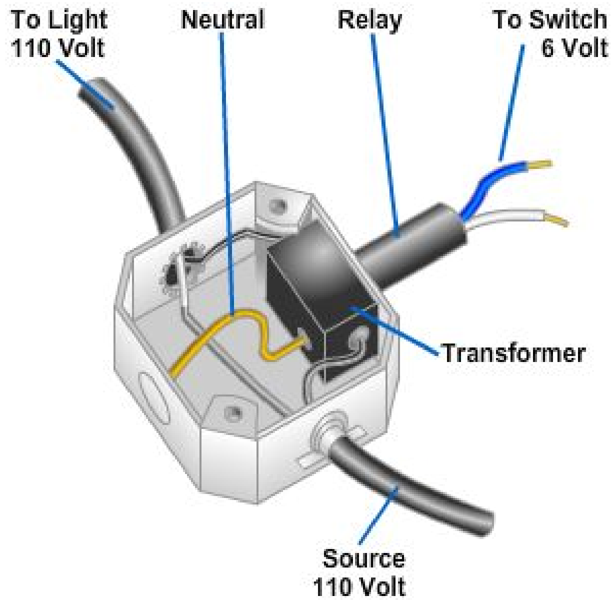

Figure 8-52 – Low-voltage relay and transformer.

Test your Knowledge (Select the Correct Response)

21. What are the names of the two stages of installation of non-metallic cable?

    A. Roughing in and cut in
    B. Cut in and finish work
    C. Roughing in and finish work
    D. Cut in and switch install

22. Within how many inches of a box, cabinet, or fitting must a non-metallic cable be anchored?

    A. 12 inches
    B. 16 inches
    C. 18 inches
    D. 24 inches

23. **(True or False)** In a three-way switch circuit, you may turn a light on or off from either of two positions.

    A. True
    B. False

24. **(True or False)** Remote control wiring provides a method of controlling standard voltage devices through the use of high voltage.

    A. True
    B. False

12.0.0 CONDUIT SYSTEMS

As a CE, you will be called upon to install all types of wiring systems. Unlike the electricians in civilian life, who often specialize in the installation of specific types, you must be able to install any type. In most locations you will have to install wiring systems that require the added protection provided by conduit. Conduits are of various types, such as rigid, flexible, intermediate metal, PVC, and electrical metallic tubing (thin-wall or EMT). As you read this section, become familiar with the different ways of bending, cutting, and threading the fittings used and the different locations where they may be used.

12.1.0 Cutting and Threading

The use of rigid conduit involves a good deal of cutting and threading of lengths. Rigid conduit is best cut with a hacksaw or special conduit cutter. An ordinary revolving wheel pipe cutter leaves a heavy inside ridge that is difficult to remove and may damage the conductors passing through the conduit. Always ensure that you make a cut at right angles to the axis of the pipe (*Figure 8-53*).

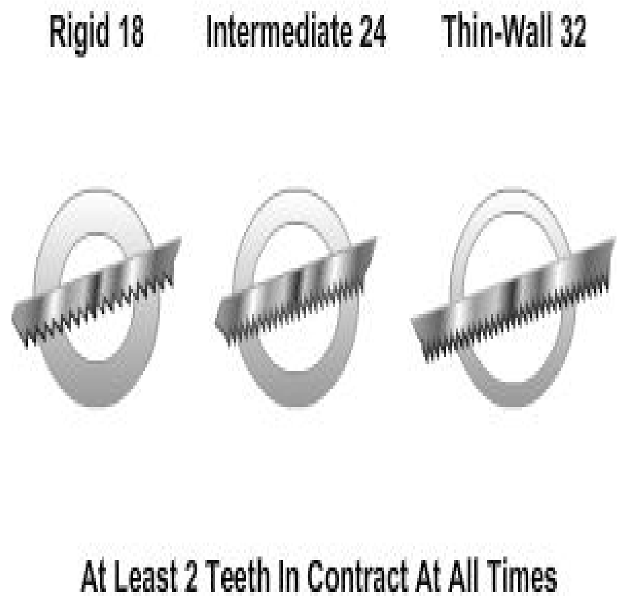

Figure 8-53 – Hacksaw blades, teeth per inch, for different types of conduit.

Thin-wall conduit (EMT) and polyvinyl chloride (PVC) should be cut with a hacksaw because pipe cutters may flatten the end of the pipe. The pipe cutters also leave a ridge on the inside of the pipe that is hard to remove. There are tubing cutters made specifically for cutting EMT or PVC, but you need to be sure you have the right cutter for the job. When you are cutting conduit, use a vise to stabilize the conduit.

Also cut flexible conduit and tubing with a hacksaw. Because of its spiral construction, flex should be cut at an angle so that only one ribbon is cut all the way through. A slight reverse twist will separate the two ends (*Figure 8-54*).

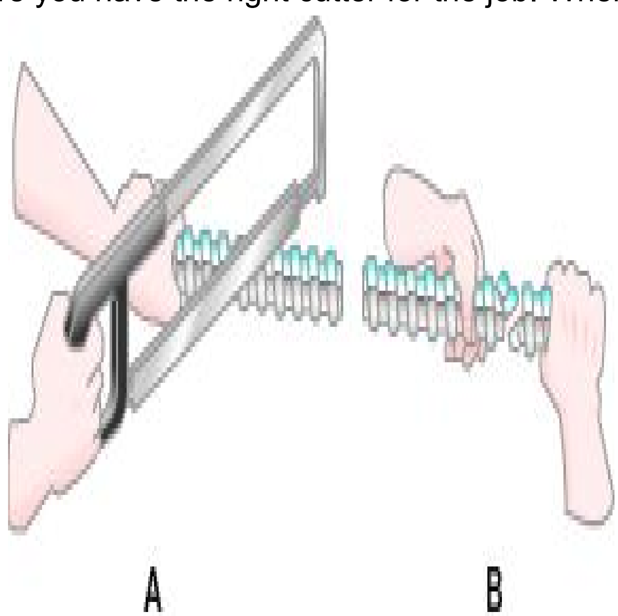

Figure 8-54 – Cutting flexible conduit.

Cutting any type of conduit leaves a sharp edge or burr on the inside of the pipe that must be removed by reaming. Reaming can be done with several tools. To ream rigid and intermediate conduit, use a pipe reamer. A rat-tailed file does a good job on any type of conduit. To ream EMT that has been cut with a hacksaw, use the heads of a pair of pliers, such as needle nose or side-cutting pliers. The important thing is to remove any edges, or burrs, in the pipe that might cut the insulation when the conductors are pulled into the conduit.

The next step is cutting the thread on the end that was cut off. For the smaller pipe, use a ratchet type of die that turns directly with the handle. On larger pipe, use a die with a mechanical advantage, that is, use a die that makes only a part of a revolution when the handle makes a complete revolution. Hand-held portable electric and shop type of threading machines are also available.

A conduit-threading die, like a plumber's die, makes a tapered thread, so that a coupling starts rather loosely but binds hard as it is set up. This tight connection serves two purposes: it makes a watertight joint, and it makes a good electrical connection for a continuous ground throughout the length of the conduit.

Rigid polyvinyl chloride (PVC) conduit has been developed by many manufacturers. Some of the advantages of PVC conduit are the light handling weight, high corrosion resistance, ease of installation, leak proof joints, and easy wire pulling (because of the mirror-like walls). Refer to Article 352 of the NEC® for installation requirements.

Permanent joints are made quickly in PVC conduit by cutting the conduit with a handsaw or hacksaw and removing the burrs with a pocketknife. When joining

PVC conduit, always follow the manufacturers' instructions listed on the cement can for best results. A variety of threaded PVC fittings are available from manufacturers. Their use is covered in Article 314 of the NEC®. The preferred method of installation is the solvent-welding technique because it creates joints that are waterproof and vapor-proof.

12.1.1 Using the Ridgid Model 535®

The Ridgid Model 535® threading machine is the standard most Seabee units use for threading conduit. The Model 535 is electric motor driven. It centers and chucks pipe, conduit and rods. The stock is automatically rotated. It is capable of cutting right hand (RH) or left hand (LH) threads. The capacity varies with cutter types and is explained in the specifications below. The specifications for the Model 535 are as follows:

- Pipe capacity is 1/8" - 2", 2 1/2" - 4", 4" - 6" with 141 and 161 geared threaders
- Bolt capacity is 1/4" - 2"
- Motor 1/2 HP, single-phase, 115V, 25-60 Hz, 15 amp reversible universal motor
- Switches are FOR/OFF/REV and integral safety foot switch
- Speed chuck with replaceable rocker-action jaw inserts
- Rear centering device which is Cam-action that turns with chuck
- Cutters include self centering, full-floating. There are two model available, the standard number 820 Wheel-type cutter, pipe capacity 1/8" - 2", bolt capacity 1/4" - 1" and the optional number 821 Blade-type cutter, pipe capacity 1/2" - 2"
- Spindle speed is 36 RPM standard (no load), 54 RPM model is also available
- The reamer is 5-flute cone, RH, 1/8" - 2". A RH/LH combination reamer is available
- The oil pump is a self-priming gerotor oil pump

Its features include the following:

- Large 1.75 gallon oil tray

- Large chip tray
- High clearance carriage
- Speed chuck with rocker-action jaws that centers and grips work piece instantly
- Can be used with geared threaders Models 141 and 161
- Uses Model 816/817 semiautomatic, Model 815A self-opening or Model 811A quick-opening die heads
- Has a length gauge for quick, accurate cut-off

Before using the Ridgid Model 535® always check the oil system. To do this, first unplug the equipment. At that time fill the reservoir in base with 5 quarts of cutting oil. Then plug the equipment back in and turn the switch to “FOR” (forward).

When installing conduit measure and mark the length to be cut. Next place the pipe through the front or rear of the machine, NOTE: if the pipe is too short to be retained by the centering device, place it through the front. Also, ensure that the pipe is centered. Then tighten the jaws with a counter clock-wise spin.

When using a quick opening of self-opening die head, install the die for right hand threads only. When inserting dies, make sure the die numbers match the die head. The reamer and cutter must be out of the way. Then bring dies against the end of conduit “by hand”. At this time switch should be to the “FOR” position (foot switch).

When reaming pipe with the power reamer, make sure the reamer is in position. Ream the pipe and shut down the threader.

The procedure for using the geared threader is to ensure the conduit is clean and smooth, move the reamer out of the way, and put the die head into position. Then install the oil spout and the 844 drive bar. Next, insert drive link E-814-X and place the 141 geared threader on the carriage. Engage the 844 drive bar. You must ensure the drive bar is properly secured. Engage the drive link assembly and make sure the conduit is properly supported.

When threading conduit, you need to adjust the threaders for the size desired. Rotate the camplate for the desired conduit size. Next, set the standard threads in which you have two reference points. Those reference points are - Undersize (deep thread) and Oversize (shallow thread). When using the close coupled method, install the threader and conduit. Then power in the machine to “FOR” (forward), making sure to flood the dies with cutting oil as you thread. Always stop when red stop line appears on the pinion sleeve. Then loosen the clamp and remove the conduit.

12.1.2 Maintenance

The Ridgid Model 535® should be maintained on a regular basis as described herein. For safety purposes always secure the machine power prior to performing any maintenance. There are three primary maintenance points on the system:

- Lubrication can change depending on the frequency of use of the machine. The main points of lubrication are shaft bearings, which are to be lubricated every two months. The large gear should be moderately greased each time the bearings are lubricated.
- Oil system maintenance consists of replacement of cutting oil when it is dirty or becomes contaminated. The filter screen should be cleared often depending on how frequently the machine is used.

- Replace the entire set of jaws at the same time. When one jaw becomes worn or broken then replace the entire set.

12.2.0 Conduit Bending

Bending conduit is an art. Like all forms of art, the more often it is done correctly, the more proficient the artist becomes. It is a good idea to attend the SCBT 240.2 course that covers bending and installation of electrical conduits using mechanical benders. Keep in mind that practice will improve your skills and always read and follow the manufacturer's instruction guide. Following the guide will normally assure that you make top quality bends in a safe and efficient manner.

The NEC® Article 340 through 358 applies to electrical conduits. It states that the "bends in conduits will be made so that the tubing will not be injured and that the internal diameter of the conduit will not be effectively reduced." In addition, the NEC® has a table that indicates the minimum radius acceptable for various sizes of conduit. It also states that "a run of electrical conduit between outlet and outlet, between fitting and fitting, or between outlet and fitting, will not contain more than the equivalent of four quarter bends (360 degrees total) including those bends located immediately at the outlet or fitting."

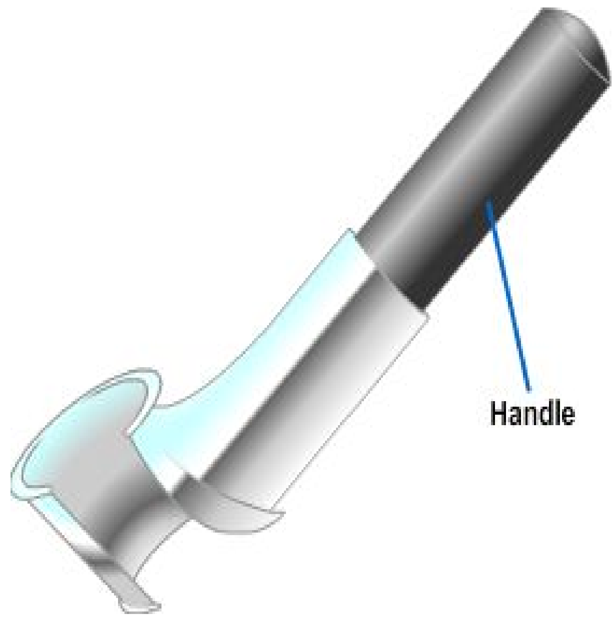

Figure 8-55 – Hickey.

When installing conduit, you will need to make bends to go over or around obstacles. You will need bends of various shapes, such as right-angle or 90-degree bends, offsets, and saddles. You must make these bends without reducing the inside diameter of the conduit in the bend. You will make most of these bends on the job as part of the installation procedure. They are called field bends. You may use factory-made bends instead of field bends; however, they require more cutting and threading, and therefore increase the cost of the job.

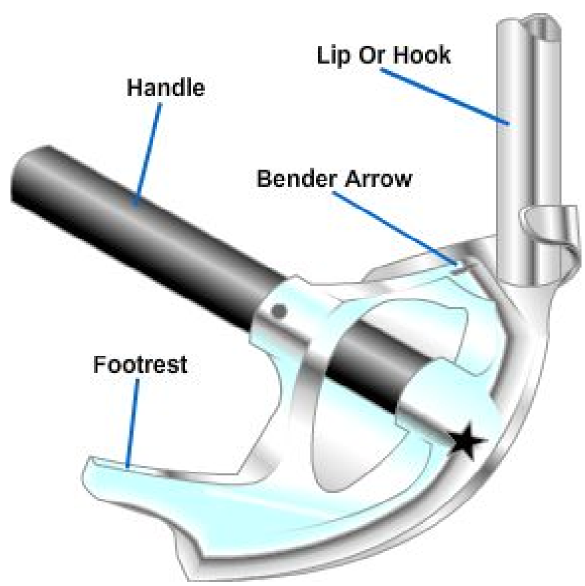

Figure 8-56 – One-shot bender.

You will create most of the field bends with manual benders or, in the case of rigid non-metallic conduit, a hot box heater. There are two types of manual benders used to bend rigid conduit and EMT. They are the rigid bender, called a hickey (*Figure 8-55*), and the one-shot bender (*Figure 8-56*). The one-shot bender is normally made for EMT, but some are made for both EMT and rigid. The one-shot bender was given its name because it can make a full 90-degree bend with a single motion. With manual benders, you can bend conduit sizes up to 1 inch rigid or 11/4 inch EMT without much trouble. Bend larger sizes with mechanical or hydraulic benders. Hydraulic benders will be discussed later in this section.

12.2.1 Rigid Nonmetallic Conduit

Although a complete line of factory elbows (90, 45, or 30 degree) is available, you can easily bend PVC conduit (1/2 through 2 inch) yourself with a PVC hot box. A PVC hot box is nothing more than a heater enclosed by metal and having a mirror finish on the inside with openings on each end. To bend PVC conduit, place it inside the hot box, turn the switch on, rotate the conduit until it becomes flexible, remove the conduit, and bend it to the desired shape.

WARNING

The hot box is a heater. If you leave the conduit in long enough, it will BURN. Always use gloves when bending PVC.

12.2.2 Electrical Metallic Tubing (EMT)

Conduit bending is a precise art form. You will use degrees, angles, measurements, and prefigured deductions for radiuses and shrinkage. Combine all these calculations correctly and you will get a finished product that is not only functional but pleasing to the eye and something to be proud of.

12.2.2.1 Ninety Degree Bends

One of the most common bends you will make in the field is the right-angle bend, more commonly called a 90-degree bend, or just a 90. Anyone can make a 90 in a stick of conduit and then cut it off to make it fit the situation, but doing so wastes time and material. The secret is to bend the conduit so that you do not have to cut it. To accomplish this, you must know the following: First, you need to know the stub-up, or distance from the end of the conduit to the back of the 90. Second, the take-up, or radius of the bend, takes up a part of the stub-up. The amount of take-up depends on the type and size of conduit you are bending. (See *Table 8-5*)

Table 8-5 – Conduit Take-up.

AMOUNT OF TAKE-UP FOR 90º BENDS (ONE-shot Benders)	
SIZE AND TYPE OF CONDUIT	**TAKE-UP**
1/2” EMT	5”
3/4” EMT OR 1/2” RIGID*	6”
1” EMT OR 3/4” RIGID*	8”
1 1/4” EMT OR 1” RIGID*	11”

Now, let us see how to make a 90 to fit a specific situation. Suppose you are going to run the conduit from the top of a panel to the ceiling and then horizontally along the ceiling, using 1/2-inch EMT and a one-shot bender. The first step is to measure from the top of the panel to the ceiling. This measurement will give you the stub length. Assume the length is 18 inches. Measure 18 inches from the end of the conduit and make a mark at that point.

Next, look at *Table 8-5* and find the take-up for 1/2-inch EMT. The take-up is 5 inches. Now, measure 5 inches back toward the end of the conduit from your first mark and make a second mark. This measurement gives you the take-up. Place the conduit on the floor with the stub in front of you. Align the bender arrow with the take-up mark, as shown in *Figure 8-57*. Put one foot on the footrest and hold the handle with both hands. Apply pressure on the footrest as you pull the handle until the handle is about at a 30 degree angle with the floor, as shown in *Figure 8-58*. You should now have a 90 degree bend with an 18 inch stub. Remember: Heavy foot pressure is critical to keep the EMT in the bender groove and prevent kinked conduit.

To check that the bend will fit the situation with which we started, you can place it next to anything that you know is a right angle and measure from the floor to the end of the stub. If the bend is not a full 90, place the bender back on the conduit and pull more bend. If it is more than a 90, place the handle of the bender over the end of the stub, place one foot on the conduit on the floor, and spring the stub back.

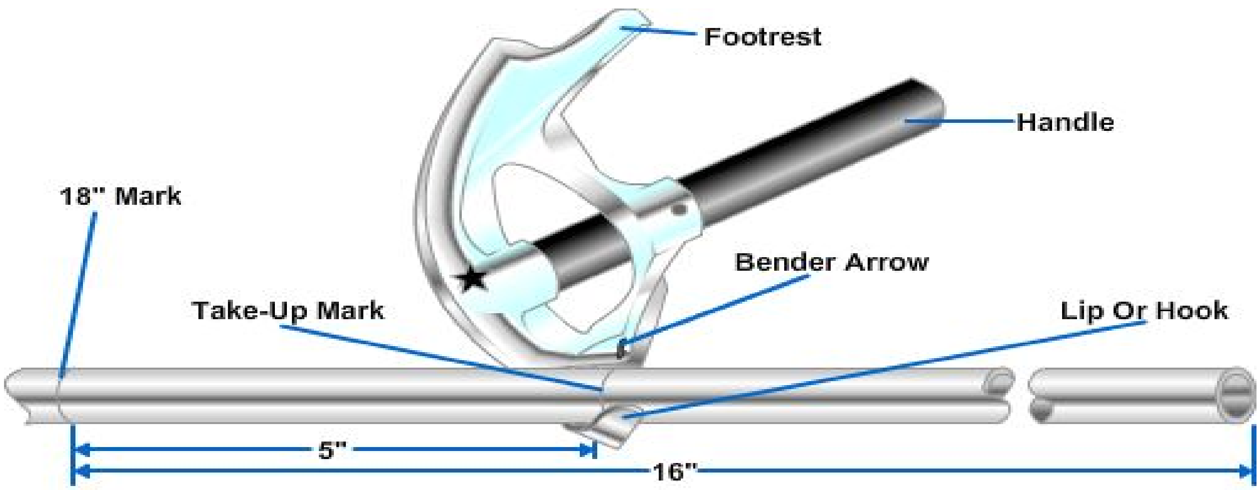

Figure 8-57 – Alignment of arrow and take-up mark for bending a 90.

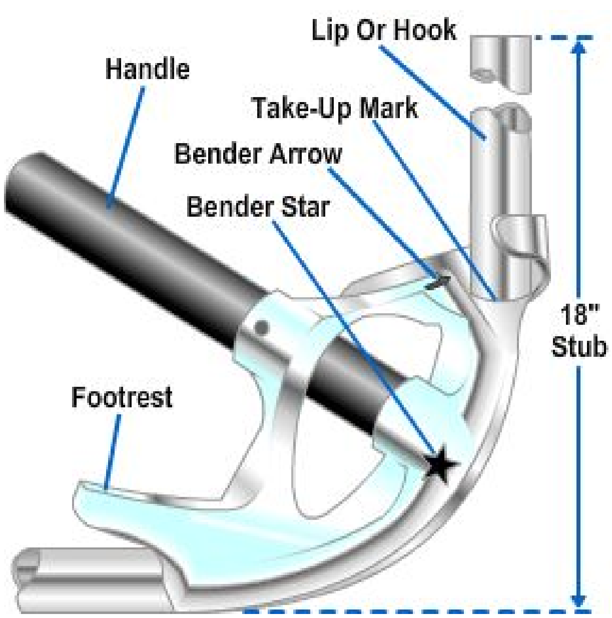

Figure 8-58 – Right-angle bend, 90.

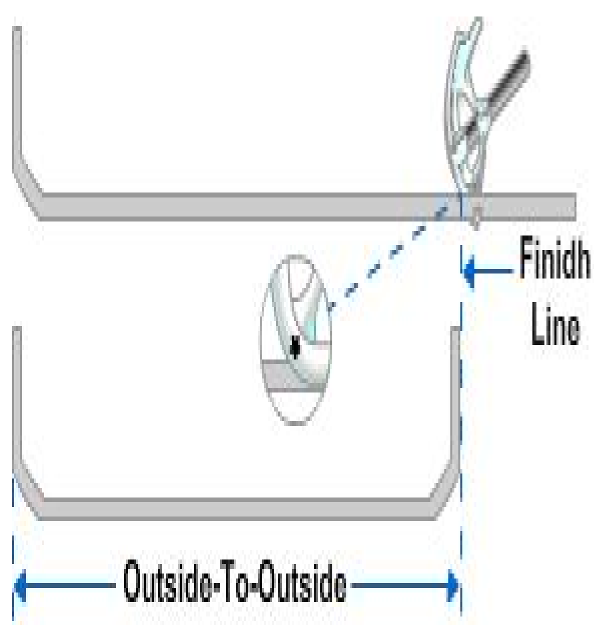

Figure 8-59 – Using the star for back-to-back bend.

12.2.2.2 Back-to-Back Bends

The back-to-back bend is actually two adjacent 90s made in the same piece of conduit. Make the first 90 with the amount of stub you need, as described previously. To determine where to place the next stub, you first need an outside to outside measurement, i.e., the distance from the back of the first bend to the point where you want the back of the second bend.

There are two methods for making the second bend. The first is to subtract the take-up, use the arrow on the bender, and pull the bend in the same direction as you did the first bend. The second method, and probably the easiest, is to turn the bender around, line up the star on the bender with your outside-to-outside measurement, and pull the bend in the opposite direction, as shown in *Figure 8-59*.

12.2.2.3 Offset Bends

An offset bend is two equal bends in opposite directions. It is used to avoid contacting a part of the structure or to bring the conduit out from the structure to match a knockout in a box or panel. The angle of the bend in an offset depends on several things; how much offset is needed, how much room there is where the offset is going to be placed, and the type of obstacle you are avoiding. *Figure 8-60* shows a box offset into a handy box. There is no way to mark the conduit for a box offset. The amount of bend and the distance between bends are estimated. The key to making good box offsets is practice.

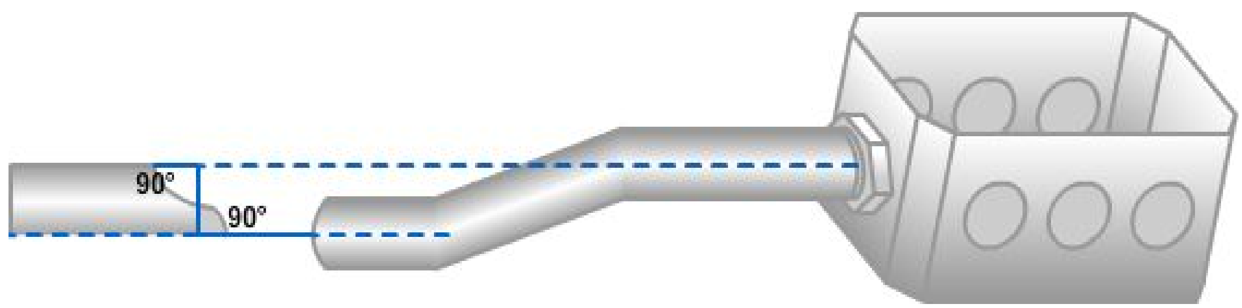

Figure 8-60 – Box offset.

To make accurate offsets of 2 inch or more depth, mark a predetermined distance on the conduit. The distance between the bends depends on the depth of the offset and the amount of bend you are going to use. *Table 8-6* shows the formula for finding the distance to mark on the conduit. It also shows the constant multiplier you must use in the formula for the angle of bends you intend to use and the shrinkage per inch.

Table 8-6 – Offset bending formula.

Formula and Constant Multiplier for Determining Distance Between Bends When Bending Offsets		
FORMULA: OD X CM = DISTANCE Where OD is Offset depth and CM is constant multiplier		
ANGLE OF BENDS	CONSTANT MULTIPLIER	SHRINKAGE
22 1/2º X 22 1/2º	2.6	3/16" PER INCH
30º X 30º	2.0	1/4" PER INCH
45º X 45º	1.5	3/8" PER INCH
60º X 60º	1.2	1/2" PER INCH

Here is an example of how the formula works. Suppose you need to avoid a part of an obstruction that requires an 8-inch offset, you are going to use 30-degree bends, and you are 40 inches from the obstruction. *Table 8-6* shows that the constant multiplier for 30-degree bends is 2.0 and the shrinkage of one-fourth inch equals 2 inches for a total of 42 inches. Using the formula, multiply the depth of the offset (8 inches) times the constant multiplier (2.0), and the result is the distance needed between the bends (16 inches).

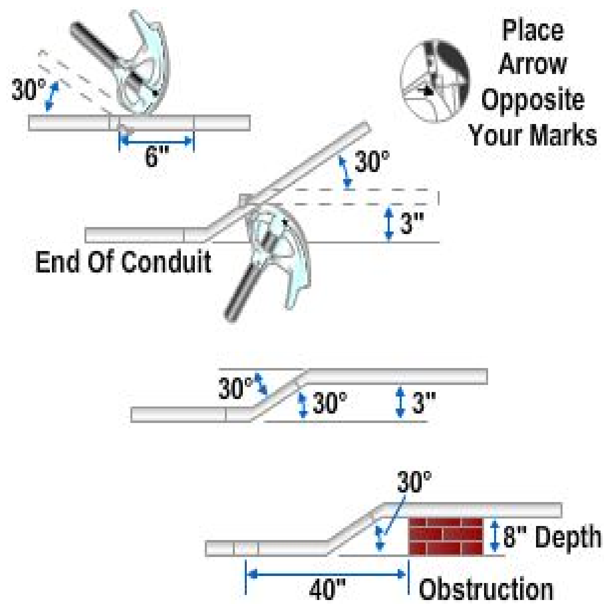

Figure 8-61 – Bending an offset

You place the first mark at 42 inches, the second 16 inches from the first, and using the arrow of the bender, make a 30 degree bend on the same side of each mark, as shown in *Figure 8-61*. In this example, a 30 degree bend provides the offset you need. If you make both bends inside the marks, you will end up with much less than the desired offset. If you make both bends outside the marks, you will have too much offset. The amount of bend, in this case 30 degree at each mark, is obtained by using the degree markings on the bender, as shown in *Figure 8-62*. Notice that the side of the conduit closest to the bender is in line with the 30-degree marking on the bender. If you have a bender without markings, you can use a protractor, which works especially well on larger conduit, or you can lay a 30 degree angle out on a large piece of paper or on the floor with chalk. Then check the bend against the 30 degree angle you have laid out.

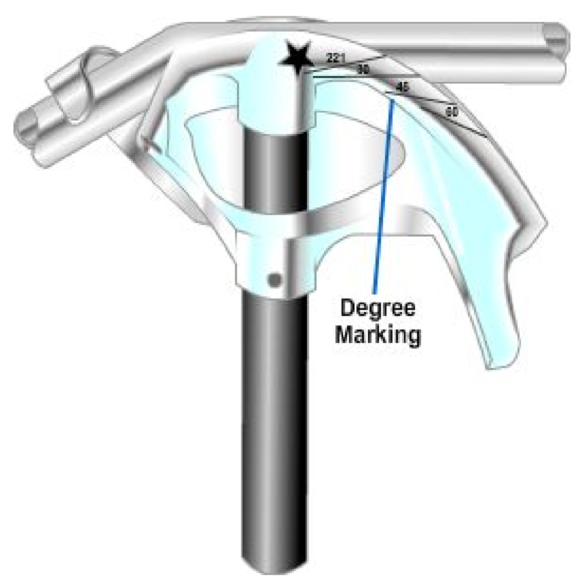

Figure 8-62 – Bender degree markings.

Normally, offsets are made by making the first bend on the floor and the second bend in the air, as shown in *Figure 8-63*.

12.2.2.4 Saddle Bends

Saddles may be necessary when you encounter obstructions (*Figure 8-64*). The most common method of straddling an obstacle is the three-bend saddle, using a 45 degree center bend and two opposing 22 1/2 degree bends. All measurements begin with locating the center of the obstruction on the conduit and marking it as Point A. *Table 8-7* shows shrinkage factors and distances for marks “B” and “C”. The formula is: from mark “A” add 3/16 of an inch times saddle depth and distance from mark “A” to marks “B” and “C” = 2.5 inches times saddle depth.

Figure 8-63 – Bending on the floor and in the air.

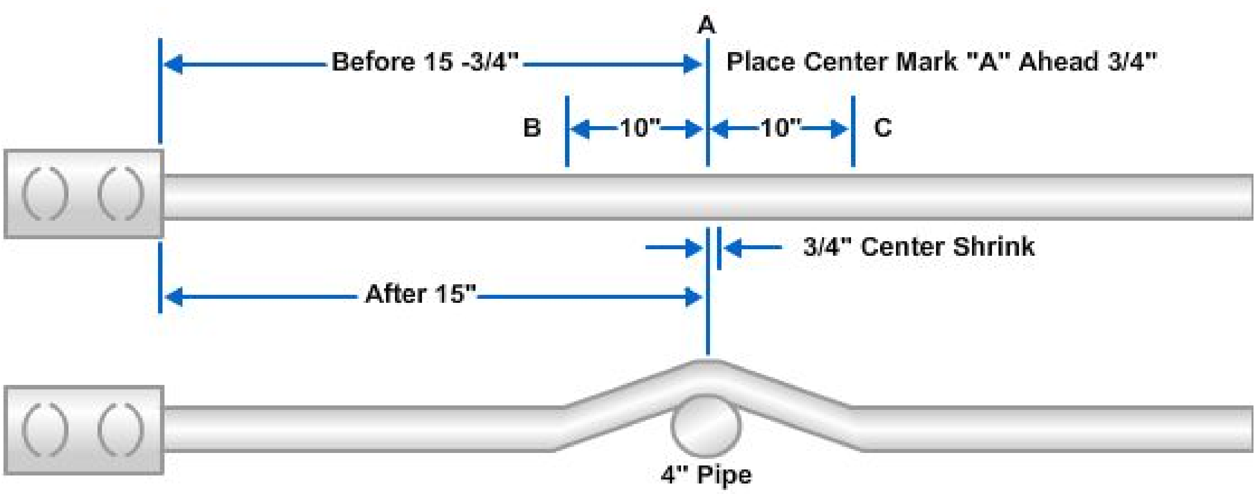

Figure 8-64 – Bending a conduit saddle bend.

Table 8-7 – Bending conduit saddle table, shrinkage factors, and distances.

Bending Conduit Saddle Table, Shrinkage Factors, and Distances		
Saddle Depth	Place Center Mark "A" Ahead of Actual Center By	Place Marks "B" and "C" Each Way From Center
1"	3/6"	2 1/2"
2"	3/8"	5"
3"	9/16"	7 1/2"
4"	3/4"	10"
5"	15/16"	12 1/2"
6"	1 1/8"	15"
For Each Additional Inch Add	3/16"	2 1/2"

Figure 8-64 shows an example of placing a 4 inch saddle around a conduit that is 15 inches from a junction box. Following the bending sequence shown, pay close attention to the orientation of the bender head. Remember to use the star arrow on the bender to align point A for the 45 degree center bend and the front arrow to align the bender with marks "B" and "C" for the 22 1/2 degree bends. Be sure to line up all bends in the same plane. This procedure is true of all bends, not just a saddle.

12.2.3 Rigid Metal Conduit

The procedures for making the different types of bends discussed thus far have all been with a one-shot bender. The same bends can be made with rigid conduit. A hickey bender can be used on rigid metal conduit also, although the procedures are slightly different. For instance, to make a 90 degree bend in 1/2 inch rigid metal conduit, take the steps shown in *Figure 8-65*. Let us say you need a 20 inch stub up at the end of the 1/2 inch stick of rigid conduit. The steps for bending with a hickey are as follows:

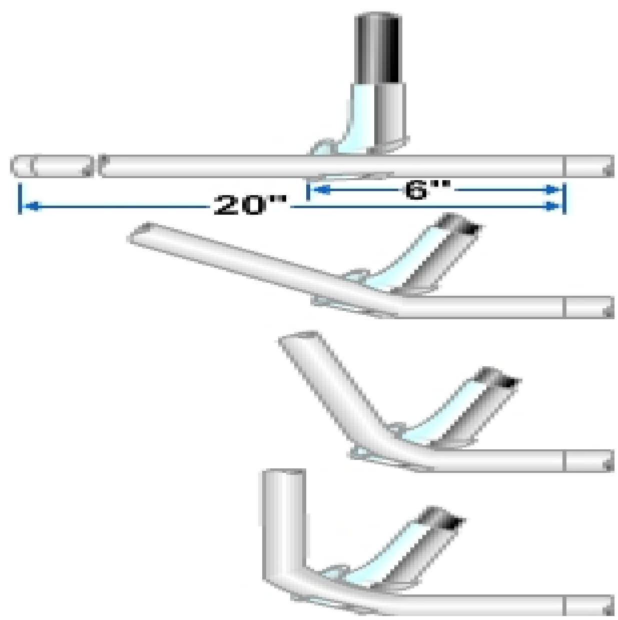

Figure 8-65 – Bending a 90 with a hickey.

- Mark off 20 inches from the end of the conduit.
- Determine the take-up for 1/2-inch rigid conduit (See *Table 8-5*).
- Make a second mark 6 inches back toward the end of the conduit.
- Place the hickey at the second mark and pull about 30 degrees of bend.

- Move the bender toward the 20 inch mark about 2 inches. Pull another 30 degrees of bend.
- Move the bender to where the heel of the bender is on the 20 inch mark and complete the 90 degree bend.

Since the hickey bender does not usually have degree markings on it, you must estimate the amount of bend you make with each bite. Small bites, as shown in *Figure 8-66*, reduce the possibility of crimping or kinking the conduit.

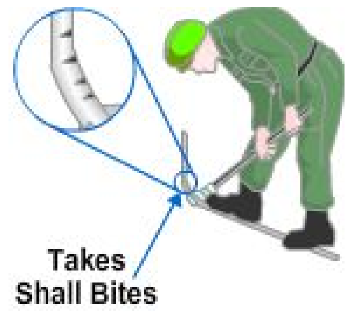

Figure 8-66 – Bending with a hickey using small bites.

12.2.4 Power Benders

Power benders are used for bending larger sizes of electrical metallic tubing (EMT), intermediate metallic tubing (IMC), and rigid conduit. Power benders come in many types and sizes. Some of the common ones are the hydraulic one-shot, sweep, and thin-wall benders. As for the mechanical benders, the thin-wall and sweep benders are common. Hydraulic benders use either a hand pump or an electric pump to move a shoe that does the actual bending. *Figure 8-67* shows a hydraulic sweep bender that uses a hand pump. By using different sizes of bending dies at different locations on the tie bar, you can use this bender to bend several types and sizes of conduit.

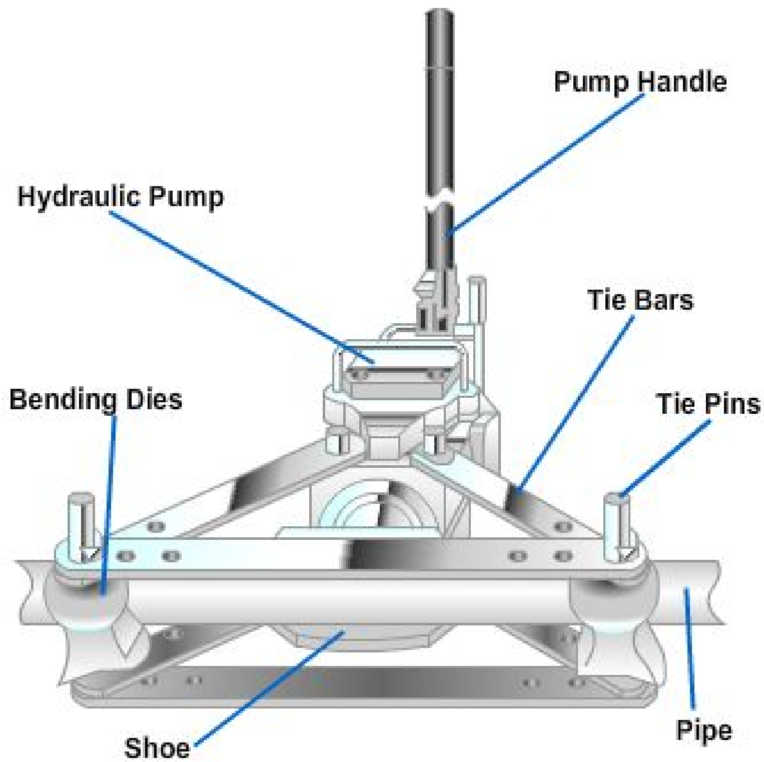

Figure 8-67 – Hydraulic sweep bender with hand pump.

The procedures for making the different types of bends with power benders are very similar to those used with manual benders. The main difference is that with the power benders, the take-up for 90 degree bends and the distance between bends for offsets will not be the same. This difference occurs because you are dealing with larger sizes of conduit or because the shoes of the bender give a different radius of bend. Because there are so many different types and manufacturers of benders, remember to check the manufacturer's instruction guide before doing any bending.

12.2.5 Bending Functions and Safety Tips

The following paragraphs contain general information about power benders. This information does not replace the manufacturer's instruction guide, but only acquaints you with some basic functions and safety tips that of which you (as a Construction Electrician) must be aware.

When you are bending conduit, the bender must be in a horizontal position. To move the bender any distance, place the pipe supports and pins in a 4 inch to 5 inch hole position. Then stand up the bender and roll it.

If you connect the high-pressure hose to the female quick-coupler on the end of the ram and the other end to the high-pressure pump female coupler, make sure that the quick-coupler is clean before making the connection. For the correct procedures for removing all the air from the pump and hoses, refer to the manufacturer's manual.

Some mechanical benders have an electrical power pump used to apply pressure on the ram. In this case, to operate the hydraulic pump, the motor must be running. Also, the quickest way to stop the advance of the ram is to stop the power pump motor.

CAUTION

Read the pump operating instructions before operating the pump. Always place the control lever in the return position before starting the electric motor pump.

Regardless of what hydraulic bender you use, always check the manufacturer's charts and tables for the minimum stub length. When the manufacturer's tables and charts are not available, make the conduit stub length equal to or greater than the minimum shown in *Table 8-8.*

Table 8-8 – Conduit size/deductions/minimum stub lengths.

Conduit Size	Deduct	Minimum Stub Length
1/2	1 15/16	10
3/4	1 1/2	10
1	1 7/8	13
1 1/4	2 3/8	15 13/16
1 1/2	2 3/4	18 3/4
2	3 1/4	21 9/16
2 1/2	4 1/8	25
3	4 15/16	28 1/8
3 1/2	5 3/4	31
4	6 1/2	33 7/8

When bending conduit up to 90 degrees with a bender that has a ram travel scale, you should make your bend according to the ram travel scale reading.

An offset bend requires two bends of the same degree. To determine the distance between the two bends, you must first decide on the distance in inches of the offset and the degree of bend your conduit routing requires. Remember that the maximum conduit size and offset in inches may restrict your bend. Mark and bend your conduit according to the benders manufacturers' instructions, tables, and charts.

If you have access to a conduit pipe holder (normally for 1 1/4-inch to 4-inch conduit), it will simplify your work by keeping the pipe in perfect alignment at all times, achieving an outstanding bend. For offset bends, the pipe holder permits making the first bend then reversing the pipe end and making the second bend. The second bend will then be 180 degrees opposite the first.

⚠ CAUTION ⚠

Before using any pipe bender, make sure the quick-lock pins are through the holes in the bottom frame and the eccentric pin is turned clockwise past the ball lock. Also, make sure the correct sides of the pipe support pins are in the proper holes. Failure to ensure correct pin placement could result in damage to the conduit and/or the bender.

Occasionally conduit will require more bending. In this case, place the conduit in the bender and continue bending to the desired degree. This step is not necessary when using the Bending Degree Indicator (used for exact bends, it reduces the necessity to correct bending caused by spring back) or when using the Bending Degree Protractor because the bend will be accurate.

Conduit pipe holders are very useful for bending long lengths of conduit. Check the manufacturer’s instruction guide for tables and charts with vital information about conduit bending kit attachments.

When you have to make a large sweep 90-degree radius bend, you will need to get the operating manual of the bender you are using and follow the suggested procedures for marking the bend spacing and finding the necessary center location.

One of the benders that you may use in the field is the Greenlee™ 880 M2 Lightweight Hydraulic Bender. This bender is designed to make bends up to 90 degrees on rigid conduit from 1/2 inch to 2 inches inclusive. The 15 ton ram, bending shoes, and frame unit allow you to make a complete 90 degree bend with one piston stroke. You can easily and rapidly assemble the units of the bender for operation without any tools. By using the bending instructions and the piston scale, you can make accurate bends. To assure easy portability, the manufacturer has designed the pipe supports for use as rollers, and many parts are made of light-but-strong aluminum alloy.

In the bending process, if the pipe is bent to the correct scale reading, over bends will not result. However: if you need to correct an over bend, you must follow the manufacturer’s instructions for the bender you are using.

As mentioned earlier, bending conduit is an art. The more you practice, the better you will be. Most bending charts show information on how to make bends to 15°. 30°, 45°, 60°, 90°, 180° and offset bends. When you require degrees of bend other than these and the accuracy of the bend, use the Bending Degree Indicator. The Bending Degree Indicator is extremely accurate and very easy to use. You should also use the indicator to make segment bends to center radii greater than those of the bending shoe.

12.3.0 Conduit Installation

In previous sections we have discussed types of conduits and the cutting, threading, and bending of conduit. Now, we will cover the requirements for installing the different types of conduit and how to pull conductors into them.

Several general requirements apply to all types of conduit installation: All raceways must be installed as a complete system before pulling any conductors into them. In other words, the “run” of conduit, as described previously, including conduit, fitting, and supports, must be complete before you install the conductors.

A run of conduit should be as straight and direct as possible. When a number of conduit runs are to be installed parallel and adjacent to each other, install them all at the same time. The minimum-sized raceway you can install is generally 1/2-inch electrical trade size. Specific exceptions to this rule include EMT, rigid, and flexible conduit installed in specific locations. The exceptions for each type are outlined in the NEC®.

All types of conduit must be reamed after being cut. Conduit threaded in the field must be threaded with a die that has a 3/4-inch taper per foot. When threaded conduit enters a box or fitting, you must use a bushing to protect the conductor insulation from cutting or tearing. Also, as shown in *Figure 8-68*, for those types that use threaded couplings, do not use running threads for connection at couplings. Running threads weaken the conduit and may come loose. Threaded couplings and connectors used with any type of conduit must be made up tight. Couplings or connectors to be buried in concrete or masonry have to be the concrete tight type; those to be installed in wet locations have to be the rain tight type.

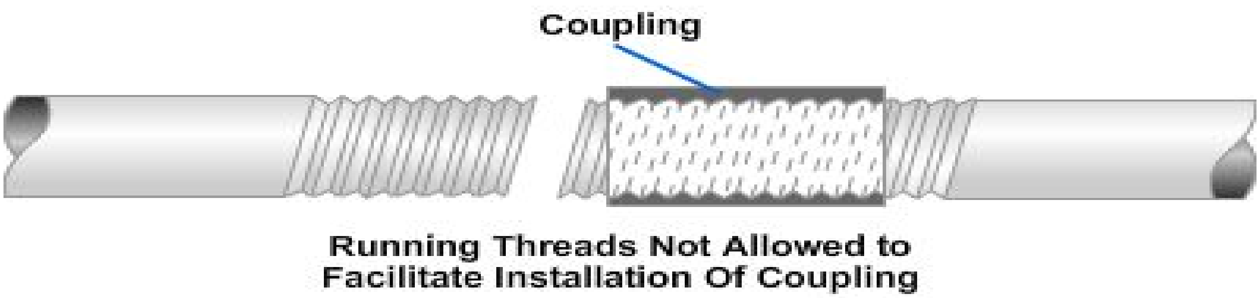

Figure 8-68 – Running threads.

Support conduit by straps or hangers throughout the entire run. *Figure 8-69* shows how to fasten straps on different types of surface. On a wooden surface, use nails or wood screws to secure the straps. On brick or concrete surfaces, first make a hole with a star or carbide drill and then install an expansion anchor. Use an expansion tool to force the anchors apart, forming a wedge to hold the anchor in the hole. Then secure the strap to the surface with machine screws attached to the anchor. On tile or other hollow material, secure the straps with toggle bolts. If the installation is made on metal surfaces, drill holes to secure straps or hangers with machine or sheet metal screws.

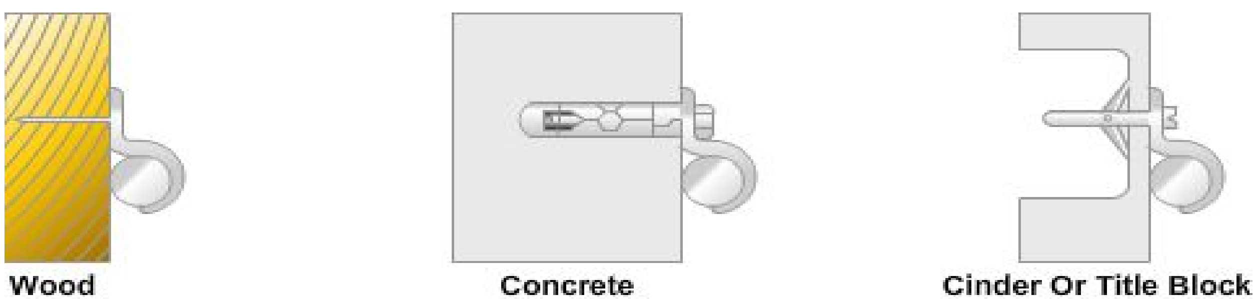

Figure 8-69 – Conduit support fastening.

The number of supports needed depends on the type of conduit used. Holes or notches in framing members may serve as supports. EMT and IMC require supports within 3 feet of each outlet box, junction box, cabinet, or fitting, and every 10 feet thereafter. Rigid metal conduit must also be supported within 3 feet of a box, but the distance between supports may be increased as the size of the conduit increases if the run is straight and made with threaded couplings. The distance between supports on direct vertical runs of rigid conduit from machine tools and the like may be increased to 20 feet if threaded couplings are used and the riser is supported at each end.

Rigid nonmetallic conduit must be supported, as shown in *Table 8-9*. In addition, it must be supported within 3 feet of each opening.

Table 8-9 – Nonmetallic conduit support.

CONDUIT (Inches)	MAX SPACE BETWEEN SUPPORTS(Feet)
1/2 – 1	-
1 1/4 - 2	3
2 1/2 - 3	5
3 1/2 - 5	6
6	7

Flexible metal conduit and liquid tight flex must be supported at intervals not exceeding 4 1/2 feet and within 12 inches on each side of every outlet box or fitting. Exceptions to this rule are runs of 3 feet or less where flexibility is needed or 6 feet where light fixtures are connected.

When you run conduit from one point to another, you often need to make more turns than the NEC® allows in a single run (360° of bends). When this larger number of turns is necessary, you can use a fitting called a conduit body. Conduit bodies are often referred to by their brand names, such as Condulet or Unilet. A conduit body is a portion of a conduit system that provides access to the system through a removable cover to the interior of that system at a junction of two or more sections or at a terminal point. An important point to remember is that all Condulets must be accessible after construction is completed. *Figure 8-70* shows some of the more common conduit bodies and covers.

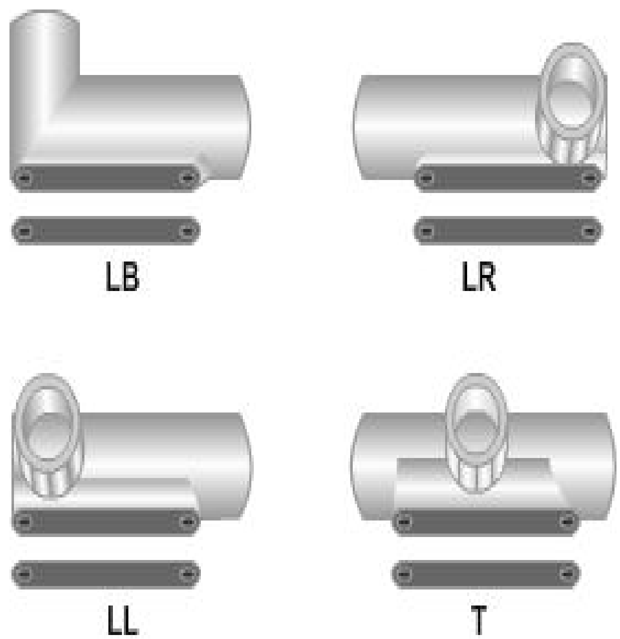

Figure 8-70 – Conduit bodies and covers.

Figure 8-71 shows how a conduit body is put in conduit between two outlets to keep the bends within NEC® limits for a single run. As you can see, the run on the left has bends that total 360 degrees, which is all the NEC® permits. Thus a conduit body, as discussed in NEC® Article 300, had to be installed in order to continue the conduit to the box on the right. After all conduit has been installed, supported, and connected to the boxes, you are ready to install the wire.

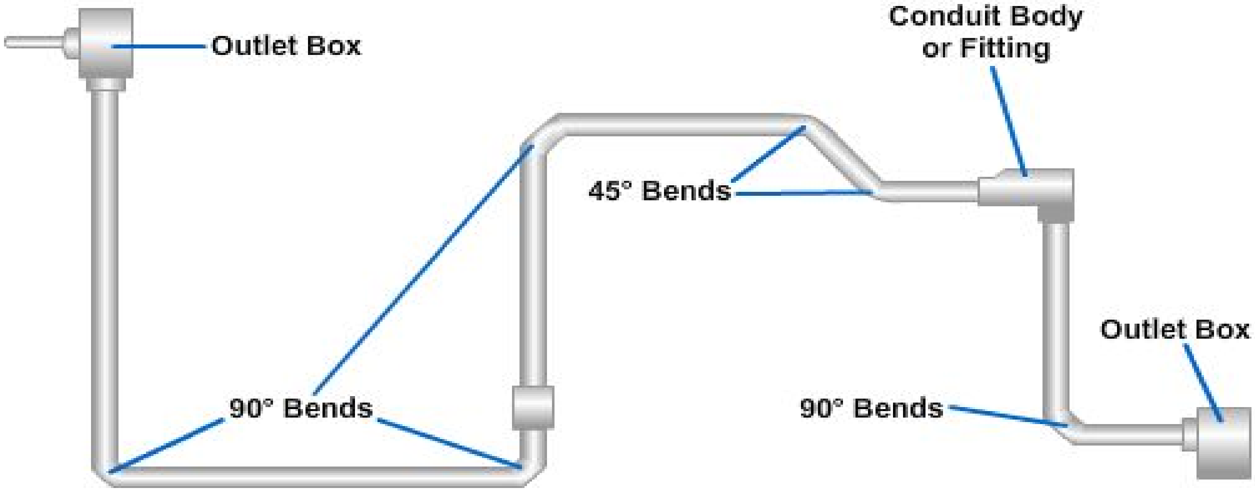

Figure 8-71 – Conduit body installed.

Conductor installation into conduits is the same for all types of conduit. The most common type of wire used is TW. This letter designation simply means that the wire or conductor has thermoplastic, moisture resistant insulation. When you are determining the length of wire needed to be pulled into the circuit, simply add the following: (1) lengths of conduit, (2) the size and number of boxes you must pull through, (3) the length of wire needed at each box, and (4) the makeup for the distribution panel.

For short conduit runs with only two wires, push the conductors through the conduit from one box to the next. When the conduit has several bends and you will install more than two conductors, you must use a fish tape to pull the wires through the conduit. The fish tape normally has a hook on one end, which is pushed through the conduit. The hook also makes it easier to push the tape through.

If the hook is broken off, you can make a new one with a pair of pliers and a propane torch.

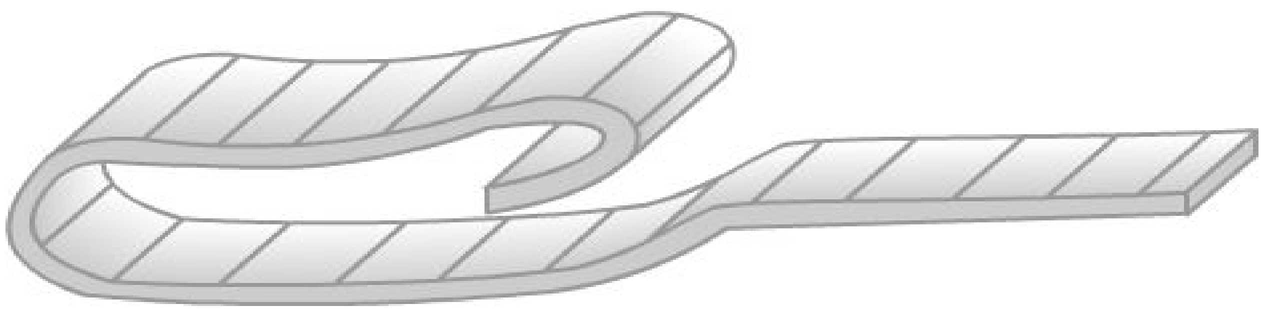

Figure 8-72 – Fish tape hook.

Use the torch to heat the end of the tape to take out the temper. On a 1/2 inch tape, heat about 3 inches at the end of the tape until it is red-hot, and bend a hook on it about an inch long, as shown in *Figure 8-72*. This shape hook seems to work best. After forming the hook, reheat the end of the tape until it is red. Allow the end to cool until it becomes straw colored. Then plunge it into a can of water until it is cool. This process restores the temper to the hook area.

Once you have the fish tape in the conduit, attach the hook to the wires to be pulled, as shown in *Figure 8-73*. Remove 4 to 6 inches of the insulation from the ends of the wires and thread the ends through the hook in opposite directions; bend them back and twist them around each other; then tape the hook and bare conductors to strengthen the attachment and make pulling easier. Use just enough tape to cover the hook and wires.

Figure 8-73 – Wires attached to fish tape.

Wire pulling usually takes two people, one to pull the fish tape and the other to feed the conductors into the conduit. The fish tape should be fed into the end of the conduit run from which it will be easiest to pull. It is usually best to pull the conductors from the distribution panel to the first box in the run, especially if the panel is energized. This procedure prevents having to pull on the steel tape near an energized bus.

⚠ WARNING ⚠

Whenever pulling conductors into energized panels, be careful to keep clear of the bus bars. Cover all energized parts with a rubber blanket.

When you must feed several conductors into a conduit, keep them parallel, straight, and free from kinks and bends. Wires that are allowed to cross each other form a bulge and are hard to pull around bends. Whenever possible, feed conductors downward, for example, from the second floor to the first, so the weight of the wires will help in the pulling process. Another way to ease the pulling of conductors is to rub an approved lubricant, such as soap, talc, soapstone, or other noncorrosive substance, onto the insulation or blow it into the conduit. You may find it hard to keep the fish tape from slipping in your hands when pulling long runs or runs with several bends. When slipping is a problem, you can use the back side (insulation crushing point) of a pair of side-cutting pliers to grip the tape to give you a good pulling handle.

Remember to leave at least 6 inches of free conductor at each outlet and switch box to make up splices or connect devices. You can pull conductors that are not spliced or connected to a device directly through the box.

The number of conductors you can have in conduit is based on the size of the conduit, the type of conductor insulation, and the size of the conductors. The NEC®, Chapter 9, has several tables to help you determine how many conductors of a certain size and insulation type you can have in a given size of conduit. These tables are based on fill; that is, the cross-sectional area of the conductors inside the conduit can take up only a certain percentage of the free space inside the conduit. Use these tables whenever there is a question on the number of conductors to be pulled. Too many conductors in a conduit cause overheating, which reduces conductor ampacity.

Once you have installed the conductors and all other finish work is complete, you are ready to do the electrical finish part. Finish work for conduit installations is the same as that for NM cable installations, which was covered previously in this chapter.

Test your Knowledge (Select the Correct Response)

25. **(True or False)** Thin wall conduit (EMT) and polyvinyl chloride (PVC) should be cut with a hacksaw because pipe cutters may flatten the end of the pipe.

    A. True
    B. False

26. What device is used to make bends in rigid nonmetallic conduit (PVC) (1/2 through 2 inch)?

    A. Blow-torch
    B. Heat wand
    C. PVC hot box
    D. Hickey

27. What is one of the most common bends you will make in the field?

    A. 10 degree
    B. 50 degree
    C. 70 degree
    D. 90 degree

28. **(True or False)** The back-to-back bend is actually two adjacent 90 degree bends made in the same conduit.

    A. True
    B. False

13.0.0 CONDUIT SUPPORTS and INSTALLATION METHODS

To install conduit overhead and underground properly, you need to review the appropriate articles of the Code. Conduit should run as straight and direct as possible. There should never be more than the equivalent of four right-angle bends between outlets or fittings.

In installing exposed conduit runs where there are several conduits in the run, it is usually better to carry the erection of all of them together rather than to complete one line before starting the others. If all are carried together, it is easier to keep all the raceways parallel, particularly at turns, and chances are that the job will look better.

Conduit can be supported on surfaces with pipe straps made in one-hole and two-hole types. On wooden surfaces, wood screws secure the straps in position. On masonry surfaces, use machine screws that turn into lead expansion anchors. Never use wooden plug because no matter how well seasoned a plug appears to be, it usually will dry out to some extent and loosen in the hole. When laying out multiple-conduit runs, you must keep in mind the spacing between the conduits to permit proper placing of the straps. The screw-hole dimension (see *Table 8-10*) enables you to order screws of the proper diameters to support the straps.

Table 8-10 – Spacing requirements when laying out multiple-conduit runs.

Size of conduit (inches)	Conduit width of opening (inches)	Conduit height of opening (inches)	Width of conduit strap (inches)	Distance between centers of screw hole (inches)	Diameter of screw hole (inches)	Size of wood screw required
1/4	9/16	17/32	5/8	1-9/16	0.20	No. 8 X 5/8”
3/8	1 1/16	21/32	5/8	1-3/8	0.20	No. 8 X 3/4”
1/2	7/8	25/32	5/8	1-5/8	0.20	No. 8 X 3/4”
3/4	1/18	1	3/4	2-1/8	0.22	No. 10 X 3/4”
1	1-3/8	1-11/32	3/4	2-3/8	0.22	No. 10 X 7/8”
1-1/4	1-3/4	1-5/8	1-13/16	2-3/4	0.22	No. 10 X 1”
1-1/2	2	1-7/8	1-13/16	3	0.22	No. 10 X 1”
2	2-1/2	2-5/16	1	3-3/4	0.22	No. 10 X 1 - 1/4”
2-1/2	2-3/4	2-15/16	7/8	4-3/3	0.25	No. 11 X 1 - 1/4”

13.1.0 Location of Conduit Supports

The Code states that rigid-metal conduit will be firmly secured within 3 feet of each outlet box, junction box, cabinet, or fitting. The Code permits this distance to be increased to 5 feet where structural members do not readily permit fastening within 3 feet. Support rigid-metal conduit at least every 10 feet unless they are straight runs of conduit made up of approved threaded couplings. Then they may be secured as shown in *Table 8-11*, provided such fastening prevents transmission of stress to terminations when conduit is deflected between supports.

Table 8-11 — Spacing of rigid-metal conduit supports.

CONDUIT SIZE (INCHES)	RIGID-METAL SUPPORT (FEET)
1/2 and 3/4	10
1	12
1 - 1/4 and 1 - 1/2	14
2 and 2 - 1/2	16
3 and larger	20

13.2.0 Conduit Hangers and Supports

Figure 8-74 shows a variety of conduit hangers and supports and several applications. U-channel supports are ideal for supporting several runs of conduits. In laying out these supports, consider future conduit runs as well as those to be installed initially. It is a simple matter to provide U-channels or trapeze hangers with additional space for future conduits. This procedure greatly reduces the cost of installing new conduit at a later date. With the U-channel system, as shown in *Figure 8-74*, special clamps are slipped into the channel slot, and the top bolt of the clamp securely fastens the conduit to the U-channel.

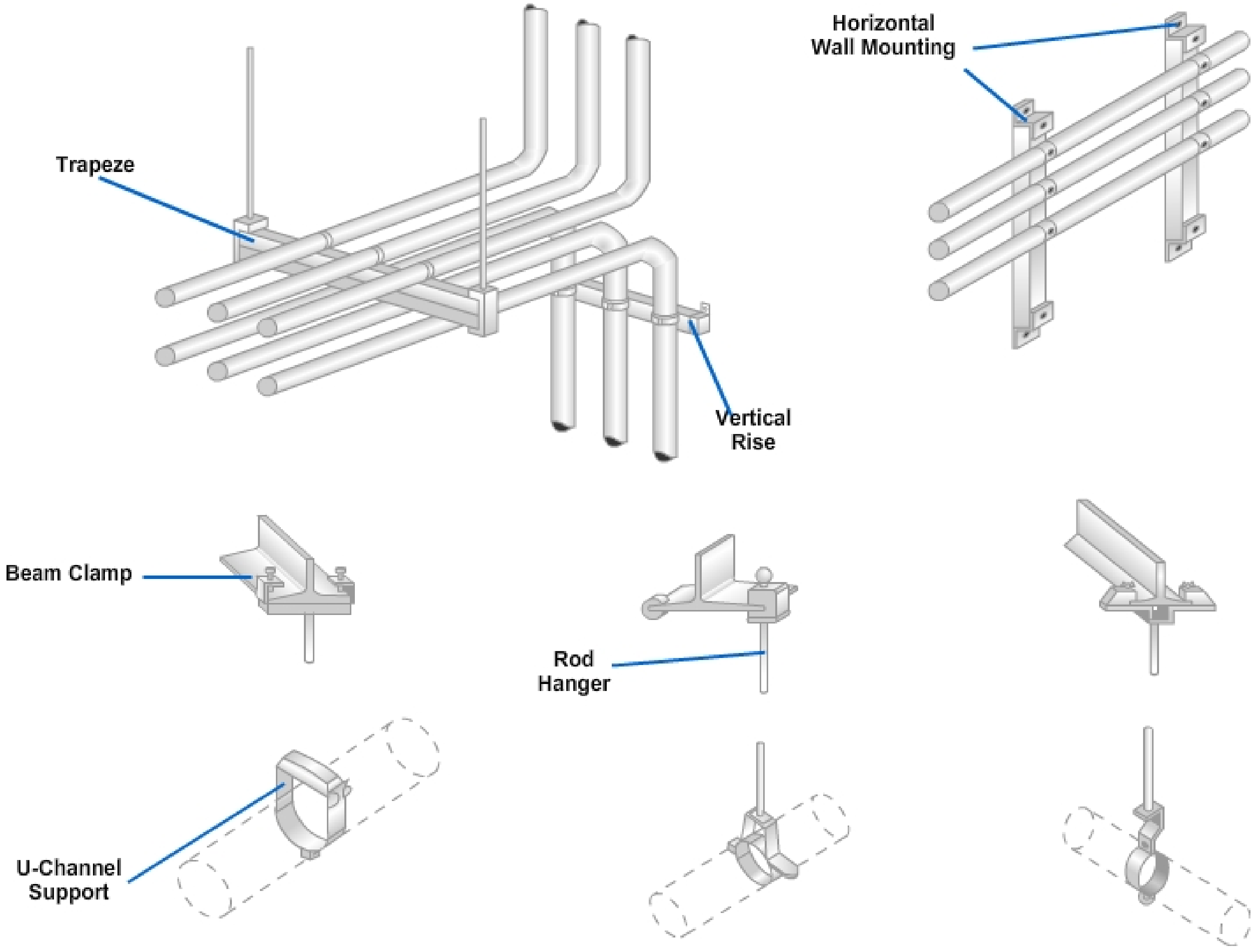

Figure 8-74 – Common conduit supports.

The U-channel can be directly fastened to a wall or ceiling, or attached to bolted threaded rod hangers suspended from ceilings, roof structures, or similar members.

Another excellent application for the U-channel is in suspended ceilings that contain lift-out ceiling panels. In modern construction, these lift-out panels provide ready access to mechanical and electrical equipment within the suspended-ceiling area. Accordingly, it is important that conduits installed in such an area do not prevent the removal of panels or access to the area. Rod-suspended U-channels provide the solution to conduit wiring in such areas.

Sections of the U-channel and associated fittings are available in aluminum or steel. Another type of material used for supports is slotted-angle-steel units. Numerous pre-punched slots allow installers to bolt on rods, straps, and similar material without drilling holes. Slotted steel has unlimited applications in forming special structures, racks, braces, or similar items.

A cable-pulling kit (80149) has everything needed for any wire or cable-pulling job. Most large Public Works and all battalions have the wire installation kit. The heavy-duty power wire/cable puller plugs into any convenient 115-volt source. It pulls 15 feet of cable per minute and can be used with various attachments for almost any type of pulling job.

After a “fish” line has been blown or run through the conduit, a rope that is provided with the power cable puller can be pulled through the conduit. This rope, used with a cable grip, makes the actual pull. The power cable puller can be used in almost any configuration. *Figures 8-75* through *8-80* are examples of the different setups.

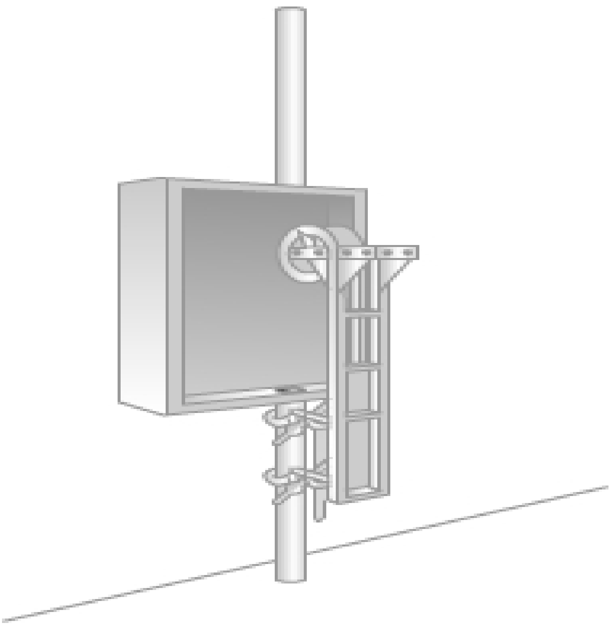

Figure 8-75 – Pipe adapter to exposed conduit.

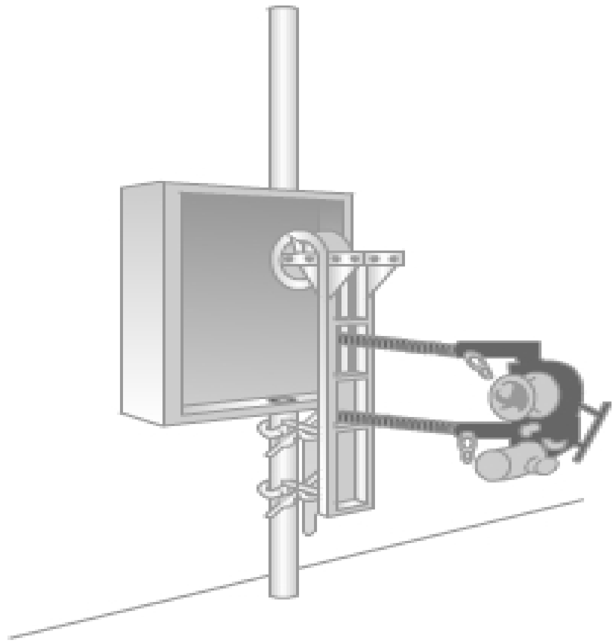

Figure 8-76 – Power unit to the power adapter.

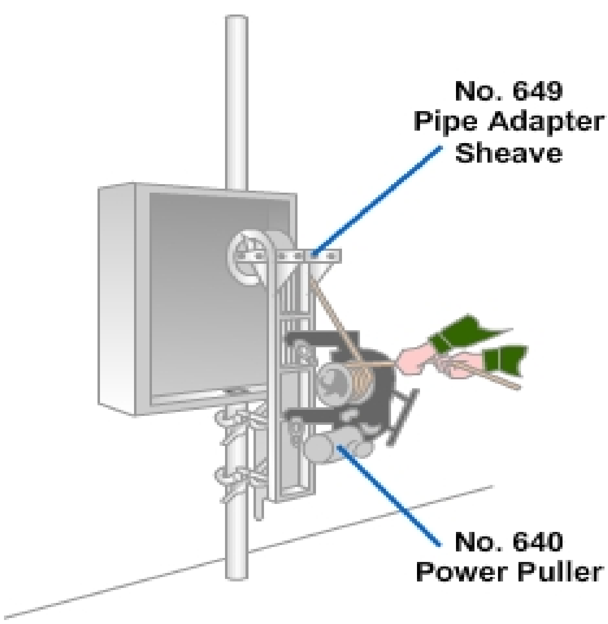

Figure 8-77 – "Up" pull, using exposed conduit.

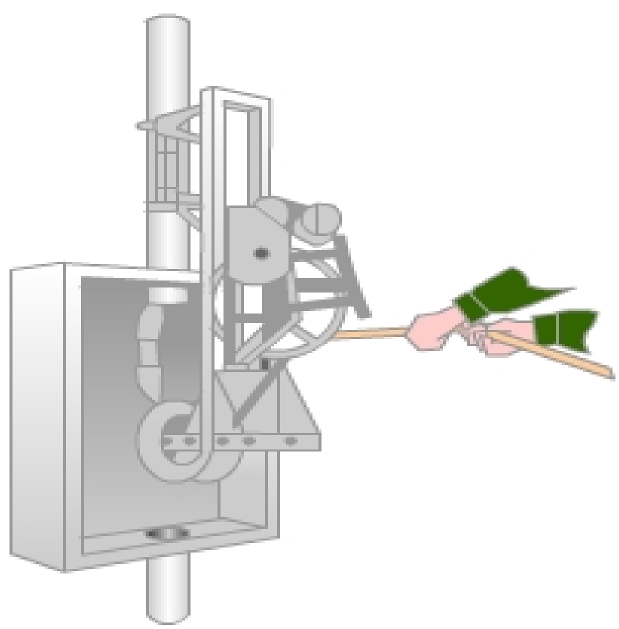

Figure 8-78 – "Down" pull, using exposed conduit.

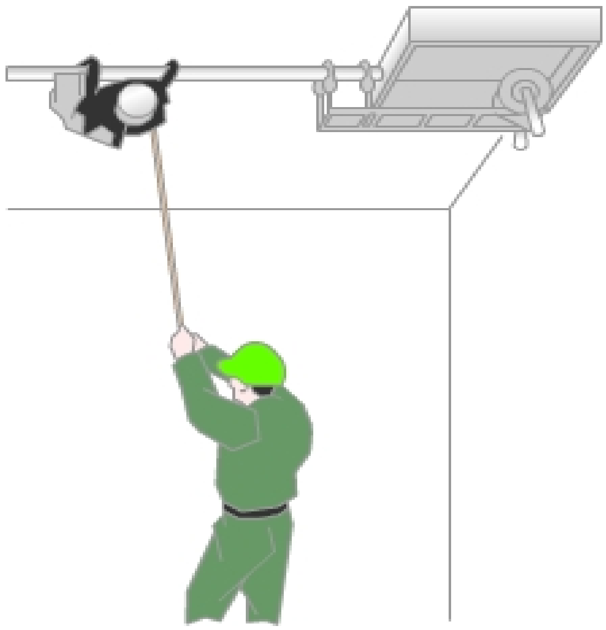

Figure 8-79 – Pulling in an overhead pull box with the puller mounted independently for extra cable.

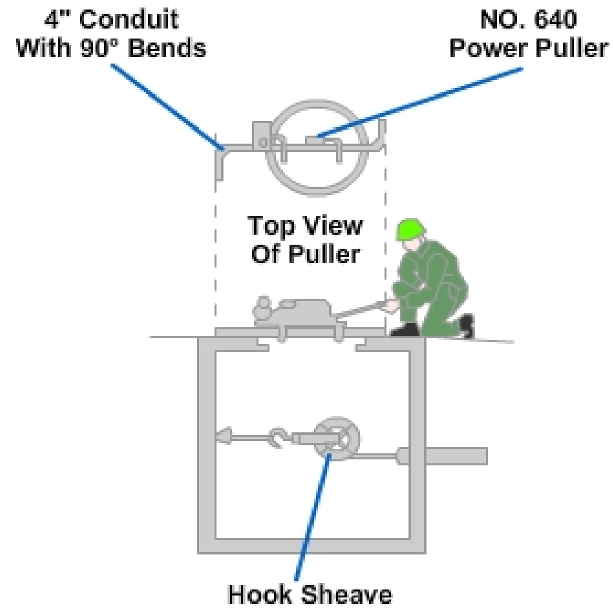

Figure 8-80 – Setup for ground pull.

14.0.0 DISTRIBUTION PANELS

14.1.0 Panelboards

The service entrance terminates in the service equipment or in a panelboard. The panelboard may be used for lighting and power branch circuits. A distribution panel, as the name implies, serves as a center or point in the electrical system where power is fed to the branch circuits. A distribution panel consists mainly of a metal cabinet that houses bus bars and individual circuit protective devices. The protective devices (fuses or circuit breakers) protect the circuits against excessive current flow. Panelboards must be rated at least as high as the feeder capacity required for the load. Panelboards are marked by the manufacturer with the voltage, current rating, and number of phases for which they are designed. This information, plus the manufacturer's name or trademark, must be unobstructed by interior parts or wiring after you have installed the panelboard. According to the NEC®, lighting and appliance panelboards cannot have more than 42 overcurrent devices besides the mains. Two pole and three-pole circuit breakers are connected as two and three overcurrent devices, respectively.

14.2.0 NEC® Requirements

According to the NEC®, each lighting and appliance panelboard must be protected from current flow on the supply side by not more than two main circuit breakers or two sets of main fuses with a combined rating no greater than that of the panelboard. This protects not only the feeders but also the panelboard. The panelboard does not need individual protection if the panelboard feeder has overcurrent protection no higher than the panelboard rating. To prevent overheating of the conductor, the total load on any single overcurrent device in a panelboard must not exceed 80 percent of its capacity where, in normal use, the load continues for 3 hours or longer.

Panelboard cabinets must be grounded. Provide a terminal for attachment of feeder and branch circuit equipment-grounding conductors where non metallic raceway or cable is used. This terminal bar must be bonded to the cabinet, but not to the neutral bar except in service equipment.

14.3.0 Three Phase Panelboards

Three-phase panelboards supplied by a four wire, delta connected system that has the midpoint of one phase grounded must have the higher voltage-to-ground conductor or bus bar marked. This high voltage conductor should have an orange outer finish or be clearly tagged. The identification is required at any point where a connection can be made and the neutral conductor is also present. The phase arrangement on a three-phase panelboard is A, B, C, from left to right, or top to bottom when viewed from the front. The B phase will be the phase that has the higher voltage to ground.

14.4.0 Types of Panelboards

There are two types of panelboards: fuse panels and circuit breaker panels. Fuse panels, as the name implies, contain fuses for protection of each circuit.

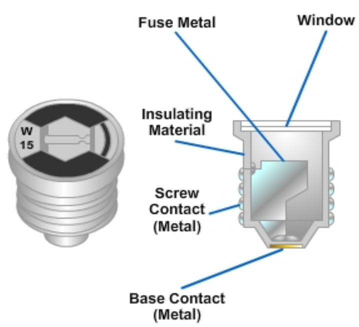

Figure 8-81 – Plug type of fuse.

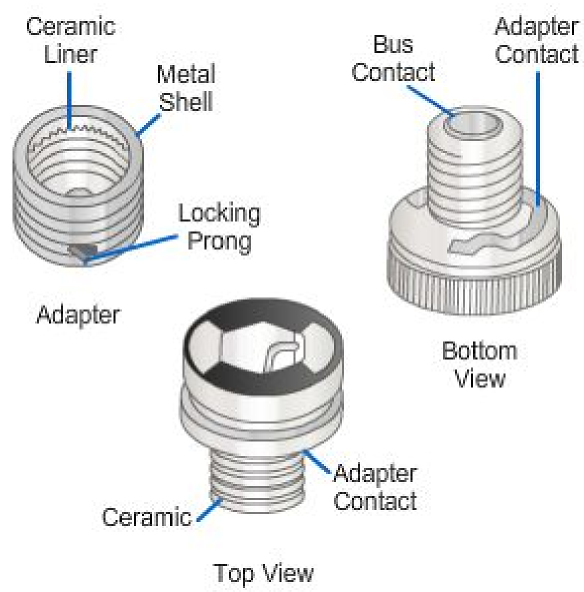

Figure 8-82 – Adapter and Type S fuses.

Fuse panels are designed in a variety of ways. These designs vary in size, capacity (amperage and voltage), and type of installed fuses. The capacity of the panel is based on the ampacity of the bus bars of the panel. The number of bus bars is determined by whether the panel is single-phase or three-phase. Fuse panels are designed for plug fuses, cartridge fuses, knife-blade fuses, or a combination of these. Fuse panels use an Edison-base fuse that screws into a socket similar to the medium-based light socket. Fuse panels still exist but are not very common. Fuse panels are not to be installed either for new work or as a replacement panel unless they have been modified to accept Type S fuses. Refer to *Figure 8-81* for a view of the plug type of fuse and *Figure 8-82* for a view of the adapter and Type S fuse.

The other type of fuse you will be dealing with as a CE is the cartridge fuse. There are two types: the ferrule and the knife blade. Both types are available with replaceable or non-replaceable fuse links. Ferrule fuses are available in ampere ratings from 0 through

60. Fuse panels that use the ferrule type of fuse have specially designed fuse clips in which only ferrule types will fit. Fuse diameter and length increase as amperage and voltage increase. Ferrule fuses are used in circuits up to 600 volts. *Figure 8-83* shows a typical ferrule type of fuse.

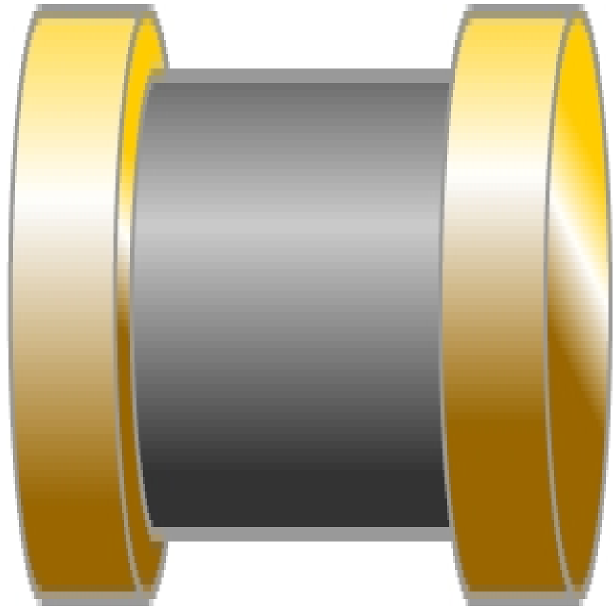

Figure 8-83 – Ferrule type of fuse.

Fuse panels that provide distribution for high capacity circuits use knife-blade fuses for protection. The fuse clips are especially designed to receive knife-blade fuses only. Knife-blade fuses are available in ampere ratings of 61 through 6,000. The maximum voltage rating for knife-blade fuses is 600 volts. *Figure 8-84* shows a typical knife-blade fuse.

Two factors are important for selecting fuses for circuit protection. These are the total current flow and the voltage of the circuit in which the fuse is to be installed. Since the purpose of the fuse is to protect the circuit, it must be the weakest point in the circuit. Thus the fuse should be rated no higher than the lowest rated component to be protected. Before installing a fuse in a panel, check the condition of the fuse holder or clips. These must be clean and hold the fuse firmly.

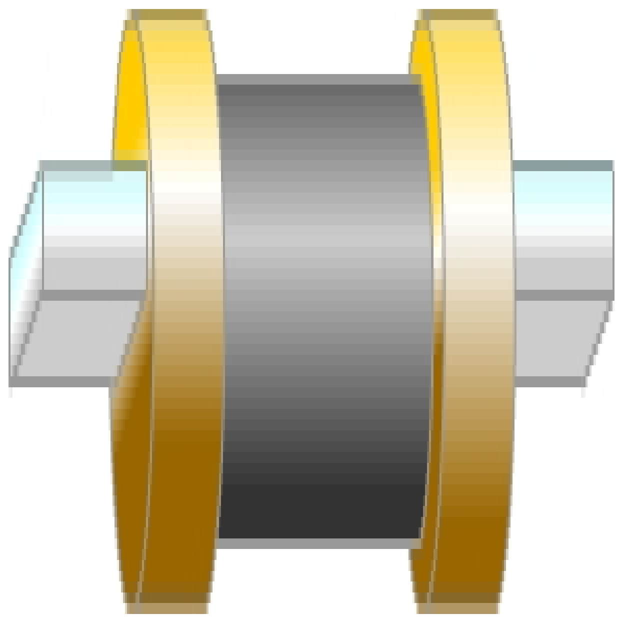

Figure 8-84 – Knife-blade fuse.

One of the newer types of protective devices, used more often than fuses because of the way it reacts to an overload, is the circuit breaker. A circuit breaker trips on an overload but can be reset to complete the circuit again without being removed or replaced. Circuit breakers are classed according to their operating principle. They may be thermal, magnetic, or a combination of thermal and magnetic. *Figure 8-85* shows typical circuit breakers with one, two, and three poles. Multi-pole breakers are designed to open all ungrounded conductors in a circuit at the same time.

The thermal circuit breaker has a bimetallic element within the breaker that responds to temperature change. The bimetallic element is made of two strips of dissimilar metal fused together. Each strip has a different expansion rate when heated. Current flowing through the breaker generates heat, which increases as the flow increases. The heat causes the bimetallic element to bend and act against a latch. The breaker mechanism is adjusted so that when the current flow reaches a set level, the element bends enough to trip the latch. This action opens a set of contacts to break the circuit. The thermal type of circuit breaker is commonly called a time lag breaker because the breaker does not open immediately when an overload occurs. The bimetallic element requires a short time (length depends on the size of the overload) to respond to the heat generated by the overload current.

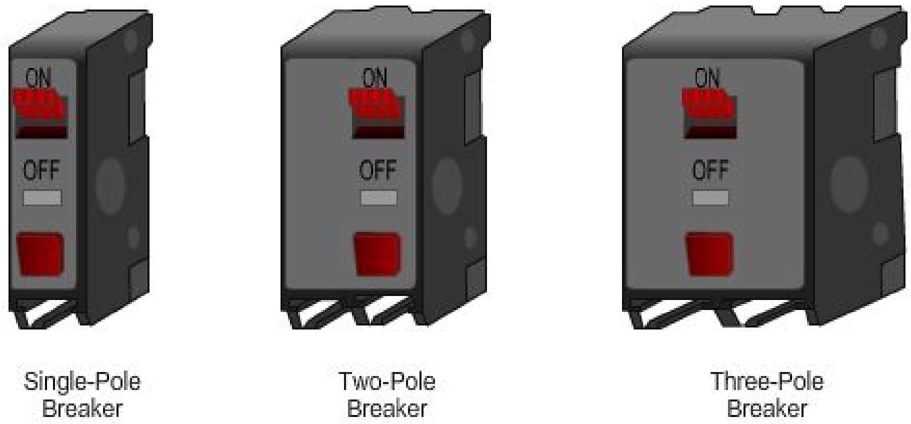

Figure 8-85 – Typical circuit breakers.

A magnetic circuit breaker responds instantaneously when an excess of current flows through the breaker. A small electromagnet actuates the breaker mechanism. Whenever a predetermined amount of current flows through the electromagnet, enough magnetic flux is created to attract a small armature. As the armature moves, the breaker mechanism trips and opens the circuit.

The thermal-magnetic circuit breaker, as the name implies, combines the features of both the thermal and the magnetic types. Of the three, the thermal-magnetic circuit breaker is preferred for general use. A small overload actuates the bimetallic strip to open the circuit on a time delay, while a large overload or short circuit actuates the magnetic trip to open the circuit instantaneously.

Circuit breakers are rated in amperes and volts the same as fuses and you select them on the same basis. Circuit breakers are sealed units and no attempt should be made to repair them or to adjust the ampere capacity. A defective breaker must be removed and replaced.

Circuit breakers used in circuits that may pose an added hazard to the user are made with an extra safety feature. This breaker is called a ground fault circuit interrupter (GFCI). It is a thermal-magnetic breaker with an additional internal circuit that detects a current leak from the hot wire to ground and opens the breaker if that current reaches a set amount. This leakage cannot be more than 5 (±1) milliamperes (thousandths of an ampere) to ground. Most of these breakers have a test button that can be used to check the GFCI to see if it will trip when there is a fault.

To install the GFCI, connect the circuit hot wire to the breaker just as on a standard breaker. Connect the circuit neutral to another terminal on the GFCI instead of to the neutral bar in the panel. The GFCI comes with an attached white neutral wire, which you then connect to the neutral bar. The NEC® requires installation of GFCI for several circuits used in the home. These circuits include ALL 120 volt, single-phase, 15 and 20 ampere receptacles in bathrooms, garages, and outdoors. GFCI may be used elsewhere when there is a need for the added protection.

Now that we have discussed the various types of panelboards, fuses, and circuit breakers, we need to discuss panelboard connections. Once you have brought all the circuits into the cabinet, you can mount the panelboard in the cabinet and attach the neutral bar and the equipment ground bar to the cabinet. The ground bar must be bonded to the cabinet either by a bonding jumper or by the more common method of running a screw through the bar into the cabinet. Do not bond the equipment ground bar and the neutral bar together unless the panelboard also serves as the service equipment.

Quite often the panelboard is not connected until the interior wiring is done and the receptacles, switches, and fixtures installed. The method of attaching circuit conductors is based on conductor size and the type of terminals on the panelboard. Small conductors, No. 10 and smaller, are normally looped around a screw type of terminal. Larger conductors may need to have terminal lugs, attached so the connection can be made to screw terminals. Pressure types of terminals are often provided for larger conductors, neutral conductors, and equipment-grounding conductors.

Connect conductors in a neat and professional manner. In many cases, you can connect them with little excess wire. Connect conductors brought in through the sides of the cabinet directly to the overcurrent device. Those brought in from the top or bottom of the cabinet, bend neatly opposite the fuse or circuit breaker to which they are to be attached and cut them just long enough to make a good connection, as shown in *Figure 8-86*. Many experienced electricians feel that this system of connecting conductors is not necessarily the best, even though it presents the most uncluttered look and leaves more space around each conductor. These electricians usually try to leave an end on each conductor that is equal to the height plus the width of the cabinet. They run each conductor along the panel and loop it back 180 degrees before connecting it to its fuse or circuit breaker. This method is shown in *Figure 8-86*A. Little added material is needed, and the extra length on the conductor permits it to be switched to another terminal on the panel if desired. Also, in the case of conductor breakage near the terminal, the conductor can be reconnected easily.

Connect ungrounded conductors in a fuse panelboard directly to terminals on the bus bars. In a circuit breaker panelboard, the underground conductors are usually connected to the circuit breaker which is then inserted in the panelboard. In most cases, the breaker is snapped into place and held by spring tension. Sometimes a screw holds breakers in the panelboard.

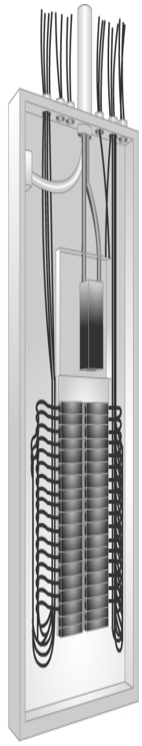

Figure 8-86 – Panelboard connections without excess wire.

Figure 8-86A – Panelboard connections with leaped conductors.

Test your Knowledge (Select the Correct Response)

29. According to the NEC®, lighting and appliance panelboards cannot have more than what number of overcurrent devices besides the mains?

    A. 12
    B. 24
    C. 42
    D. 48

30. What are the two basic types of panelboards?

    A. Fuse panels and circuit breaker panels
    B. Circuit breaker panels and meter stop panels
    C. Meter stop panels and fuse panels
    D. Fuse panels and cut-out panels

31. What is the maximum voltage rating for knife-blade fuses?

    A. 400 volts
    B. 600 volts
    C. 700 volts
    D. 800 volts

15.0.0 HAZARDOUS LOCATIONS

The NEC® describes hazardous locations as areas where sparks generated by electrical equipment may cause a fire or explosion.

15.1.0 Classification of Hazardous Locations

Locations are classified by the properties of the flammable vapors, liquids, or gasses, or combustible dusts or fibers that may be present in them and the likelihood that a flammable or combustible concentration or quality is present. There are three classes, described as follows:

Class I (Article 501, NEC®) are locations which contain flammable gasses or vapors in the air. This includes spray paint booth, dyeing plants, and gas generator rooms. This class is divided into two divisions and four groups. Division one is where volatile, flammable solvents are used. Division two is where flammable gasses, vapors, or volatile flammable gasses or volatile liquids are handled in either a closed system or closed space. Article 500.5 of the NEC® lists the groups as A, B, C, or D and describes them in detail as to hazard.

Class II (Article 502, NEC®) are locations where combustible dust is present. Class II locations include grain handling and storage plants and sugar pulverizing plants. Location may be where there may be enough combustible dust in the air to produce explosive or ignitable mixtures. This class is divided into two divisions and three groups. In Division one locations combustible dust may be present under normal operating conditions. Division two is locations where dust may accumulate. Article 500.5 of the NEC® lists the groups in detail as A, B, or C, according to hazard.

Class III (Article 503, NEC®) are locations hazardous because of the presence of easily ignitable fibers or "flyings", but in which such fibers or "flyings" are not likely to be in suspension in the air in quantities sufficient to produce ignitable mixtures. Likely Class III locations include cotton mills, rayon mills, and clothing manufacturing plants. They do not usually require explosion proof fittings and enclosures, but they may employ many special wiring techniques.

15.2.0 Prevention of External Explosions

In locations specified by the NEC® (Articles 510 through 517) as explosion-hazardous, you must install explosion proof fittings. Locations are classed by number in descending order of danger: Class I, Division 1, highly hazardous; Class I, Division 2, slightly less hazardous; and so on.

The following is an example of explosion proofing. In a gasoline filling station, the pump island is classed as Class I, Division 1. All the conduits in this area must be sealed with a special sealing fitting. On conduit for lights above the pumps, the sealing fitting must be located at a height of not less than 4 feet above the driveway surface. No

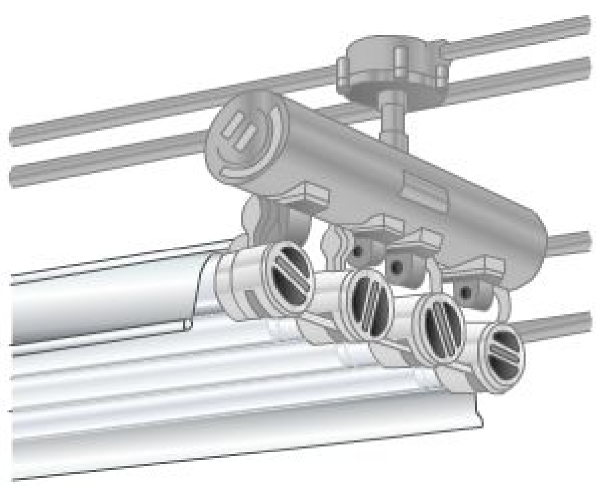

Figure 8-87 – Explosion proof fluorescent fixture.

junction boxes (explained in the NEC®) or Condulets may be used in the pump area. Conduits running from pumps to panels in the building must be sealed not less than 18 inches above the finished floor of the building to avoid fumes from the gasoline pumps. An approved seal must be installed on any conduit entering or leaving a dispensing pump or the enclosure on the pump island.

Inside the building of a gasoline station, the Class I, Division 1, space extends 18 inches above the floor. Space above the 18-inch level is classed as Class I, Division 2.

Paint spray booths are listed as Class I, Division 1. Therefore all fixtures (exhaust fans, air compressors, or other electrical appliances) located in such booths must be explosion proof, as well as all switches, convenience outlets, and motor starters.

Figure 8-87 shows an explosion proof fluorescent lighting fixture for installation in a paint spray room. In this fixture, the fluorescent tubes are sealed in a larger glass tube. The four-tube seal ends can be seen in the figure. The ballast (explained in NEC® Article 410, Part P) is enclosed in the container above the tube seals.

Figure 8-88 shows an explosion proof incandescent lighting fixture; *Figure 8-89* shows an explosion proof on-and-off switch for lighting.

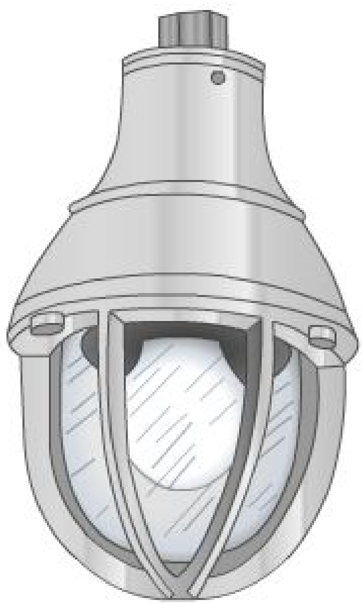

Figure 8-88 – Explosion proof Incandescent fixture.

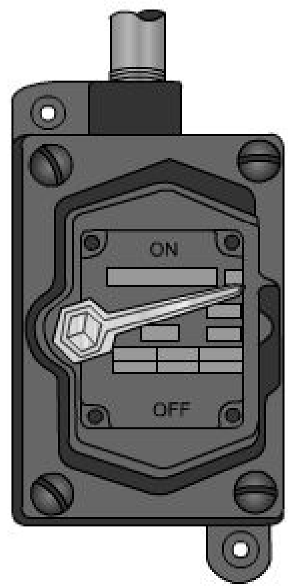

Figure 8-89 – Explosion proof ON-and-OFF lighting switch.

When you have completely installed the interior wiring system, make an overall inspection to be sure that good installation practices have been observed and all connections are correct. While you are making this check, do not forget neatness. Make sure that ground connections are tight and that ground wire is protected against injury. Be sure all connections in the entrance switch and panelboards are tight. See that all metal noncurrent-carrying parts of portable equipment are grounded.

Test your Knowledge (Select the Correct Response)

32. How many classes of hazardous locations are there according to the NEC®?

    A. Two
    B. Three
    C. Four
    D. Five

33. What type fittings must be installed in locations specified by the NEC® as explosion-hazardous?

    A. Spark proof
    B. Water proof
    C. Flame retardant
    D. Explosion proof

16.0.0 ELECTRICAL TEST EQUIPMENT

The right test equipment and a Construction Electrician who knows how to use it are a valuable combination for solving electrical circuit problems. As with most pieces of electrical test equipment, there will be a variety of makes and models available for your use. Because of this, your first step should always be to familiarize yourself with the manufacture's operating manual prior to using the meter. In addition to following specific manufacturer's operating instructions, check that the power to which the meter is to be connected does not exceed the voltage rating of the meter itself.

Also, prior to connecting the meter's leads to the load-side of the disconnect, verify how the leads are marked, i.e., 1-2-3, A-B-C, or colored red, white, blue; and strictly observe the connection instructions in the operating manual. (In most cases connection procedures will be from left to right, 1, 2, 3 or A, B, C.) Once you have ensured that secure connections have been established, then apply power and check the results. The following are various types of electrical testing equipment and their uses.

16.1.0 Ammeters

The model of clamp-on-ammeter shown in *Figure 8-90* allows electricians to measure the amount of current on an energized circuit without having to open the circuit first and connect any test leads. It is important to note that, like the multimeter, some models of clamp-on ammeters will also be capable of measuring voltage and resistance. The clamp-on ammeter is indispensable for working on current flow on motor circuits, transformer banks, and virtually any type of electrical circuit. Use the following procedures to take meter readings:

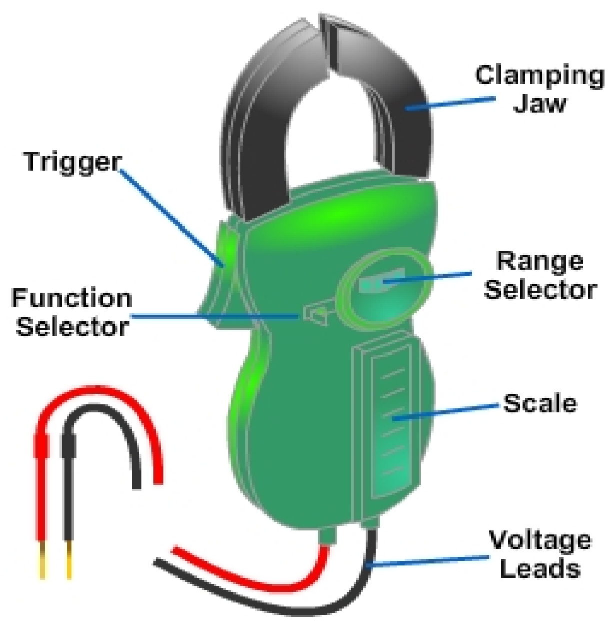

Figure 8-90 – Clamp-on Ammeter.

- Move the selector switch to the desired amperage range (if you know it). **Note** - If you do not know what amperage you are likely to be encountering, always set the meter range to its highest setting for the first reading.

- Use the trigger assembly to open the jaws.
- Place the open jaws around one of the circuit conductors. **Note -** If the jaws encircle more than one conductor, their magnetic fields will cancel each other out and you will not be able to obtain an accurate reading.
- Close the jaws by releasing the pressure on the trigger assembly.
- Read the meter. If the initial reading is negligible, remove the meter from the conductor and adjust the selector switch to a lower scale until a readable level is obtained. A mid-scale meter reading is recommended. Caution: Make sure to open the jaws and remove the meter from around the conductor before switching scales.

16.2.0 Voltmeters

The meter component (or voltage indicator) of a voltmeter is actually a micrometer. This instrument is series connected to a resistor (called a voltage multiplier) to operate as a voltmeter. The series resistance must be appropriate to enable measurement of the range of voltage. The scale of an instrument designed for use as a voltmeter is calibrated (marked off) for voltage measurements. Panel voltmeters are similar in appearance to the ammeters except for the calibration of the scale. Connect voltmeters across a circuit or voltage source to measure voltage.

Panel-mounted voltmeters are permanently wired into the circuit in which they are to be used. Portable voltmeters like the one pictured in *Figure 8-91* are designed to measure one or more ranges of voltage.

Figure 8-91 – Portable voltmeter.

Voltmeters intended for measurement of more than one voltage range have range selector switches. The range selector switch internally connects the appropriate multiplier resistor into the meter circuit for the range of voltage to be measured. For each setting of the selector switch, connect a different multiplier resistor into the meter circuit. For each selection, a particular resistor value is designed to limit the current through the milliammeter to a maximum of 1/1,000 of an ampere (1 milliampere) for a full-scale reading.

In a similar way, voltmeters designed to use a micrometer, for example, a 50 microampere meter, include multiplier resistors that limit the meter current to a maximum value of 50 microamperes. In this case, 50 microamperes are flowing through the meter for a full-scale deflection of the needle. Voltmeters that use either a milliammeter or micrometer to indicate voltage have a scale calibrated to read directly in volts. The flow of current in either type of meter represents the electrical pressure (voltage) between two points in an electrical circuit.

In the center of the tester is a neon lamp indicator. The lamp is used to indicate whether the circuit being tested is AC or DC. When the tester is operated on AC, it produces light during a portion of each half-cycle, and both lamp electrodes are alternately surrounded with a glow. Two other indications of AC voltage are an audible hum and a noticeable vibration that can be felt when the instrument is hand-held. When the tester is operated on DC, it produces light continuously, but only the negative electrode glows; therefore, the tester will indicate polarity on DC circuits. Both the test probes and the glow lamp enclosure are colored red and black. While you are testing a DC circuit, the electrode of the glow lamp on the side colored black is glowing. This glow indicates that the black probe of the tester is on the negative side of the circuit; likewise, the opposite electrode glows when the red probe of the tester is on the negative side of the circuit. The line voltage indicator does not determine the exact amount of circuit voltage.

16.3.0 Ohmmeters

The fastest method of determining resistance is by taking a resistance reading directly from an ohmmeter. The simplest type of ohmmeter consists of a housing that includes a milliammeter, a battery, and a resistor connected in series. Before using an ohmmeter for a precise resistance measurement, short the leads together and set the needle to zero by rotating the “zero ohms” (variable resistor) knob. The result is a full-scale reading at zero ohms.

Figure 8-92 – Ohmmeter.

Be certain not to place the ohmmeter leads across an energized circuit or a charged capacitor. Do not ignore this rule, as doing so will likely result in damage to the test equipment. Always turn off the power on a circuit to be tested before making continuity or resistance tests. Before you test with an ohmmeter, bleed any capacitors that are included in the circuits under test. Use extreme care in testing solid-state components and equipment with an ohmmeter. The voltage from the internal batteries of the ohmmeter will severely damage many solid-state components. Always turn an ohmmeter off after you have completed your test to lengthen the life of the batteries.

After you zero the meter, place the leads across the circuit or component under test. The resistance reading may then be taken from the point along the scale at which the needle comes to rest. Taking accurate readings becomes progressively more difficult toward the high-resistance end of the scale. When the needle comes to rest at the high end of the scale and the ohmmeter has several resistance ranges, simply switch to a higher range for a reading closer to center scale. Read the resistance directly from the scale at the lowest range.

The series type of ohmmeter is only one type of instrument used for resistance measurements, but it is common in the design of ohmmeters used by Construction Electricians. *Figure 8-92* is an example of a commonly used ohmmeter.

16.4.0 Multimeters

One of the more common meters used by Construction Electricians is a multimeter similar to the ones pictured in *Figure 8-93*. Multimeters are made in both analog and digital readout and perform several (or multiple) functions. An analog instrument usually makes use of a needle to indicate a measured quantity on a scale. Digital meters indicate the quantity in figures. Each multimeter consists of a case to enclose the indicating device, one or more functions and/or range switches, and internal circuitry and jacks for external connections.

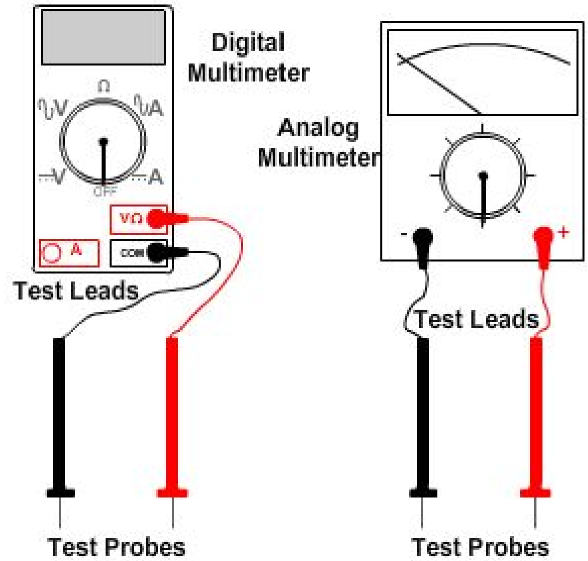

Figure 8-93 – Multimeter.

16.5.0 Voltage, Amperage, and Resistance Measurements

When taking voltage measurements, be sure to set the switches for the voltage to be measured before plugging the test leads into the jacks. Then plug the test leads into the appropriate jacks for the test you are about to perform. When you have red and black test leads, as in *Figure 8-93*, get into the habit of using the black lead with the common or (- negative) jack, even when measuring AC volts. For an analog meter, plug the red lead into the (+ positive) jack. With the digital meters, use the jack marked “V-O” (volts-ohms). Then connect the two test leads to the device you are testing. Do not touch the probes or clips of the test leads. If you have the meter range switch at the highest setting and see that the voltage value is within a lower voltage range, set the range switch to the lower range that is still higher than the voltage reading you remember.

When you take a reading at a higher range and switch to a lower range, the reading at the lower range will be more accurate. Be sure to read from the scale that matches the range setting of the switch. Simply take the reading directly from the digital multimeter.

WARNING

Always be alert when taking voltage or amperage measurements if it is necessary to move the meter. If you move the instrument in a way that causes tension on the test leads, one or both leads may be pulled from the jack(s). The leads will be energized just as the circuit to which they are connected, and they can be dangerous.

Most multimeters used to take amperage measurements are designed with quite low current ranges. The clamp-on ammeter discussed earlier is the most convenient.

Just as you must set up the meter to measure voltage accurately, you must set it up for measuring resistance accurately. If you are to measure a 120-ohms resistor, for example, set the selector switch to ohms at the appropriate range. For the analog instruments, set the switch to the R x 1 or x 1 as appropriate. Read the value from the ohms scale directly. For higher values of resistance, like 1,500 ohms for example, use the R x 100 or x 1000 ranges. In this case, multiply the reading from the ohms scale by 100 or 1000. For all critical resistance measurements, always touch the leads together and set the indicator needle to zero with the appropriate adjustment knob. Do not let the leads touch your fingers or anything else while you are zeroing the meter. On multimeters, use the common (- negative) and (+positive) jacks for resistance measurements.

WARNING

Be certain that there is no power on the circuit or component you are to test when measuring resistance. Be sure to discharge any capacitors associated with the circuit or component to be tested before connecting the instrument to the circuit or component.

For critical measurements, make sure that only the circuit or component you are to test touches the leads while you take the reading; otherwise, the reading may be inaccurate, especially on the higher resistance ranges. Many times you will use the ohmmeter for continuity tests. You will not have to zero the meter for non critical continuity tests. Touch the leads together to see where the needle comes to rest. If the needle stops at the same place when you place the leads across the circuit, there is continuity through the circuit.

16.6.0 Megohmmeters

The megohmmeter is a portable instrument consisting of an indicating ohmmeter and a source of DC voltage. The DC source can be a hand-cranked generator, a motor-driven generator, a battery-supplied power pack, or rectified DC. The megohmmeter is commonly called a “megger” although Megger® is a registered trademark. The megger tester shown in *Figure 8-94* is an example of a dual-operated megohmmeter. It has both a hand cranked generator and a built-in line power supply in the same chapter.

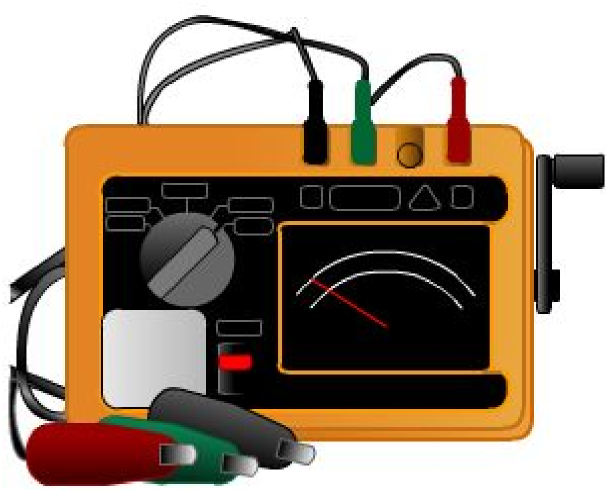

Figure 8-94 – Megohmmeter.

The megger is capable of applying a much higher value of DC voltage to the circuit or component under test than is the typical ohmmeter. Meggers that supply a test potential of 500 volts are common. The megger shown in *Figure 8-94* is capable of several test voltages up to 1,000 volts, depending on the setting of the selector switch.

Ohmmeters are generally designed to include batteries as voltage sources. These batteries apply approximately 1/2 to 9 volts to the circuit under test. The design of the megger is such that the needle floats freely until the generator is operated. When the generator is not operating, the needle may come to rest at any point on the scale. This characteristic is due to internal design, unlike the typical ohmmeter.

16.7.0 Insulation Resistance Testers

The megger (*Figure 8-94*) is used to measure high-insulation resistance. If the test leads connected to the line and earth terminals are open-circuited (as when they are not allowed to touch anything) and the hand-cranked generator is operated, the needle is deflected to infinity. “Infinity” means that the resistance is too high for the instrument to measure. A reading at or near infinity means either the insulation is in excellent shape or the test leads are not making contact with the component being tested. A zero deflection in the above mentioned reading can mean that the conductor under test is touching the sheath or conduit surrounding it. This deflection could also be an indication that the insulation is worn or broken somewhere close to the test point. Any reading near the low end of the scale may mean faulty or wet insulation. The relatively high voltage of the megger will likely cause enough leakage current to reveal an insulation problem by a lower than normal resistance indication on the meter scale.

Test your Knowledge (Select the Correct Response)

34. **(True or False)** When taking voltage measurements, be sure to set the switches for the voltage to be measured before plugging the test leads into the jacks.

    A. True
    B. False

35. **(True or False)** The megohmmeter is a portable instrument consisting of an indicating ohmmeter and a source of AC voltage.

    A. True
    B. False

17.0.0 TESTING ELECTRICAL CIRCUITS

In this section, you will find out how easy it is to assist and train your crew in troubleshooting. Many different types of electrical multimeters are available to assist you. You can test electrical circuits safely and inexpensively with a neon tester (*Figure 8-95*). You can solve most electrical problems just by determining the presence or absence of voltage.

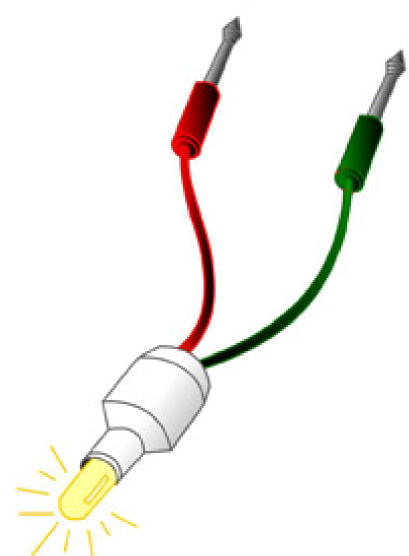

Figure 8-95 – Neon testers for 110/220 volt circuits.

17.1.0 Types of Trouble

An open circuit is an incomplete circuit. Somewhere the circuit has a break; therefore, there is not a complete patch for current to flow through, and the circuit cannot operate. If the lights are not on, you know you will be looking for a break in the circuit. Usually the break will be at the unit(s) of resistance (burned out lamp, broken resistor, etc.). Sometimes it will be in the cable. The cable is most likely to break at a splice or connection. When a circuit is open, the portion of the system being supplied by the open cable will not operate.

If fixtures are working when they are not supposed to be, or if a circuit is affected by another circuit, you most likely have a cross type of short between the two circuits. The logical point at which to start looking for this trouble is where the two cables cross or are close to each other.

When a string of lights burns dim or when fuses blow on a circuit, you have a short to ground. Most likely the insulation on the cable is damaged. This defect lets current pass directly from the conductor to earth and prevents the lamps from receiving enough power to operate correctly. In other words, some of the resistance in the circuit is being bypassed. The amount of the resistance being bypassed in the circuit governs the effect of the short to ground. If enough resistance is removed (bypassed), then the current rises to a point sufficient to blow the fuses and thus disconnect the circuit. Improper power can result when regulators or distribution transformers are not connected properly.

17.2.0 Checking For a Defective Receptacle

One of the most common tests made with a neon tester is determining whether a receptacle is providing power. *Figure 8-96* shows the first step in testing a receptacle. Firmly press each lead of the tester into the receptacle slots to form a good electrical contact.

If voltage is present, the neon tester will glow softly for a 110 volt circuit and more brightly for a 220 volt circuit. If the tester does not light, remove the receptacle cover and make a second voltage check at the terminals of the receptacle (*Figure 8-97*). If voltage is present at the terminals but not at the receptacle the receptacle is defective and should be replaced. If voltage is not present at either the receptacle or its terminals, the problem lies in the overload protection or in the electrical circuit leading to the troubled receptacle.

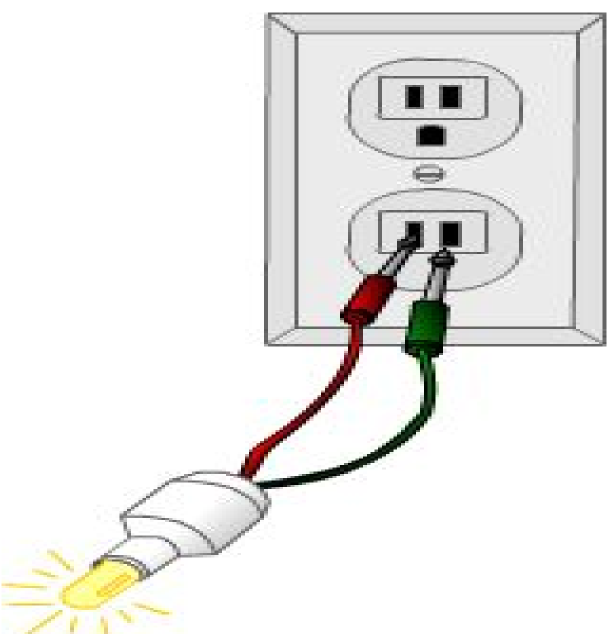

Figure 8-96 – First step in testing an outlet with a neon tester.

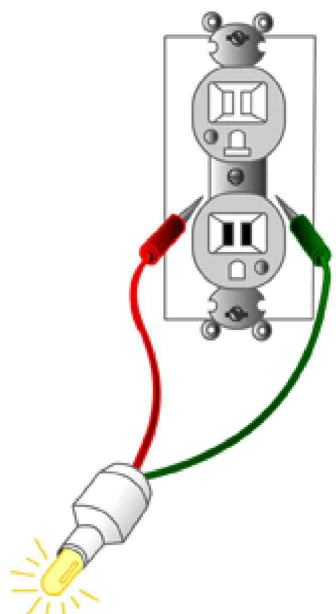

Figure 8-97 – Using the neon tester to check for a defective receptacle.

When the problem is in the electrical circuit leading to the receptacle, check each splice or each terminal point along the entire circuit for a break or a loose connection.

17.3.0 Checking For Defective Switch

Determining whether a switch is defective requires only a simple two-step procedure. You must determine whether voltage is reaching the switch and whether voltage is passing through the switch.

Figure 8-98 shows how you can position the neon tester to determine if voltage is reaching the switch. *Figure 8-99* shows how you reposition the tester to determine if voltage is going through.

With a grounded system, you need only touch the metal box and the terminals (*Figures 8-98 and 8-99*), or you may find it necessary to remove the wire nut from the neutral wire and use the neutral as the other test point. If voltage is not present at either switch terminal, the problem lies in the overload protection or in the electrical circuit leading to the troubled switch.

When the problem is in the electrical circuit leading to the receptacle, check each splice or terminal point along the entire circuit for a break or loose connection. Before starting this test procedure, be sure the power to the suspected switch is turned OFF.

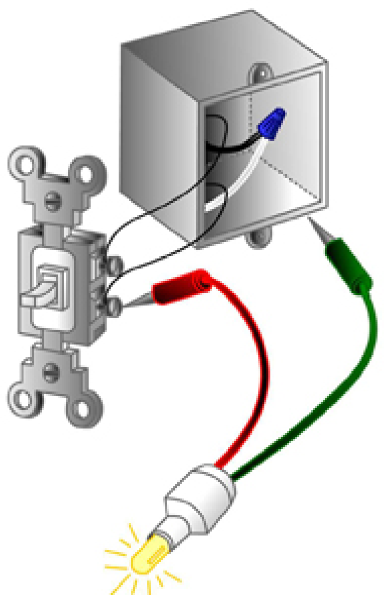

Figure 8-98 – Checking switch in OFF position for proper operation.

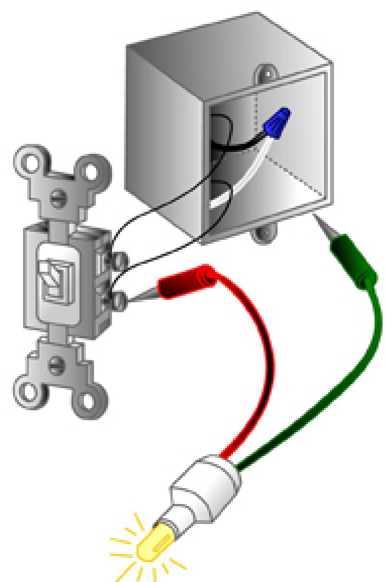

Figure 8-99 – Checking switch in ON position for proper operation.

WARNING

Failure to secure power could result in a fatal electrical shock. More people are killed by normal household current than high voltage. Workers working on energized circuits should be trained according to 29 CFR 1926.417 and use the protective equipment specified in 29 CFR 1926.400, 29 CFR 1926 Subparts G and K.

Remove the faceplate from the switch and unscrew the switch from the junction box. Pull the switch away from the metal box and position it so that no bare wires can touch the box. When the switch is in a SAFE position, power may be restored and the test procedure started.

17.4.0 Checking For Hot Wire

In remodeling, it may be necessary to check which wires provide power to the circuit and which wires merely continue on to feed other circuits. The neon tester can simplify this procedure by individually identifying each pair of wires. The pair that is hot will cause the neon tester to glow.

The grounded system is easiest to check because only the potential hot wires need to be disconnected, separated, and tested. *Figure 8-100* shows how the wires are separated and tested. The wire that causes the neon tester to respond is the hot lead.

Check an ungrounded system just like a grounded system, except remove the solderless connector from the neutral wire and use the neutral wire as a reference, as shown in *Figure 8-101*. *Figure 8-102* shows how to determine if voltage is reaching a light fixture. With the switch in the ON position, the neon tester should light.

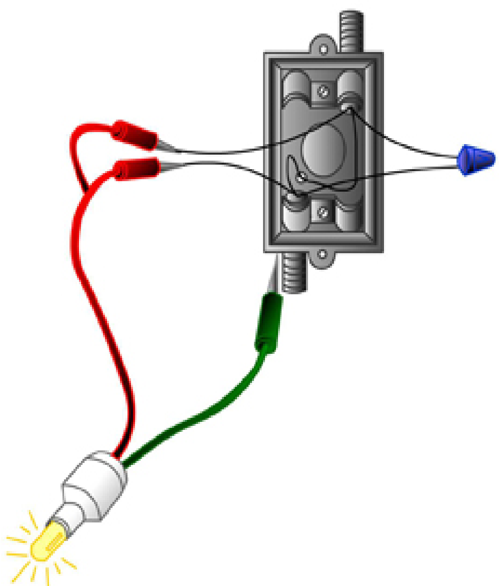

Figure 8-100 – Technique for determining which wire is hot.

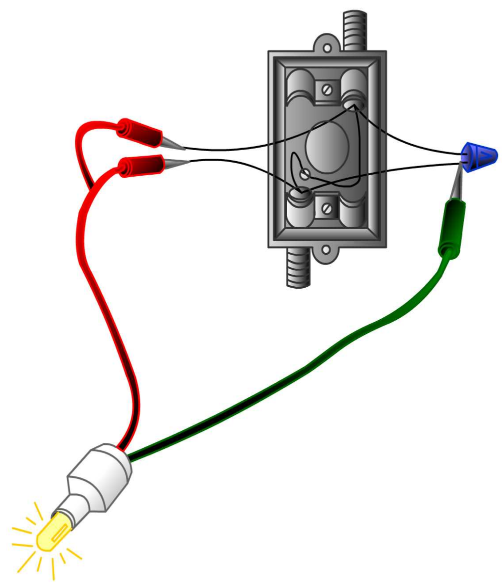

Figure 8-101 – Checking for hot wire in underground system with neutral wire exposed.

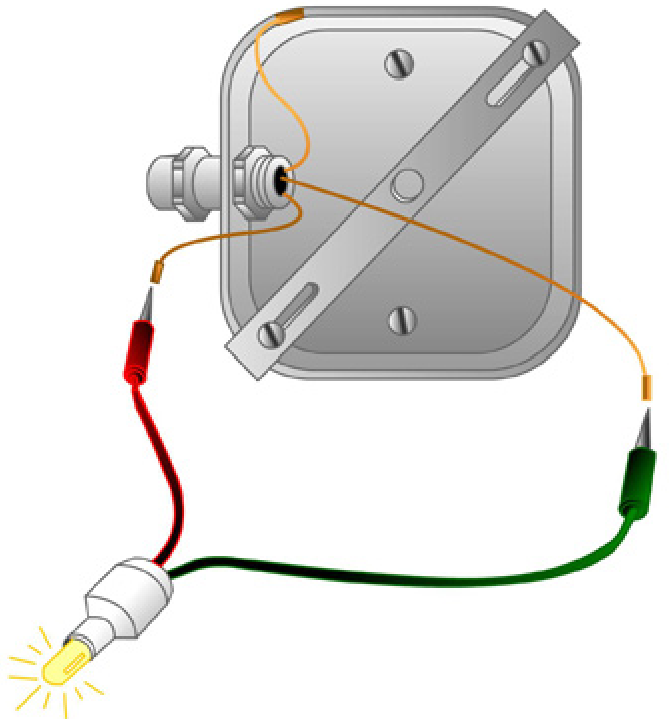

Figure 8-102 – Technique for determining if voltage is reaching a light fixture.

17.5.0 Testing the Ground Terminal

You may use the simple test procedure shown in *Figure 8-103* to check each receptacle for ground. Hold one lead of the neon tester stationary on the ground terminal while repositioning the opposite lead on each plug slot. If the receptacle is properly grounded, the neon light will light when placed in only one of the slots. If the light does not glow in either slot, the receptacle is not grounded.

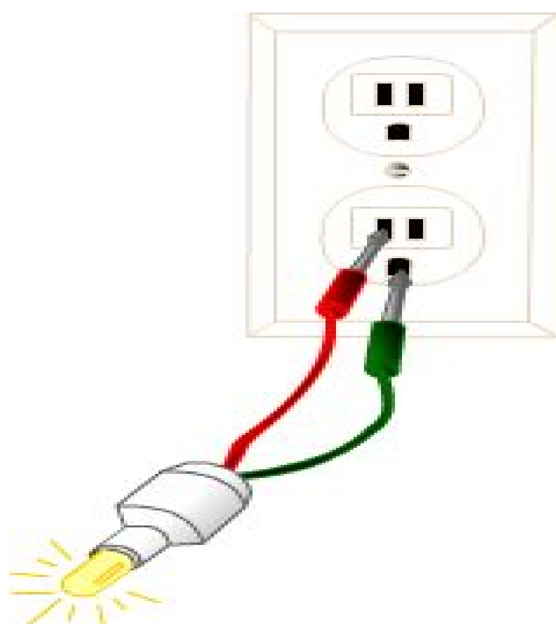

Figure 8-103 – Checking for a properly grounded receptacle.

17.6.0 Testing Circuit Breakers and Fuses in Circuits

When you are troubleshooting large electrical systems, it is important to follow the systematic approach: localize, isolate, and locate. It is never a good procedure to make haphazard measurements in a system hoping that luck will lead to the problem. Testing circuit breakers and fuses in the circuit first may eliminate unnecessary troubleshooting. Practice safe habits. Remember, getting too friendly with electricity can be a shocking experience.

17.6.1 Circuit Breaker

A circuit breaker operates in much the same manner as a switch - the breaker is either ON or OFF. Place the neon tester lead on the neutral bar and the other lead on the screw terminal of the circuit breaker (*Figure 8-104*). If the breaker is good, the neon tester will light when the breaker is in the ON position and will not light when the breaker is in the TRIPPED position.

If the neon tester remains lighted in both positions, the breaker is shorted and should be replaced. If the neon tester does not light in either position, the circuit breaker is open and should be replaced. Remember to reset the circuit breaker.

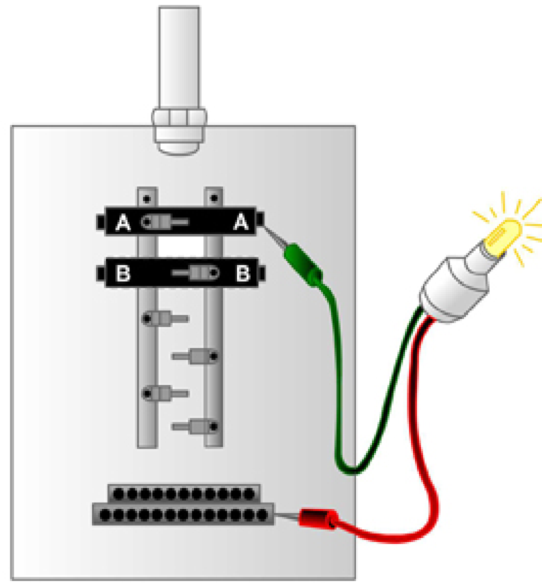

Figure 8-104 – Testing for proper operation of a circuit breaker.

17.6.2 Fuse

If you suspect a fuse is defective, check it with a neon tester using the four-part procedure shown in *Figure 8-105*.

1. First determine if the voltage is present at the top of the fuses from the incoming lines. (Light should glow.)
2. Determine if the voltage is passing through the fuse. (If the neon tester fails to light, one or both fuses are defective.)
3. Check the left fuse to see if the voltage is present. If the light glows, the fuse is good; however, if it fails to light, the fuse is defective. Shut off the power and replace the fuse.
4. Check the right fuse to see if the voltage is present. If the light glows, the fuse is good; however, if it fails to light, the fuse is defective. Shut off the power and replace the fuse.

WARNING

To prevent electrical shock, do not replace fuses unless the circuit is de-energized and then only with fuse pullers.

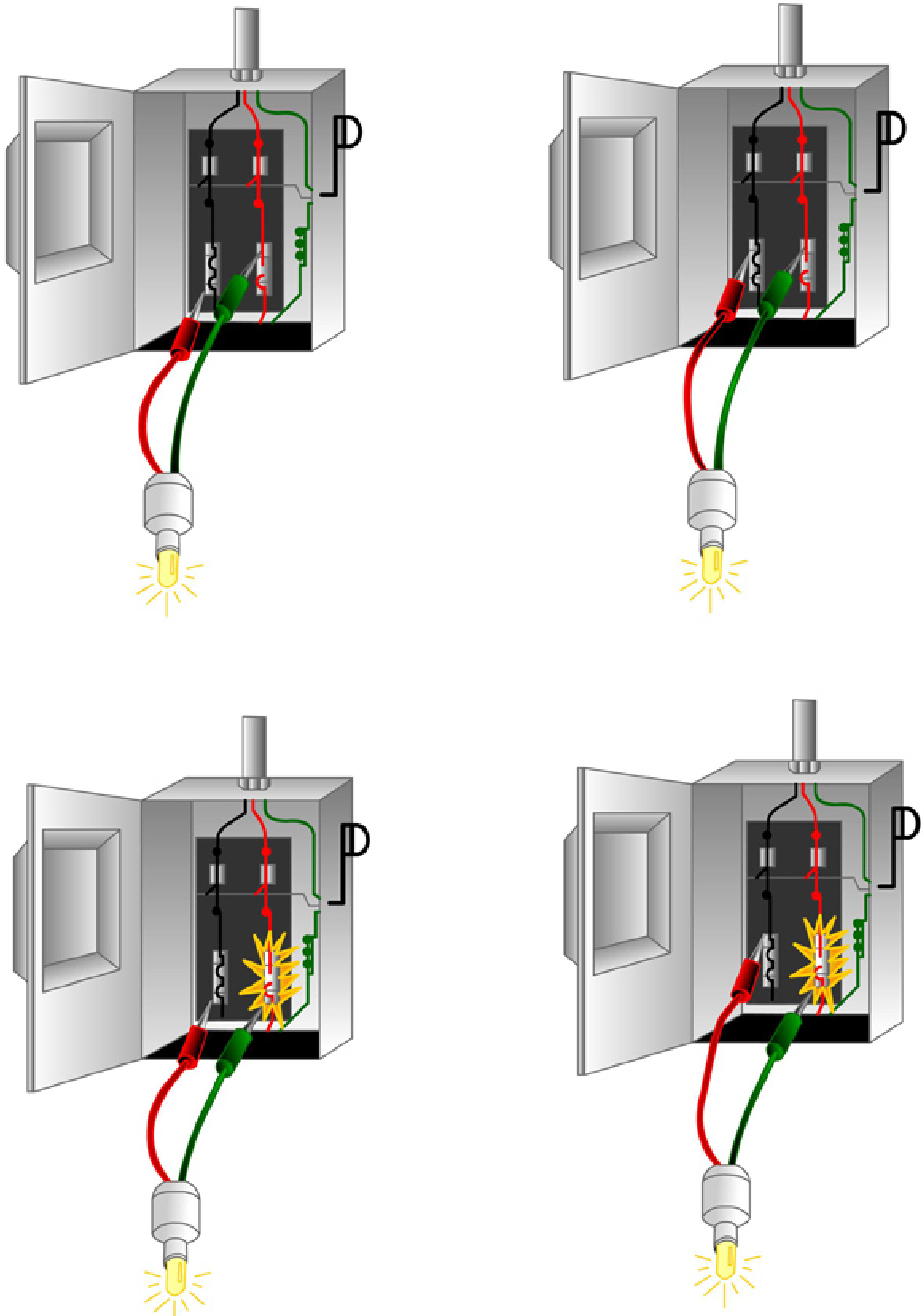

Figure 8-105 – Procedure for using a neon tester to isolate a defective fuse in a live circuit.

Test your Knowledge (Select the Correct Response)

36. What condition, if any, exists when a string of lights burns dim or when fuses blow on a circuit?

    A. Fixture is defective
    B. Too much power to circuit
    C. A short to ground exists
    D. No condition exists

37. In what way is a circuit breaker's operation much the same as that of a switch?

    A. The breaker is either ON or OFF
    B. The breaker cannot short to ground
    C. The breaker is always open
    D. The breaker is always closed

18.0.0 TROUBLESHOOTING and REPAIR of INTERIOR WIRING SYSTEMS

Electrical troubleshooting is an important part of your job. Your ability to find a faulty condition quickly can play an important part in shortening downtime caused by failure. To find faulty conditions in circuits, you must do some inspecting, some calculating, and some instrument testing. A few moments spent studying the circuit diagrams before you start actual troubleshooting will simplify the task of isolating the trouble. If a circuit fails to function, use logic when you check for the fault. The trial-and-error method of finding faults in circuits is inefficient and time consuming.

The first step to take in troubleshooting circuits is to inspect the circuit visually. Check for loose connections, loose wires, abraded wires, and loose fittings. An overloaded circuit is a serious problem. Many times the electrical demand on a circuit is so great that the circuit fuses blow or the circuit breakers trip. In some cases, the wrong fuses or circuit breakers are used, and the wires overheat and burn off the insulation. This condition causes shorts and grounds and sets up potential fire hazards.

18.1.0 Open, Shorted, and Grounded Circuits

An OPEN CIRCUIT occurs in a wiring system when one or more conductors in a circuit are broken or otherwise separated. An open circuit is determined by failure of a part or all of an electrical circuit to operate even though the fuses may not be blown. Use the following maintenance procedures for locating the source of the trouble:

- Initially, make a visual check for a broken or loose connection at the first dead (non-operating) outlet in the circuit. If you find a defective connection, tighten or repair it.
- If you do not find the trouble, or open circuit, by a visual check, use a voltmeter to determine whether the circuit is live (operating) up to the point of the component.

A SHORT CIRCUIT results when two bare conductors of different potential come into contact with each other. If a conductor inadvertently contacts a metallic part of a wiring system, such as a motor frame or conduit, the system is sometimes said to be GROUNDED instead of having a short circuit. Grounds or short circuits can be (1) solid, (2) partial, or (3) floating. This situation presents a serious safety hazard because the machinery may be in operation, even though it has a short circuit. This condition is especially true in motors and some appliances.

A solid ground or short circuit is one in which a full voltage reading is obtained across the terminals of a blown fuse when the load is disconnected from the circuit. The circuit resistance, in this case, is quite low, and the current is quite high so that the fuse will blow.

A partial short or ground is one in which the resistance between the phase wires, or between the phase wire and the ground, is partially lowered. However, enough current still remains to blow the fuse. Grounds of this type are generally more difficult to locate than solid grounds.

A floating ground is a condition in which the resistance of the defect in a system varies from time to time. Grounds of this type may be present in an electrical system for some time before their existence becomes known. A floating ground is indicated when fuses are blown on the phase side of a circuit a number of times, and a circuit test shows no defects in the system. In grounds of this type, fuse trouble may not occur for several days. Then the ground recurs, and blows the fuses again.

The procedures used to repair the troubles mentioned thus far are usually fairly simple. In the case of an open, short, or ground in NM cable, simply replace the bad section from box to box using the same procedures outlined for installation. Another method is to cut the cable at the trouble spot, install junction boxes, and add a short piece of cable to replace the bad section. Although the latter is the cheapest, it may not be possible if the trouble is concealed. Remember, you must have at least 6 inches of free conductor in a junction box to make the splices.

Once you find out where the trouble is in a conduit system, the repair procedure is even easier. All that is required is to pull the open, shorted, or grounded conductor out and replace it with a new one. You can do this replacement by attaching the new conductor to the one that is to be removed. In any case, a little common sense and knowledge of the NEC® requirements will dictate the action you should take.

18.2.0 Meters

Many times a visual inspection does not uncover an apparent problem; therefore, you must advance to troubleshooting with meters. In electrical troubleshooting, you will use voltmeters, ohmmeters, ammeters, and the meter that incorporates many meters, the multimeter.

When you use a voltmeter, you must connect the power to the circuit before testing. On the other hand, you cannot use the ohmmeter on an energized circuit. Start voltmeter tests at the power input end of the circuit and ohmmeter tests at the ground end.

Electrical circuit troubles develop either in the wiring or in the operating unit. If you analyze the problem carefully and take systematic steps to locate it, not only will you save much time and energy, but you will also prevent damage to expensive equipment.

You can test both dead and live circuits with instruments. You can sometimes locate circuit defects more easily by one method than the other, depending upon the type of circuit and the trouble.

To test a dead circuit, disconnect the device from the outlet or disconnect switch. Equipment for this method of testing includes such units as ohmmeters and battery-powered test lamps. A suitable continuity tester can be made easily from a flashlight in an emergency. An ohmmeter that contains its own batteries is excellent for continuity testing. A basic factor to consider in choosing continuity test equipment is to use relatively low-voltage instruments, reducing the danger of sparking.

WARNING

When connections are made in the presence of combustible vapors, sparking is a serious fire hazard.

When you test live circuits, energize the circuit under test from the power source. Generally, you will test with a voltmeter. Make certain that the voltmeter is designed for the type of current to be tested and has a scale of adequate range. Ensure that the circuit is disconnected from the power source before making the necessary circuit changes, and then reapply the power.

WARNING

Be extremely careful not to touch the hot conductors when you use this method of testing because these live points of the circuit are exposed when the junction box covers are removed.

Let us troubleshoot a circuit with a voltmeter. The power to the circuit must be turned on. The first and most logical place to check is the fuse or circuit breaker panel. Set the voltmeter to the proper scale. If you do not know the value of the incoming voltage, set the meter to the highest scale; then work down to the proper scale. Check each incoming phase by connecting one lead of the voltmeter to the neutral and the other to each phase separately.

On a three-phase 120/208, 240 volt service, you must get 120 volts on each phase to ground. Less than 120 volts on one phase means that phase is open and you are getting a feedback from equipment connected to the lead side of the panel. Sometimes there will be a slight variation of normal voltage from the different phases; therefore, to determine if one phase is dead, check between the phases.

To perform this test, place one lead of the voltmeter on Phase A and the second lead on Phase B and read the voltage. It should read approximately 208 or 240, depending upon the system. After taking this reading, move the second lead to Phase C and take the reading. After this reading, move the first lead to Phase B and take the reading. You have now read between all phases, and a lower than normal reading indicates an open phase.

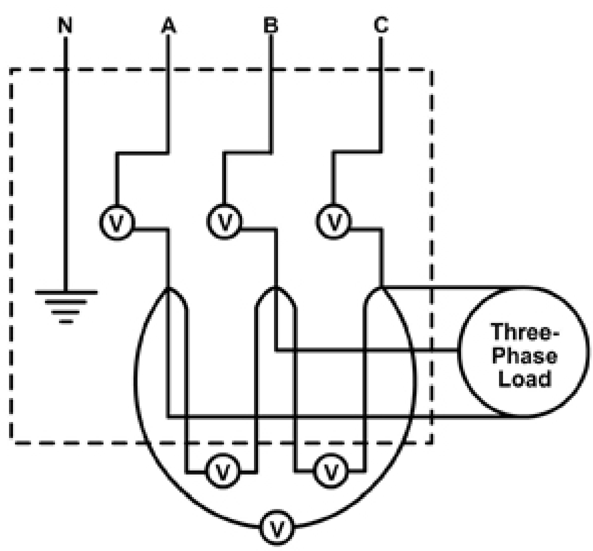

Figure 8-106 – Checking a three-phase circuit for a blown fuse.

Which phase is dead? Assume that Phase B has a blown fuse. When you take your reading between Phases A and B (*Figure 8-106*), you get a low-voltage reading. Your next reading, between Phases A and C, reads normal. But the next reading, between Phases B and C, again is a low reading. Each time you read to Phase B, you get low voltage. This reading is a good indication that Phase B is open.

Another way to determine which phase is open is to place one voltmeter lead on the top of the fuse and the other lead on the bottom of the same fuse. If you get a voltage reading across the fuse, that fuse is open.

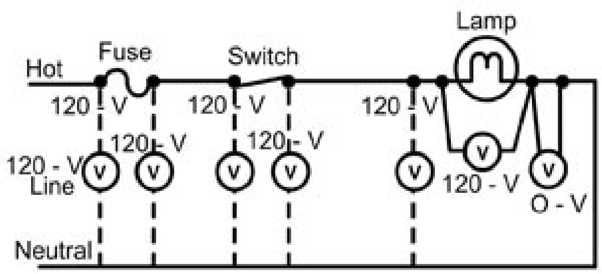

Figure 8-107 – Circuit with fuse, switch, and lamp.

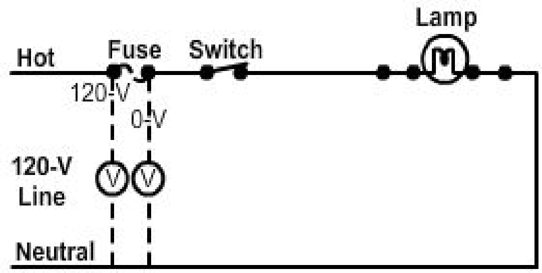

Figure 8-108 – Circuit with blown fuse.

Assuming everything is all right at the main panel, let us examine a single 120 volt circuit. Illustrations help explain the procedure for locating an open in a circuit. *Figure 8-107* shows a circuit with a lamp in series with a single-throw switch and fuse and the normal voltage readings at the various points of the circuit. If the lamp fails to light, check the circuit in progressive steps through the circuit and lamp from the last point where voltage is known to be present. In *Figure 8-108*, we have voltage at one connection of the fuse and no voltage at the other. Since the fuse is a conducting unit, normally the same voltage reading should occur between both sides of the fuse and the ground. The only conclusion in this case, then, is that the fuse is open.

Figure 8-109 shows that there is a voltage reading when the voltmeter is connected across the lamp. The logical assumption is that the lamp is inoperative. To be sure the lamp is inoperative; you must check it with an ohmmeter. Fuses, switches, and lamps are vulnerable, and you should check them first in a circuit.

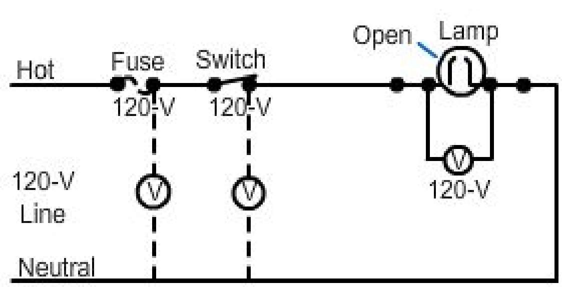

Figure 8-109 – Circuit with burned-out lamp.

In *Figure 8-110* the lamp does not light and the voltmeter shows voltage from the ground screw of the lamp to the neutral wire. These conditions indicate an open in the ground wire. When you connect the voltmeter at another point at the right of the lamp and it indicates no voltage, there is probably an open in the wiring between this point and the lamp connection.

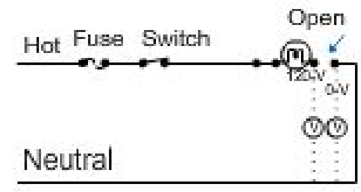

Figure 8-110– Circuit with open in the wiring.

In *Figure 8-111*, you find two lamps wired in parallel so that they can be controlled by a double-throw switch. With the switch in the OFF (center) position, there is no complete circuit, and neither lamp lights. When the switch is in the BRIGHT position, a circuit is completed through the switch and through both lamps. With the switch in this position, the only resistance in the circuit is the resistance of the lamps. When the switch is in the DIM position, the circuit is completed through the lamps as before; but this circuit has an additional resistor in series with the lamps. This added resistance causes a decrease in current flow; therefore, the lamps glow with less intensity than before.

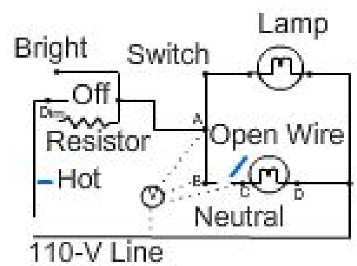

Figure 8-111 – Trouble shooting an open circuit with a voltmeter.

If one of the lamps lights and the other one does not, it is not necessary to check the complete circuit to find the open. The part of the circuit up to Point A is common to both lamps, and that much of the circuit must be completed for even one lamp to light. The place to begin checking the circuit is after Point A in the affected part of the circuit. In a circuit like the one shown in *Figure 8-111*, it is best to use a voltmeter to locate the trouble. If you connect the negative lead of the voltmeter to the ground and the positive lead to Point A, you will get a reading on the voltmeter scale because Point A is connected through the switch to the positive line wire. If you move the positive lead of the voltmeter in succession from A to B to C, you are able to check the continuity of wires AB and BC. If the check at Point C reveals no voltage, this condition indicates that wire BC is open.

You can make this same check with an ohmmeter, but several additional steps are required. First, remove power from the circuit by placing the circuit breaker and circuit switch in the OFF position. Next, disconnect the junction of wires at Points A and C. Then, with one ohmmeter lead placed on the loose wire at A and the other one on B, check the continuity of the wire. If this check indicates a low resistance, you have continuity in the wire. But if you place one ohmmeter lead on B and the other on the disconnected wire at C and get an infinite resistance, there is an open in the wire.

WARNING

For your safety, before you begin testing with an ohmmeter, BE SURE that the circuit that you are about to test is de-energized. Isolate the circuit being tested to prevent reading resistance from other circuits.

Many times you can determine the approximate location of an open by simply studying the circuit diagram before doing any actual circuit testing. For example, suppose both lamps in *Figure 8-111* light when the circuit switch is placed in the BRIGHT position, but neither lamp lights when the switch is placed in the DIM position. Because the lamps light when the switch is in one position, you can gather that all wires and lamps are good. The only units that could be faulty are the resistor, half of the switch, or the wires that connect the switch and the resistor. By using the ohmmeter as you did before, you can check the continuity of these parts.

A short circuit exists when there is a direct connection between two wires or conductors of different potentials. If you do not find the trouble by visual inspection, you must isolate it step by step. First, disconnect all the equipment in the circuit and install a new fuse or place the circuit breaker to the ON position. If the short is clear, then the trouble will be found in the equipment. However, if the short circuit does not clear and the fuse burns out again or the circuit breaker trips, then the trouble is in the wiring.

To find the short in the electrical wiring, you first disconnect the wires at both ends of the circuit and test each wire with an ohmmeter.

If there is a short between the wires, a low resistance reading will appear on the ohmmeter. If no short exists between the wires, a high resistance reading will appear on the ohmmeter. You should continue this procedure until you find the short.

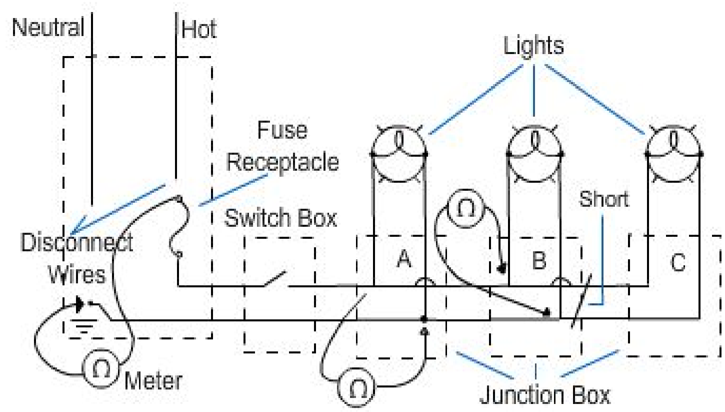

Figure 8-112 – Faulty lighting circuit.

Let us assume that a light circuit is faulty. Using *Figure 8-112* as an example, you see a circuit with three lights controlled by a switch with a short at the junction box of the middle lamp. Disconnect the wires at the fuse panel to isolate the circuit and to prevent feedback from the other circuits.

Connect one lead of the ohmmeter to neutral and the other to the wire you have just disconnected. With the switch open, the ohmmeter will read infinity. Closing the switch will cause the ohmmeter to read continuity, showing that the short is beyond the switch. You can now proceed to the nearest junction box and test at the first light. Remove all light bulbs from the circuit.

Disconnect Point A and connect the ohmmeter between the neutral and the wire leading to the first lamp. You will read infinity. Remember, "infinity" means that the circuit is good, and "continuity" means a short. Now, connect the ohmmeter between the neutral and the lead going to the middle lamp. The reading will show continuity, indicating the short is beyond Point A. You should leave Point A open at this time and continue to the middle lamp.

Disconnect Point B and take the same readings that you took at the first light. From these tests you can determine that the circuit between the first and middle lamp is all right (infinity reading), and the trouble must be between the second and third lamp. If you check closely at the middle junction box, you can probably see charred or frayed wires indicating the problem. You may need to continue your check to Point C. Use the same procedure as with the other lamp, and find the trouble between Points A and C.

Test your Knowledge (Select the Correct Response)

38. Which of the below problems are you trying to find when visually troubleshooting a circuit?

    A. Loose connections
    B. Abraded wires
    C. Loose fittings
    D. All of the above

39. **(True of False)** When using a voltmeter, you have to connect the power to the circuit before testing.

    A. True
    B. False

19.0.0 SOLDERING and SPLICING PROCEDURES

As a CE project supervisor or crew leader, you need to train your crew on the proper solderless connector splices, soldering splices, and taping splices. You will need to spot-check the connections to ensure proper installation.

19.1.0 Solderless Connectors

Solderless connectors (wire nuts) have almost completely eliminated soldering and taping for certain types of splices. They are designed to hold several electrical wires firmly together and provide an insulating cover for the wires. They are available in several sizes. The size of the solderless connector is determined by the number and size of the wires to be joined.

19.2.0 Splices

An electrical splice is the joining of two or more electrical conductors by mechanically twisting them together or by using a special splicing device. Since splices can cause electrical problems, make them carefully. Splices must be able to withstand any reasonable mechanical strain that might be placed on the connection. They also must allow electricity to pass through as if the wire had never been broken. Some of the more common splices are explained below.

19.2.1 Pigtail Splice

Because it is simple to make, the pigtail splice is probably the most commonly used electrical splice. *Figure 8-113* shows how to make a pigtail splice. Note the two ways to end the splice. When the splice is taped, the ends must be bent back so the sharp edges will not penetrate the tape (*Figure 8-113*). When you use a solderless connector instead of tape, cut off the ends (*Figure 8-113*). When more than two wires are joined in a pigtail splice, as shown in *Figure 8-114*, twist them together securely before the putting on the solderless connector. Twisting the wires together first ensures that all the wires are fastened together properly.

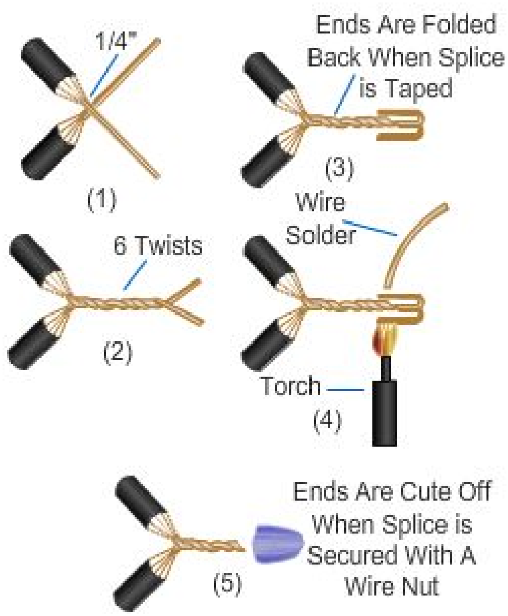

Figure 8-113 – Simple pigtail splice.

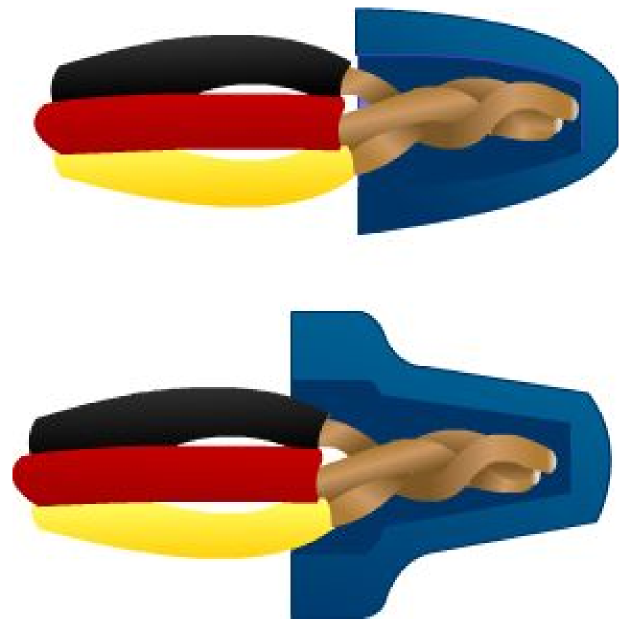

Figure 8-114 – Multiple-wire pigtail splice.

19.2.2 Western Union Splice

The Western Union splice (*Figure 8-115*) when the connection must be strong enough to support long lengths of heavy, wire. In the past this splice was used to repair telegraph wires. If the splice is to be taped, take care to eliminate any sharp edges from the wire ends.

19.2.3 T-tap Splice

The T-tap (*Figure 8-116*) is a type of splice that allows a connection to be made without cutting the main line. This connection is one of the most difficult to make. A certain amount of practice may be necessary to make this connection look neat. Study *Figure 8-116* to determine the proper technique in making this splice.

Figure 8-115 – Western Union splice used where substantial strain may be placed on the connection.

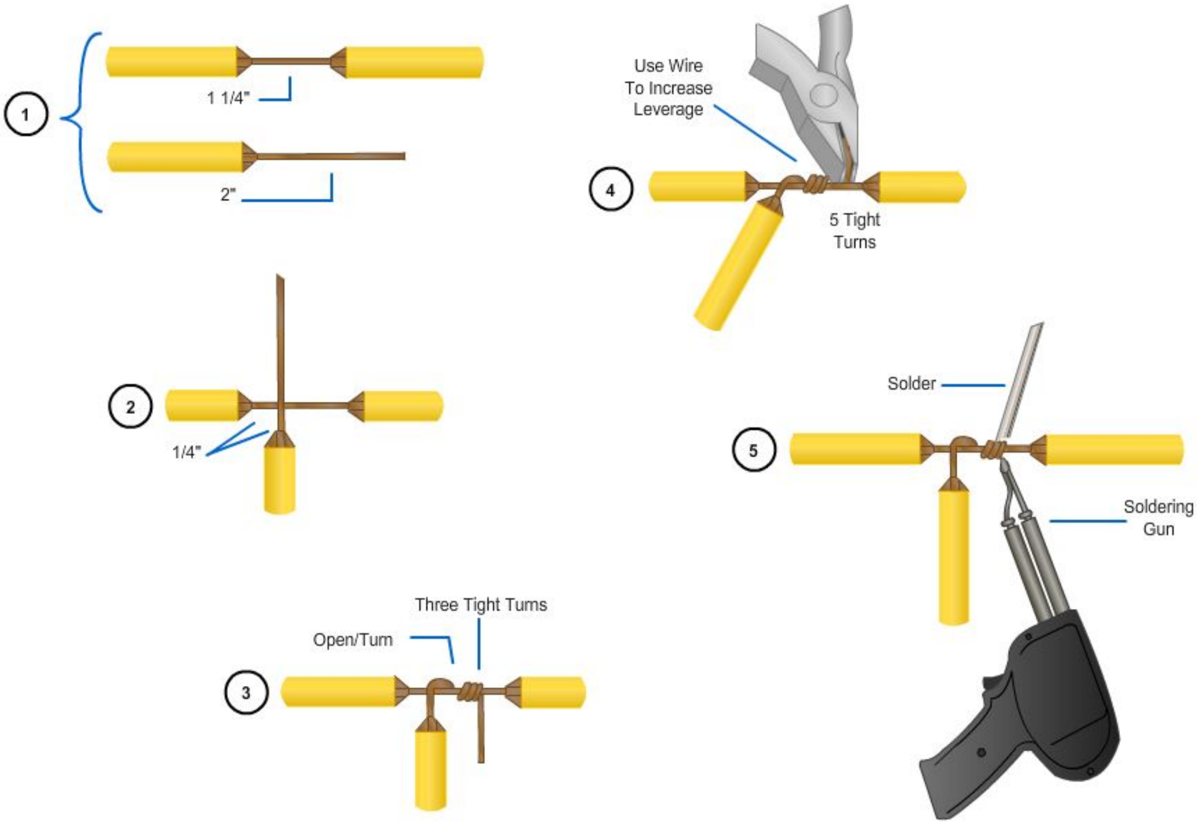

Figure 8-116 – T-tap used to connect into an ongoing line.

19.2.4 Portable Cord Splices

Cord splices are weak because there is no connector to hold them together; therefore, use them for emergency purposes only. If you must save the cord, use twist lock plugs and receptacles to rejoin the cord. *Figure 8-117* shows how to splice solid wires. Stagger the individual splices to prevent a large bump when the cord is taped. You may add additional strength to this splice by soldering each individual splice.

Figure 8-117 – Portable cord splices.

19.2.5 Cable Splices

Large stranded cables (*Figure 8-118*) are not often used in residential wiring; however, they are used in other situations, such as for battery jumper cables and welding cables. When jumper cables or welding cables are broken, they can be temporarily repaired, as shown in *Figure 8-118*.

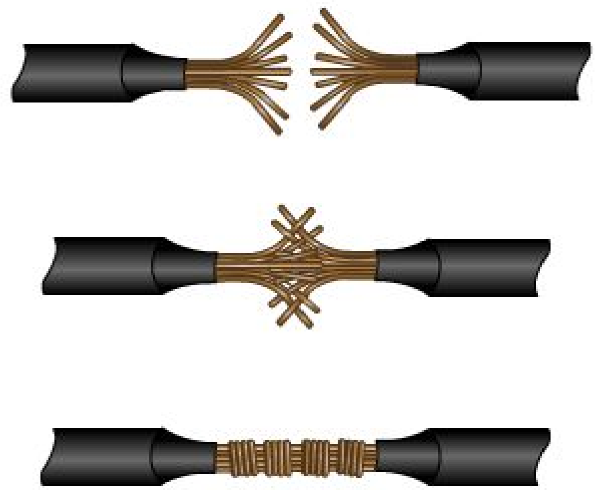

Figure 8-118 – Cable splices.

19.3.0 Soldering Splices

Because solderless connectors (such as plastic end caps) are time-saving and easy to use, the electrician no longer needs to solder each and every splice. It not only takes less time to make a solderless connection but also requires less skill. However, soldering is still the most reliable method of joining pieces of wire, and every electrician should learn how to solder.

Once you have made the decision to solder an electrical splice and have stripped the insulation off the wire, solder the splice as soon as possible. The longer the splice is exposed to dirt and air, the more oxidation will occur thus lessening the chance of a good solder joint. Clean metal surfaces, free from oil, dirt, and rust (oxidation) are necessary to allow the melted solder to flow freely around the splice. The surfaces may be cleaned by using light sandpaper or an emery cloth or by applying flux to the joint as it is heated.

Solder usually comes in either bar or wire form and is melted with heat from soldering devices, such as a soldering iron, soldering gun, or propane torch (*Figure 8-119*).

Figure 8-119 – Sources of heat for soldering splices.

Use the electric soldering iron or soldering gun when electrical service is available. Use the propane torch to solder large wires or when there is no electricity at the jobsite. Whatever method you use, be sure to apply solder on the side of the splice opposite the point where you apply the heat. *Figure 8-120* shows the three methods of soldering. The melting solder will flow toward the source of heat. Thus, if the top of the wire is hot enough to melt the solder, the bottom of the wire closest to the heat source will draw the solder down through all the wires. Allow the splice to cool naturally without moving it. Do not blow on the joint or dip it in water to cool it. Rapid cooling will take all the strength out of a solder joint. Once it is cooled, clean off any excess flux with a damp rag, then dry and tape it.

WARNING

Avoid breathing the fumes and smoke from hot solder. Some solder contains lead, which if inhaled or ingested can cause lead poisoning. Avoid prolonged skin contact with fluxes. Your supervisor will give you a Material Safety Data Sheet (MSDS) with the precautions for solder and flux.

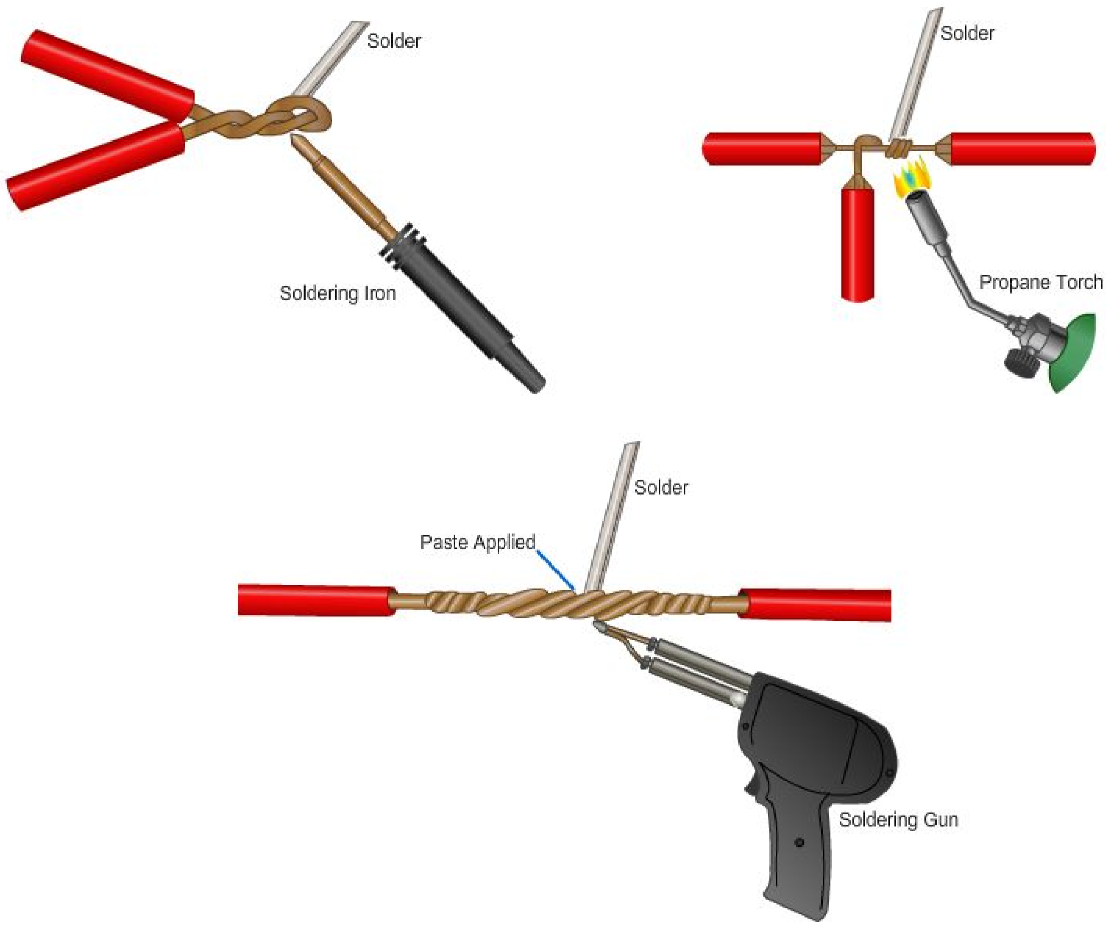

Figure 8-120 – Three methods of heating a solder joint.

19.4.0 Taping Splices

Taping is required to protect the splice from oxidation (formation of rust) and to insulate against electrical shock. Taping should provide at least as much insulation and mechanical protection for the splice as the original covering. Although one wrap of plastic (vinyl) tape will provide insulation protection up to 600 volts, several wraps may be necessary to provide good mechanical protection.

When you use plastic tape, stretch it as you apply it. Stretching will secure the tape more firmly. *Figures 8-121 through 8-124* show the most commonly used methods of taping splices.

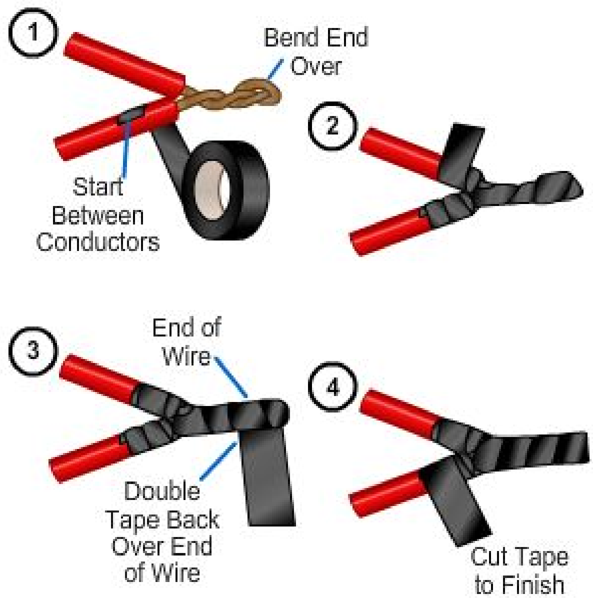

Figure 8-121 – Technique for taping a pigtail splice.

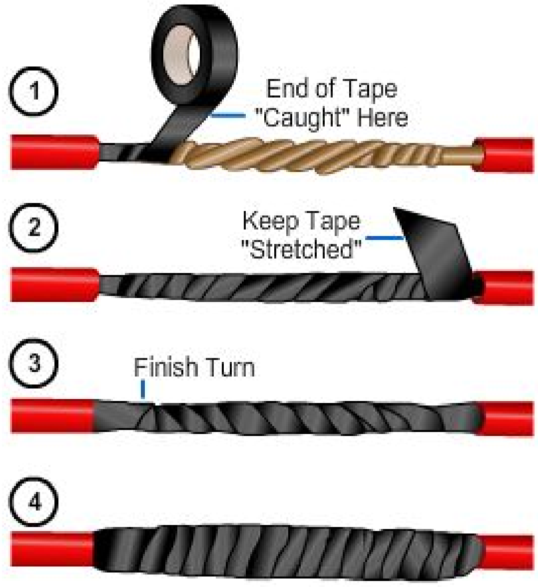

Figure 8-122 – Technique for taping a Western Union splice.

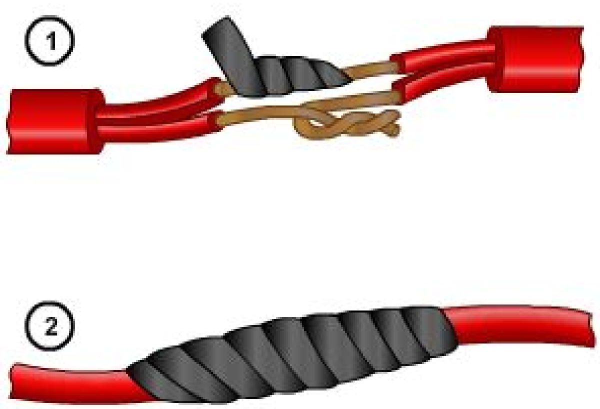

Figure 8-123 – Technique for taping a cord splice in emergency only.

Figure 8-124 – Technique for taping a solderless connector.

Test your Knowledge (Select the Correct Response)

40. What is the determining factor(s) when deciding on what size solderless connector (wire nut) to use for a job?

    A. Size of wire only
    B. Size and number of wires
    C. Number of wires only
    D. Amount of current in wire

41. What is the most common used splice due to its being easy to make?

    A. Western Union splice
    B. T-tap splice
    C. Portable cord splice
    D. Pigtail splice

20.0.0 LIGHTING

After installing the switches needed to control the lighting, you need to mount the light fixture itself. Each lighting installation is designed to produce a specific level of illumination adequate for those working in the area. The amount of illumination initially provided starts to decline almost as soon as it is put in operation. This reduction is caused by dirt on the lamps and luminaries, a decrease in lamp lumen output, and dirt on the room walls and ceilings. Illumination should be sufficient to eliminate eyestrain, support a high level of production, and promote safety and employee morale.

Lighting fixtures are designed for a particular lamp size and type. Many fixtures, however, were installed in military buildings long before the manufacturers started producing higher and higher wattage lamps in ever smaller envelopes. Consequently, it is possible to use much higher wattage lamps than the fixture or the circuit can handle adequately.

CAUTION

Excessive heat of higher wattage lamps can damage the sockets, increase failure rate, and overload the circuits. Personnel are cautioned to use only the lamp size (in watts) recommended for the fixture, rather than a higher wattage lamp that may physically fit.

20.1.0 Incandescent Lamps

Incandescent lamps come in a variety of voltage ratings. For most applications, select the lamp voltage rating nearest the available line voltage. Under this condition, the lamp will produce its rated values of life, watts, and light output. Many incandescent lamps are available with life ratings considerably in excess of ordinary general service lamps. Some have ratings of 5,000 hours or more, and some even are guaranteed to burn for 5 years. General use of these lamps is not recommended because the initial cost is comparatively high and the extended life is gained by reducing the light output. There are, however, a few areas where it is necessary to use bulbs with a long life. Typical locations include high-ceiling auditoriums, exit lights, stairwells, and marker lights on towers or fire alarm boxes. For these areas, do not use a special rated lamp. Do use an ordinary general service lamp whose voltage rating is higher than the circuit voltage; for example, 130 volt or higher lamps for 120 volt circuits. When you are operating the lamp below its rated voltage, the life is increased at a sacrifice in light output. For general use, use the lamp voltage rating nearest the available line voltage.

Many kinds of incandescent lamps are especially designed for placement in a variety of situations; for example, under severe physical conditions (such as vibration or extreme temperatures), in inaccessible locations, or when special lighting effects are desired. Some of these types of incandescent lamps and their uses are the following:

- Inside Frosted Lamps are used in most fixtures designed for incandescent lamps. The frosted finish reduces lamp brightness and glare.
- Clear Lamps are used in fixtures where control of the light is required (such as in reflectors having polished reflecting surfaces and in enclosed globes or reflectors of prismatic glass), particularly where concentrated light control is required, as in high, narrow bays. Reflector equipment of the diffusing globe type, where the lamp protrudes through the bottom of the fixture, requires WHITE BOWL LAMPS. The white bowl reduces the surface brightness and glare from the working surfaces.
- Silvered Bowl Lamps are used principally for indirect lighting and in reflector equipment. The fixture parts should not touch the lamp as the thermal expansion may cause the bulb to crack and fail prematurely.
- Reflector Lamps with the reflecting surface inside the lamp are, in effect, a fixture in themselves. A collection of dust and dirt on the exterior of the lamps can cause them to lose their effectiveness.
- Projector Lamps are installed in indoor and outdoor display fixtures. They use a self-contained reflector but have an advantage over the reflector type since they are suitable for extreme temperature conditions and provide more accurate light control.
- Heat and Drying Lamps, available with built-in reflectors or with separate reflectors, are an inexpensive answer to a requirement for instantaneous infrared energy. The reflector bulb keeps the initial cost to a minimum and provides a new reflecting surface with each new lamp.
- Hard Glass Lamps, made of special glass with high resistance to thermal shock, are effective where rain, splashing liquids, insects, snow, fixture parts, or hot metallic spray may touch the glass bulbs.
- Vibration Service Lamps are available that withstand excessive vibration that cannot be eliminated by flexible fixture mounting. Where the lamp will be subjected to shock, such as at the end of a drop cord or near machinery, you will want to select ROUGH SERVICE LAMPS. With filament supports, these lamps can withstand severe shocks without failure. High cost replacement areas, such as towers, industrial high bays, theater marquees, halls, and stairwells are lighted with LONG LIFE LAMPS.
- Quartz-Iodine Lamps offer a concentrated source of incandescent light with excellent light control characteristics, good color, and a life twice that of regular general service incandescent lamps. They depreciate at a lower rate than the general service lamp. The lamp's cost is considerably higher, however, than a general service lamp, and it requires a special fixture.

20.2.0 Fluorescent Lamps

There are two principal types of fluorescent lamps: instant-start and rapid-start preheat lamps. Both have practically the same physical dimensions but different internal construction. The type of circuit in which the lamp should be used is etched on the end of the lamp. The rapid-start preheat lamp operates satisfactorily with either the preheat or rapid-start circuit. It has a short lamp life in an instant-start circuit. The instant-start lamp operates satisfactorily with instant-start ballast. It burns out the ballast in a rapid-start circuit, and does not light in a preheat circuit. Preheat lamps dominated the field for many years but are no longer considered a major type. They continue to be in use, however, particularly in fixtures using lamps smaller than 40 watts.

Examples of circuits for the major types are readily found in current manufacturers' publications. *Figure 8-125* shows examples of some circuits. The 4 foot rapid-start lamp is the preferred lamp for most applications.

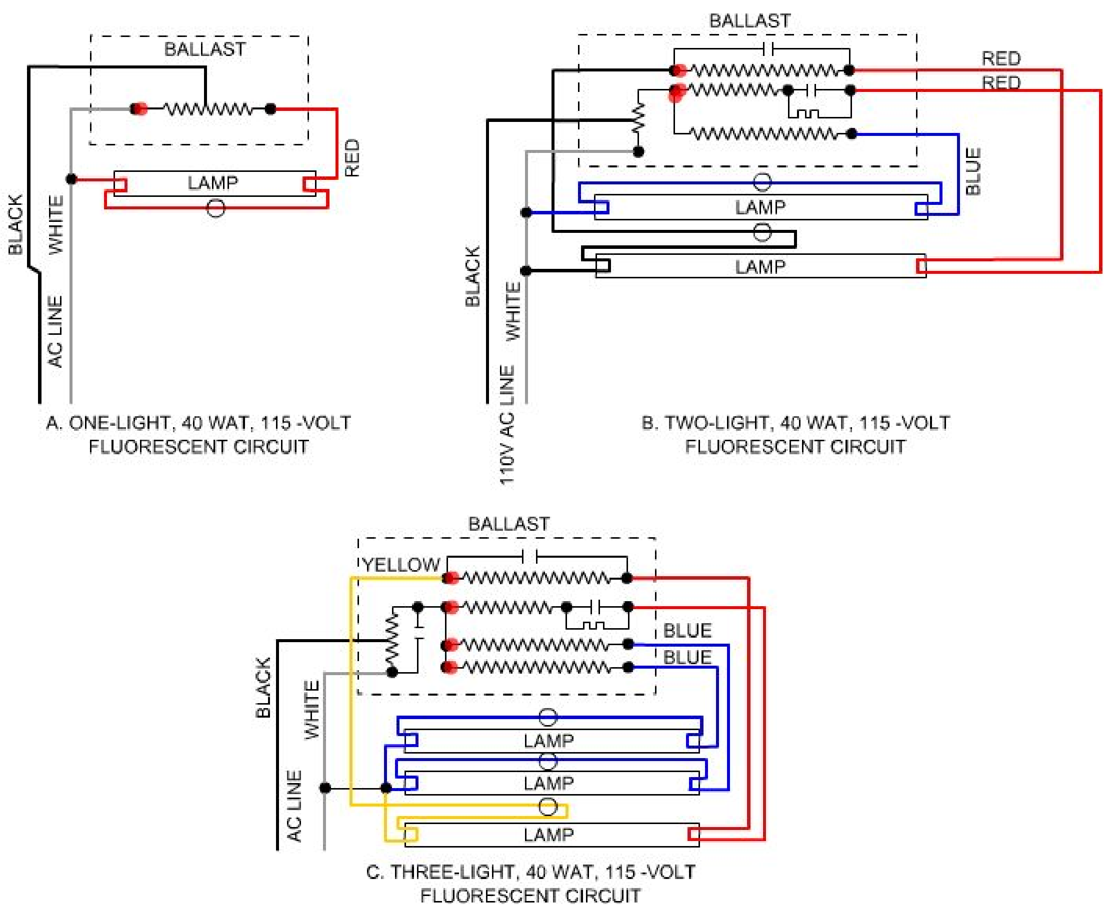

Figure 8-125 – Representative fluorescent circuits.

Fluorescent lamps are available in a variety of colors for decorative use as well as numerous shades of white for general illumination. The predominant white shade recommended for most office areas is cool white. Other shades of white used for various purposes include daylight, deluxe cool white, white, warm white, and deluxe warm white. Daylight and cool white provide a crisp, cool, businesslike atmosphere, and the warm whites find application in restaurants, homes, theaters, and similar areas. The appearance of colored materials will be better under a fluorescent light that contains a high component of the same color. Blue backgrounds improve with the cool whites and daylight. Deluxe warm whites strengthen oranges and yellows.

Fluorescent lamps require ballasts to limit the current and to supply proper voltage to start and to operate the lamps. For general lighting purposes, the ballasts also contain a capacitor to improve power factor. The NEC® requires that all indoor fluorescent fixtures (except those with simple reactance ballasts) incorporate ballasts with thermal protection. The thermal protector isolates the ballast and fixture from the circuit in the event of overheating. As a result, damage from fires and from leaking compounds should be reduced. Small fuses are available that can be installed in the fixture to provide this protection for existing ballasts.

20.3.0 Mercury Lamps

Mercury lamps (*Figure 8-126*) have the best maintained light output because the electrodes operate at a relatively cool temperature, resulting in less evaporation of the metals and oxides. The clear mercury lamp has better lumen maintenance than those with phosphor coating. Long average life (16,000 hours and up) is a primary characteristic of most mercury lamps. There will be a different economic life for mercury lamps at each installation, depending on lamp mortality, power cost, equipment and wiring costs, frequency of replacement and cleaning of lamps, and other factors.

Mercury lighting is one of the most economical means of lighting high- and medium-bay industrial areas, particularly in areas where color rendition is not critical. Small wattage lamps have been introduced, and future designs will probably see a more widespread use of these in low-ceiling nonindustrial areas. An objectionable characteristic of mercury lamps is the time required to reignite (several minutes) after a momentary loss of power.

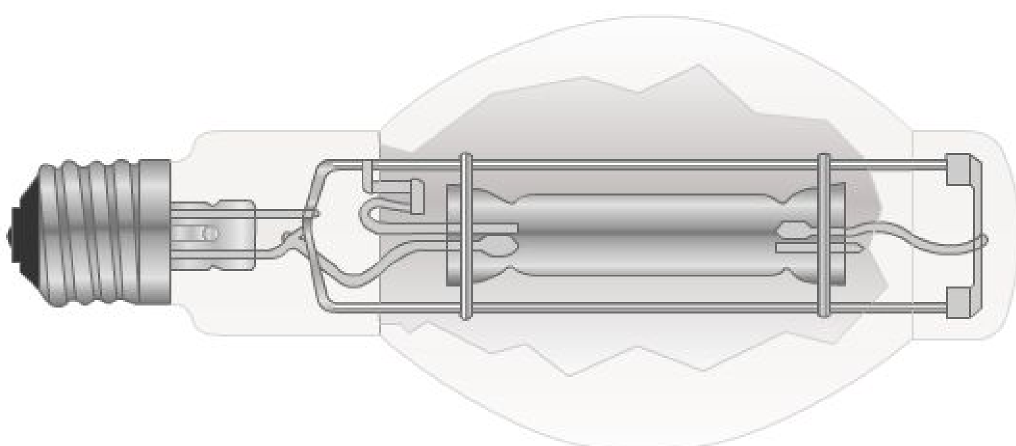

Figure 8-126 – Mercury lamp.

CAUTION

While the lamp bases are the same size as incandescent lamps, mercury lamps must never be used to replace a burned-out incandescent lamp because ballast must be used with mercury lamps.

20.4.0 Metallic-Vapor Lamps

Metallic vapor lamps resemble mercury-vapor lamps in appearance and have similar uses. The initial efficiency and control are better with metallic-vapor lamps than with mercury vapor lamps. In regard to disadvantages, the rate of depreciation is much greater with metallic than with mercury, the cost is higher, and the life expectancy is shorter.

High pressure sodium vapor lamps are used for highway interchanges, parking lots, and high bay industrial areas. They are the most efficient of the light sources in general use in number of lumens produced per watt of electricity. Their relative cost is high; their life ratings are not well established, and they require special ballast. The color is slightly yellowish.

20.5.0 Overall Illumination

Walls, ceilings, and surroundings are an important part of the overall illumination system since they redirect light to the working area. The most efficient lighting system is obtained when the fixtures are new and when the walls, ceilings, floors, and furnishings of the room are colored with a high-reflectance color. Lighting is, however, only one of many factors that make up the whole environment. While a completely white room allows the highest lighting efficiency, the psychological effect of such surroundings on the occupants may be less than harmonious. The use of color in the surroundings, even if it means sacrificing lighting efficiency, is necessary for the well-being of the occupants. Ceilings should have the lightest color, preferably an off white. Shiny surfaces should be avoided, as they result in glare. As mentioned earlier, lighting levels start dropping immediately after the installation of the fixtures. Lamp burnouts and lamp depreciation contribute to this, but the principal cause is the accumulation of dirt. It is not uncommon to find lighting levels one half of the initial values after only a year or so of operation. The lighting maintenance program must include cleaning and painting of the walls and ceilings in addition to the fixture cleaning schedule.

When mounting any light fixture, follow the manufacturers' step by step instructions. The most important thing to remember when mounting any fixture or device is to ensure that all connections are both electrically and mechanically secure.

High-intensity discharge lamps (HID) will be discussed further later in this manual.

Test your Knowledge (Select the Correct Response)

42. What are the two principle types of fluorescent lamps?

    A. Delay-start and instant start
    B. Instant-start and rapid-start preheat
    C. Ballast and non-ballast
    D. Ballast-saver and non-ballast

43. What section of the room should be colored the lightest when considering the overall illumination of a room?

    A. Wall opposite window
    B. Wall nearest window
    C. Wall closest to door
    D. Ceiling

21.0.0 TROUBLESHOOTING LAMPS

As light sources are designed to operate most efficiently and economically at their rated voltages, give special emphasis to using lamps to suit the voltage of the circuit.

Operation within the normal operating range is desirable because both over-voltage and under-voltage operations have a determined effect on the life, efficiency, and economy of the light source. The effect on lamps of operating them over or under their rated voltage range is described below.

21.1.0 Fluorescent Lamps

Line voltage higher than the maximum of the ballast range will shorten lamp and ballast life. Line voltage below the minimum range will reduce illumination and may cause uncertain starting of some types of fluorescent lamps.

21.2.0 Incandescent Lamps

Line voltage higher than the maximum lamp range will increase the light output but will shorten lamp life. Line voltage below the minimum range will extend lamp life but will reduce light output approximately three percent for each one percent in voltage drop.

21.3.0 Mercury Lamps

Line voltage higher than the maximum lamp range will shorten lamp and ballast life. Line voltage below the minimum range will reduce illumination and may cause uncertain starting.

21.4.0 Lamp Guides

Table 8-12 contains the most common troubles encountered with lamp equipment, the probable causes, and the suggested solutions.

Table 8-12 – Lighting maintenance chart.

INCANDESCENT		
SYMPTOM	POSSIBLE CAUSE	REMEDY
Lamp out, but defective	Loose lamp or loose or broken connections	Tighten in socket, or secure terminals, or repair wiring
Lamp burns dim	Low voltage	Match lamp rating to line voltage. Replace lamp. Replace with lamp of proper rating. Use shock absorbing device
Lamp breakage	Water contacts lamp bulb, or bulb touches luminaire	Use in closed, vapor-tight luminaire if water vapor is present. Seal joint where conduct stem enters luminaire. Use correct size lamp. Straighten socket.
FLUORESCENT		
SYMPTOM	POSSIBLE CAUSE	REMEDY
Lamp does not start or flashes on and off	Lamp pins not contacting or lamp worn out, or starter defective or low line voltage or fault in circuit or luminaire.	Seat lamp firmly and correctly. Replace with tested lamp. Replace with tested starter. Check with voltmeter. Check wiring and lamp holders. Check ballast.
Lamp flickers: ARC wiggles, swirls, or flutters	Defect which occurs in both new and old lamps.	Turn luminaire on and off several times. Allow a new lamp to operate a few hours for seasoning. Remove lamp and shake one end down. Replace lamp if flicker persists. If flicker is repeated in new lamp, replace starter.
Lamp starts slowly (should start in a few seconds)	Low line voltage or slow starter	Check with voltmeter. Replace starter.
Short lamp life (A few early failures do not indicate average for group. Some fail after a few hundred hours; others last 4000 - 6000 hours.)	Low line voltage or lamps turned on and off too often.	Check with voltmeter
Radio interference	May originate from other source. Radio too close to lamp. Aerial lead-in not shielded.	Operate radio with fluorescent lamps turned off. Move radio 9 to 10 feet from lamp. Shield lead-in and ground shield. Install filter radio or luminaire.
Noise from ballast. (Don't expect perfect silence)		If quiet necessary, take special precautions in locating ballast. If unit very noisy, replace ballast.
MERCURY LAMP		
SYMPTOM	POSSIBLE CAUSE	REMEDY
Lamp fails to start	Lamp loose. Lamp burned out. Low voltage. Wiring fault. Low temperature.	Tighten in socket. Replace. Increase lamp voltage by changing transformer tap. Check wiring. Tighten connections. Lamps may not start when temperature is below 32° F. Where there is a three phase supply. Connect luminaries on alternate phases. On single-phase, add incandescent luminaries to the system.
Lamp frequency goes out	Fluctuating voltage or wiring fault.	Check line voltage. (Momentary dips of 10 percent, or more, often cause light to go out.)
Annoying stroboscopic effect	Cyclic Flicker	Tighten connections. Check wiring. Separate lighting circuits from heavy power circuits.

22.0.0 MAINTENANCE of LIGHTING SYSTEMS

Lighting has a great influence on the quality and quantity of work as well as a direct bearing on employee morale. The necessity for periodic attention to the lighting system cannot be overemphasized. To prevent progressive deterioration of the system, personnel must provide regular maintenance and prompt repair of any deficiency.

Maintain the required illumination intensity by keeping lamps, fixtures, and reflective areas clean and in good repair, by replacing defective lamps, and by keeping the voltage steady.

It is well known that dirt absorbs and masks light. The progressive decrease of light caused by accumulating dirt renders periodic cleaning of lighting equipment a necessity. The frequency of cleaning depends largely upon local conditions. Fixtures in air-conditioned and air-filtered rooms may require cleaning only once a year. In an atmosphere that is heavy with dust and fumes, cleaning every few weeks may be necessary.

The cleaning schedule for a particular installation should be determined by light meter readings after the initial cleaning. When subsequent foot-candle readings have dropped 20 to 25 percent, clean the fixtures again. Make readings with the light meter at the working surface with the meter reader in the position of the operator or person using the working surface.

Wash lighting equipment; do not just wipe it off with a dry cloth. Washing reclaims 5 to 10 percent more light than dry wiping and reduces the possibility of marring or scratching the reflecting surface of the fixtures.

To clean removable glassware, reflectors, and diffusing louvers, immerse them in a solution of synthetic detergent cleaner and scrub them with a soft brush or sponge. If scrubbing does not remove incrustation, use No. 0 steel wool to remove dirt film.

Rinse in warm, clear water and dry with a clean cloth.

CAUTION

Do not immerse lamp base or electrical connections in the cleaning solution.

Glassware, reflectors, and diffusing louvers that cannot be removed should be cleaned as follows:

Wipe with a moist cloth or sponge, using a solution of synthetic detergent cleaner. If sponging does not remove the incrustation, use No. 0 steel wool to remove dirt film. Ensure that shreds of steel wool do not touch the pin contacts or get into the lamp socket. Wipe off excess moisture with a clean cloth. Clean fixture holders and stem hangers with a moist sponge or cloth dampened with synthetic detergent cleaner and wipe dry. Replace any enameled, chrome, aluminum, or silver-plated reflecting surfaces that cannot be adequately cleaned and polished.

Neglected lamp outages reduce illumination. If burned-out lamps are not promptly replaced, illumination may drop to unsafe foot-candle levels in a short time because of outages alone. In some cases, it may be satisfactory and more economical to clean lamp surfaces and fixture interiors only at the time of re-lamping. Each activity must determine whether electrical, self-help, or custodial service personnel will perform cleaning.

Replace burned-out lamps on request. To prevent reduced illumination from lamp outages, do the following:

- Instruct employees to report burnouts as they occur.
- Replace blackened or discolored lamps, even though they are still burning. Discoloration indicates the lamp is nearing the end of its useful life.
- Replace fluorescent lamps as soon as they begin to flicker. A burned-out lamp in a live circuit may cause damage to starter and ballast. Blackening at the ends of the tube adjacent to the base indicates that the lamp is near the end of its useful life.
- In general, replace with the same type, wattage, and voltage as that of the lamp removed. If frequent burnouts occur, the voltage rating of the lamps may be too low. Do not use lamps of higher wattage than called for on lighting design plans.

23.0.0 SCAFFOLDING

As the working level of a structure rises above the reach of crew members on the ground, temporary elevated platforms, called “scaffolding,” are erected to support the crew members, their tools, and materials.

There are two types of scaffolding in use today: wood and prefabricated. The wood types include the swinging scaffold, which is supported on the ground. The prefabricated type is made of metal and is put together in sections as needed. As a CE, you will be working more often with the prefabricated type of scaffolding.

This section provides only general information on prefabricated scaffolding. For further details of scaffolding, consult the latest copy of Code of Federal Regulations (29 CFR 1926).

23.1.0 Prefabricated Scaffolding

Several types of patent-independent scaffolding are available for simple and rapid erection, as shown in *Figure 8-127*. The scaffold uprights are braced with diagonal members, as shown in *Figure 8-128*, and the working level is covered with a platform of planks. All bracing must form triangles, and the base of each column requires adequate footing plates for bearing area on the ground. Patented steel scaffolding is usually erected by placing the two uprights on the ground and inserting the diagonal members. The diagonal members have end fittings that permit rapid locking in position. The first tier is set on steel bases on the ground. The second tier has the bottom of each upright locked to the top of the lower tier. A third and fourth upright can be placed on the ground level and locked to the first set with diagonal bracing. The scaffolding can be built as high as desired, but high scaffolding should be tied to the main structure.

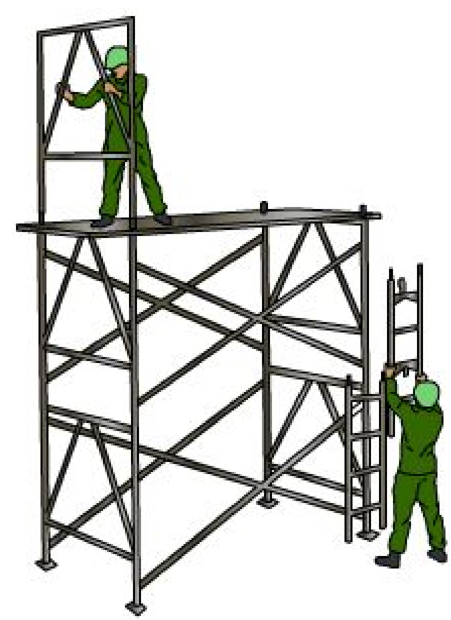

Figure 8-127 – Assembly of pre-fabricated independent-pole

Steel and aluminum scaffolding is used to speed up construction and maintenance operations. Many types are available for interior work and erection. This kind of scaffolding is used around many construction sites because it can be disassembled and transported whenever necessary. The scaffolds are mounted on steel casters with brakes and adjustable supports, which permit quick movement and positioning of each tower. This scaffolding is equipped with special 12 foot long trussed planks that are placed to enable crew members to be within comfortable and safe working distance of all working space.

Prefabricated scaffolding of this type comes in three categories: light, medium, and heavy duty. Light duty scaffolding has nominal 2 inch-outside-diameter steel-tubing bearers. Posts are spaced no more than 6 to 10 feet apart. The load it can handle is 25 pounds per square foot. Medium-duty scaffolding normally uses two inch outside diameter steel tubing bearers. Posts should be spaced no more than five to eight feet apart. If 2 1/2 inch-outside-diameter steel-tubing bearers are used, posts are spaced six to eight feet apart. The load it can handle is 50 pounds per square foot. Heavy-duty scaffolding should have bearers of 2 1/2 inch-outside-diameter steel tubing with the posts spaced not more than six feet six inches apart. The load it can handle is 75 pounds per square foot.

Figure 8-128 – Prefabricated independent-pole scaffolding.

To find the load per square foot of a pile of materials on a platform, divide the total weight of the pile by the number of square feet of platform it covers.

23.2.0 Scaffolding Safety

All persons working on scaffolds or tending other persons who are working on scaffolds must observe the following safety precautions. Construction Electricians must not only observe the safety precautions themselves, but they must also issue them to others in the crew and ensure that the crew observes them.

- Keep scaffolds clear of accumulations of tools, equipment, materials, and rubbish.
- Do not use any scaffold for the storage of materials in excess of those currently required for the job.
- Store tools not in immediate use on scaffolds in containers to prevent tools left adrift from being knocked off. Lash or otherwise secure all tool containers to the scaffolds.
- Throwing objects to or dropping them from scaffolds is absolutely prohibited. Use hand lines for raising or lowering any objects that cannot be passed hand to hand.
- Provide a standard guardrail and toe-board on the open side of all platforms five feet or more above ground; otherwise, use safety belts tied off to safety lines.
- No person should remain on a rolling scaffold while it is being moved.

- Maintain all scaffolds in safe condition, and do not alter or disturb them while in use. Personnel must not be allowed to use damaged or weakened scaffolds.
- Access to scaffolds must be by standard stairs or by fixed ladders only.
- When dismantling scaffolding, clean it and make it ready for storage or use. Never store scaffolding that is not ready for use.

Summary

Electrical safety today is far more complicated than it was 20 years ago. With common sense and safe working practices all work can be accomplished safely. A basic rule to live by is that electricity must be respected.

The National Electrical Code (NEC)® has all of the requirements for installing electrical systems. The NEC® should be checked frequently for proper installation methods.

The starting point for interior wiring is the service entrance. Usually, electrical loads are divided into four categories which are two-wire, single-phase; three-wire, single-phase; three-wire, three-phase, and four-wire, three-phase.

A myriad of conductors exist for interior wiring. Each has a specific use and some are required for special areas of installation. Some are made for use in wet, humid, or corrosive areas.

When planning conduit runs refer to the blueprints and specifications. Proper bent conduit turns look better than elbows and are preferable for exposed work. Bending conduit is an art and with experience you will learn to make the proper bend the first time.

All lighting and power systems start at the panelboards. Careful planning in the wiring layout can result in substantial savings by eliminating long runs of excess wire.

Hazardous locations are described as areas where sparks generated by electrical equipment may cause a fire of explosion. These locations are designated by three classes and each has distinct characteristics.

There are various types of electrical test equipment. Each has a specific purpose and can be valuable tools when used to solve electrical circuit problems. Always make sure you familiarize yourself with the operating instructions furnished by the manufacturer prior to use.

Electrical troubleshooting is an important part of your job as a Construction Electrician. The ability to find a faulty condition quickly can plan an important part in shortening the downtime caused by failure of the circuit. The first step to take in troubleshooting circuits is to inspect the circuit visually.

Once the switches are in place to control the lighting you need to mount the light fixture itself. Each lighting installation is designed to produce a specific level of illumination adequate for those working in the area. Various types of lamps are available to provide the most cost effective, yet adequate lighting for the area.

Lighting has a great influence on the quality and quantity of work as well as a direct bearing on worker morale. Maintenance of the lighting systems is required to prevent progressive deterioration of the system. Cleanliness of the light fixture itself can help to maintain the best illumination for the work area.

Several types of scaffolding are available for simple and rapid erection of overhead work. When working at heights always remember that safety is a must for yourself and your crew.

Trade Terms Introduced in this Chapter

Lockout Device	Is a positive means to hold an energy-isolating device in a SAFE position in order to prevent the energizing of a machine or equipment
Tagout Device	Is a prominent warning device which can be securely fastened to an energy isolating device
Service Entrance	Serves to bring power from the service drop to the panelboard inside the building
Grounded	Is defined by the NEC® as connected to the earth or to some other conducting body that serves in place of the earth
Grounded Conductor	Is a circuit conductor that is intentionally grounded
Grounding Conductor	Is a conductor used in connecting equipment in the circuit of a wiring system to a grounding electrode or electrodes
Ampacity	Is described as **current rating** or **current-carrying capacity**, is the RMS electric current which a device can continuously carry while remaining within its temperature rating.

Additional Resources and References

Construction Electrician Basic NAVEDTRA 14026, Naval Education and Training Program Management Support Activity, Pensacola, FL, Jan 1998.

Construction Electrician Intermediate NAVEDTRA 14027, Naval Education and Training Program Management Support Activity, Pensacola, FL, Oct 1998

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29 CFR 1910

29 CFR 1926.417

29 CFR 1926. 400

29 CFR Subparts K and G.