Electrical Tech Note — 330

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Michigan State University

WIRING CIRCUITS – BASIC RULES

Introduction: Electrical current flowing through a wire or electrical connecting device, such as a plug and receptacle, produces heat. The heat is a result of resistance which is a property of all conductors except in the special case of superconductivity. As the current flow through a wire produces heat, the temperature of the wire increases. Electrical wire sizes are matched to levels of current flow so that under normal conditions wires will not become too hot and start a fire. A loose connection such as at a screw terminal or a loose plug and receptacle connection will result in heat concentrated at a single point sometimes resulting in enough heat to melt the device and start a fire.

Arcing is a condition where two conductors with a voltage between them touch with sparks flying in all directions. Arcing results in an extremely large amount of heat being produced at a single point of contact. Arcing can result when wires are damaged such as a cord run across the floor, a nail or screw penetrates the wiring within a wall, floor, or ceiling, or when wires are installed in such a way that the wires rub against a sharp edge. Arcing can occur when wires are not connected properly, or a screw terminal is not properly tightened.

The chance of electrical shock is always present with electrical wiring that is not installed properly, maintained, or used carelessly. But, the *greatest danger from the use of electricity is fire*. Electrical code rules having to do with wiring installation are primarily concerned with fire prevention.

Wiring Materials: Electrical wires are required to be protected form physical damage. Individual wires, even when insulated, are not permitted to be exposed. The wires are required to be protected from damage by cable jacket, cord jacket, by placing the wires in a conduit or other raceway, by placing them inside electrical boxes or other electrical equipment enclosures, or by direct burial of the wires at an adequate depth in the earth. The most common ways to protect electrical wires from damage is with an outer protective cable jacket or by running the wires through protective tubing or conduit, Figure 330.1.

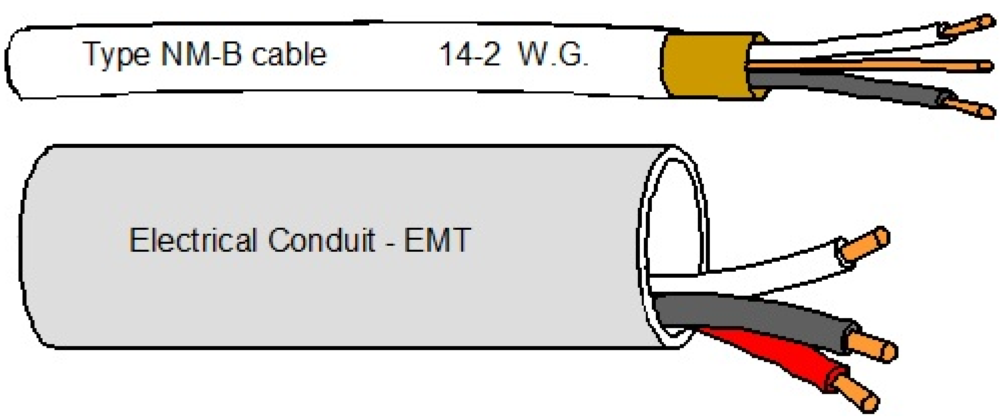

Figure 330.1 *Individual wires installed for electrical circuits within buildings are not permitted to be exposed, and must be protected within a cable jacket, conduit, or some other approved means.*

Electrical wiring is usually installed in dwellings as cables because cables are flexible and fairly easy to install. This helps reduce installation cost, but care must be taken to avoid exposure to physical damage. Cable must also be installed where they are not exposed to damage by animals, machinery, or the environment such as wet weather and direct exposure to the ultraviolet rays of the sun unless rated for such conditions. The following wiring materials are commonly used for installing electrical circuits in dwellings in most areas.

Nonmetallic-sheathed cable* (Type NM-B)** is most frequently used for the wiring of circuits in dwellings. This type is only permitted to be installed in dry locations. Animal confinement barns, milkhouses and similar areas are not dry locations, and this type is not permitted for this application. The letter "B" in the type designation indicates the wire insulation is rated to operate at a temperature of up to 90°C without sustaining heating damage. The most common sizes of nonmetallic-sheathed cable (Type NM-B) used for dwelling wiring are 14 AWG for circuits rated at 15 amperes, 12 AWG for circuits rated at 20 amperes, and 10 AWG for circuits rated at 30 amperes. So that cable size can easily be identified, the cable manufacturers have standardized on a color scheme for the outer jacket. Type NM-B cable **size 14 AWG** has a ***white outer jacket, **size 12 AWG** has a ***yellow*** outer jacket, and **size 10 AWG** has an ***orange*** outer jacket, Figure 330.2.

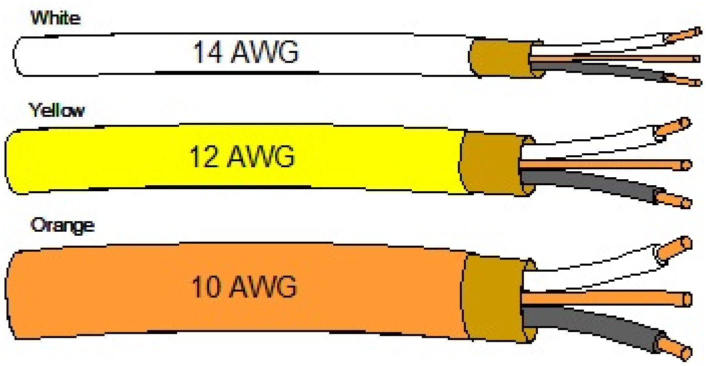

Figure 330.2 *The outer jacket of nonmetallic-sheathed cable is usually color coded according to size. The smallest size is 14 AWG with a white jacket, 12 AWG has a yellow jacket, and 10 AWG has an orange jacket.*

For direct burial in the earth or use on or within buildings rated as damp or wet locations, the preferred cable is ***Type UF.*** This is a nonmetallic-sheathed cable with a special outer jacket that can withstand prolonged exposure to moisture. This type is suitable for use in wet, damp, and dry locations in all types of buildings including dwellings. It is hard to strip the outer jacket of Type UF cable because the wires are completely embedded within the jacket material. There are special tools available to help make cable stripping easier.

The large main wires entering a building from the utility meter are called service entrance conductors. These wires usually terminate inside the building at a circuit breaker panel with a main circuit breaker used as a disconnect for all power entering the building. Sometimes these wires are installed within a metal or nonmetallic pipe called a conduit. These wires are also permitted to be installed at a dwelling or farm building in the form of a cable called ***service entrance cable*** which is listed as **Type SE.** This type of cable is suitable for installation in wet, damp, and dry locations. It is also permitted to be installed within a building to supply equipment such as supplying a large motor in a farm building. These service entrance cables are permitted to contain copper or aluminum wires. Copper wire will have a higher current capacity than aluminum wire of the same size. In some type of environments aluminum wire may be more prone to corrosion than copper. For farm buildings housing animals copper wire is required.

Armored cable **(Type AC)** has a somewhat flexible metallic outer jacket and is only permitted to be installed in dry dust free areas. As a result, it is not generally permitted for use in agricultural buildings. The metal outer sheath is more resistant to physical damage or chewing by rodents than the nonmetallic-sheathed cables.

Flexible Cords: *Flexible cords* are not permitted to be installed as permanent wiring except for connection to electrical equipment which requires flexibility or which must be disconnected from power from time to time. Flexible cords used to supply portable equipment must be of a type with an outer jacket suitable for the conditions and adequate to protect the wires from damage. Small size flat flexible cords have limited applications such as in a dwelling or office to supply such things as lamps. Always look for the wire size when purchasing an extension cord. The longer the run the larger the wire size that is required to prevent excessive voltage drop when the load is operating. Extension cords that are too small can overheat and even result in a fire. Typical extension cord copper wire sizes are AWG 18 which is limited to loads not exceeding 7 amperes, AWG 16 for loads up to 10 amperes, AWG 14 for loads up to 15 amperes, AWG 12 for loads up to 20 amperes, and AWG 10 for loads up to 25 amperes.

Typical *flexible cords* used for portable equipment and extension cords have a round cross-section and are generally known as hard service cord. This cord is listed as extra hard usage. For applications where conditions that may cause physical damage are limited, the cord has a thinner protective jacket and is only listed as hard usage. Hard service flexible cords have a type letter designation that starts with the letter **S** which means extra hard usage. For applications where only hard usage is required the type letters start with **SJ**. Typical applications on farms and shops require flexible cords that are suitable to withstand exposure to lubricants and water. The letter **O** in the type means the cord is suitable for exposure to oil and similar lubricants. The letter **W** means the cord can be used in wet locations, although the cord connector ends must not be exposed to wet conditions unless protected or of a water resistant type. Typical flexible cord types suitable for use on farms and in shops are *Type SOW* for extra hard usage applications, and Type *SJOW* for hard usage applications. If there is a letter **T** in the type designation, that means thermoplastic covering and those cords are also suitable for farm applications but they tend to get rather stiff in cold weather.

Conduit and Tubing: For many farm and commercial applications installing circuits using cable is not satisfactory. Circuit wires are not permitted to be run exposed, they must be protected from damage. If not protected by a cable jacket, the wires must be run inside a protective tubing generally called conduit. These conduits are manufactured for used with electrical wiring. Pipes and fittings used for plumbing are <u>not</u> suitable for electrical wiring. Special skills are needed to install electrical conduits and to install the wires within the conduits. For some applications such as connections to motors, the conduits must be flexible, and there are types suitable for those applications. For agricultural applications, conduits must be suitable to withstand corrosive conditions as well as severe physical abuse in some locations.

Galvanized *rigid metal conduit* (RMC) has the greatest wall thickness of the metal conduits although it is subject to corrosion for some agricultural and industrial applications. It is generally steel, however, aluminum is available where weight is an issue. Rigid metal conduit has threaded fittings. The same standard thread is used as normal plumbing, but there is a different taper to the threads. Water pipe fittings are <u>not</u> to be used with rigid metal conduit.

Electrical metallic tubing (EMT) is made of steel, but it has a thin wall thickness. Wall thickness is too thin to support threads. It is galvanized, but subject to corrosion in locations where the air is constantly damp or water is frequently present. This type should not be used in most agricultural locations. Special fittings are made for EMT. When installed outside, the fittings must be of a type that resists the entrance of water. Because of the thin wall thickness, EMT is not suitable for locations where it may be subjected to physical damage.

Rigid nonmetallic conduit is available in several types. The most common type is made of polyvinyl chloride plastic, which is gray in color and is listed as Type PVC. It is recommended for use in agricultural buildings where corrosion may be a problem. A major disadvantage of PVC conduit is that it does not have the physical strength of rigid metal conduit. It will break if it is hit hard when it is cold. When the weather is hot, it will get soft and may sag. Supports are not permitted to be more than three feet apart for trade sizes one inch diameter and smaller. A solvent is brushed on the end of the conduit, and it is inserted into a smooth fitting. Once installed a PVC fitting cannot be removed. This material expands and contracts as the temperature changes and this characteristic must be considered during installation. Standard PVC conduit is listed as Schedule 40. If the PVC conduit with a greater wall thickness is needed to resist physical damage the type to use for those applications is Schedule 80.

Intermediate metal conduit (IMC) looks similar to rigid metal conduit and is also threaded, but it has a thinner wall thickness than rigid metal conduit. It is constructed of a special galvanized steel alloy. It is made for applications where physical strength and stiffness is important but weight must be limited. This type is not recommended for installation in agricultural applications because of the corrosive conditions.

Liquidtight flexible conduit is available with a metallic inner core and completely nonmetallic outer covering. The completely nonmetallic type (LFNC) with nonmetallic fittings is recommended for agricultural applications where flexibility is required, but not subject to abuse.

Flexible metal conduit (FMC) is a type of metal conduit that consists of exposed overlapping metal which gives the conduit flexibility. This type of flexible conduit is only permitted to be installed in dry, dust free, and non-corrosive areas. This type is not recommended for most agricultural applications. It is frequently used where flexible connections are required to such equipment as motors in dwellings and commercial buildings.

Cable for Wiring Circuits: Cables used for wiring circuits is either of the 2-wire type, 3-wire type, and 4-wire type. When cable is called 2-wire, it is understood that there are two insulated wires inside the cable and one equipment grounding wire in the cable. The equipment grounding wire is usually bare or it sometimes has green covering. Two-wire cable has a white insulated wire and a black insulated wire in addition to the equipment grounding wire. A typical nonmetallic-sheathed cables (Type NM) are shown in Figure 330.3. A 3-wire cable has a white wire, a red wire and a black wire in addition to the equipment grounding wire. The circuit wire insulation colors of a 4-wire cable are white, black, red, and blue plus a bare equipment grounding wire.

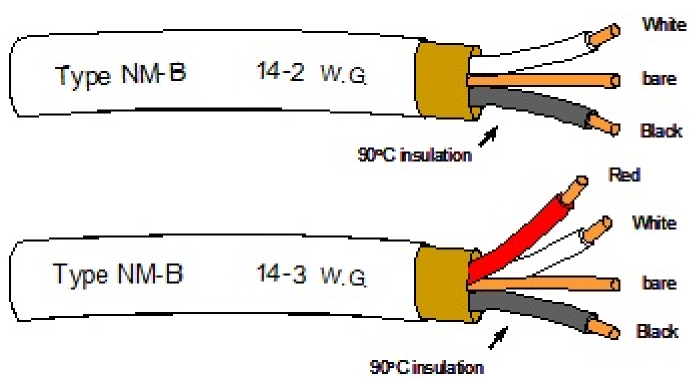

Figure 330.3 *Cables are typically available with two insulated conductors (white and black) and an equipment grounding wire, and with three insulated wires (white, black, and red) and an equipment grounding wire.*

How to Properly Install Nonmetallic-Sheathed Cables (Type NM):

All splices in wires and connections to lighting fixtures, receptacle outlets, and switches are required to be made inside of an electrical box. *The cable is required to be securely connected to the box so that it will not move.* There is an exception to this rule for some nonmetallic boxes in a dwelling. It is important to allow enough wire inside of the box to make repairs at a later time. *It is required to allow not less than 6 inches of wire at an electrical box* and not less than 3 inches extending outside of the box. Figure 330.4 shows an electrical cable with 6 inches of the outer covering removed. This is inserted into the box so that the entire 6 inches of exposed wire is inside of the box.

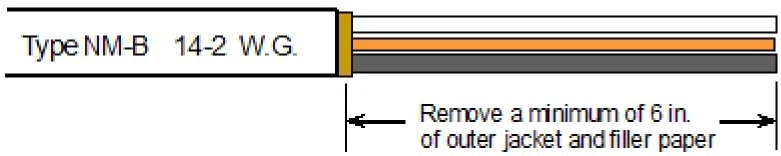

Figure 330.4 *A minimum of 6 inchs of cable jacket is required to be removed from the cable and inserted into the box or enclosure for making connections. This is a code requirement.*

It is important to strip an adequate amount of insulation from a wire to make splices and to connect to screw terminals of switches and receptacle outlets. Do not strip too much insulation from a wire. *For most situations, ¾ inches of exposed wire is adequate for splices and terminations.* Use a wire stripper set for the size of wire. For example, set the stripper for size 14 AWG for size 14 AWG wire. If this is not done correctly, the wire may be nicked by the stripper. A nick in the wire can easily result in a broken wire at a later time. The proper amount of wire to be exposed for splices and terminations is shown in Figure 330.5.

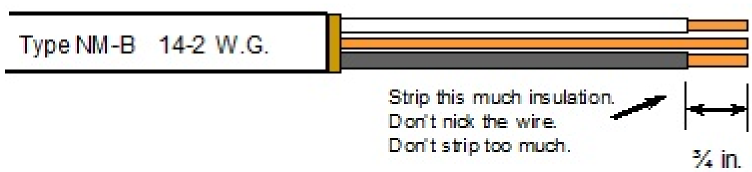

Figure 330.5 *Strip ¾ inches of insulation form a wire for making splices and terminations.*

It is important to wrap a wire around a screw in the ***clockwise*** direction. When the screw is tightened, the wire will wrap tighter around the screw. This will help prevent strands of stranded wires from coming loose and sticking out from under the screw. If the wire is wrapped around the screw in the opposite direction it will most likely slip out from under the screw when it is tightened. Figure 330.6 illustrates the proper way to wrap a wire around a screw terminal.

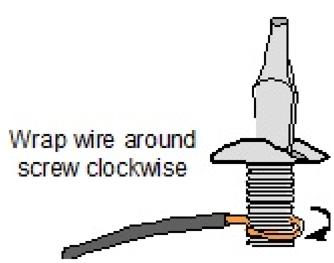

Figure 330.6 *Wrap a wire around a screw in the clockwise direction so that the wire will be drawn into the screw when it is tightened.*

Making Wire Splices: Making a splice in a wire is usually done with a connector frequently called a *wire nut*. Wire nuts come in different sizes, and the sizes are usually color coded for easy recognition. The most common size is yellow. It will splice two wires together of sizes 14 and 12 AWG. If you will splice three wires together the next size larger (Red) is recommended. When connecting to wires of a lighting fixture a wire nut smaller than the yellow is recommended. That wire nut usually is the color orange. Figure 330.7 shows the proper way to splice wires with a wire nut. After stripping ¾ inch of insulation form each wire, hold the wires firmly in one hand with the ends of the wire even with each other. Push the wire nut over the ends of the wires and twist until the wire nut is tight. Just to make sure all of the wires are held firmly with the wire nut, hold the wire nut with one hand and pull on each wire. If one wire comes out then remove the wire nut and try again. This is very important. *An improperly installed wire nut is a frequent cause of failure of electrical circuits*.

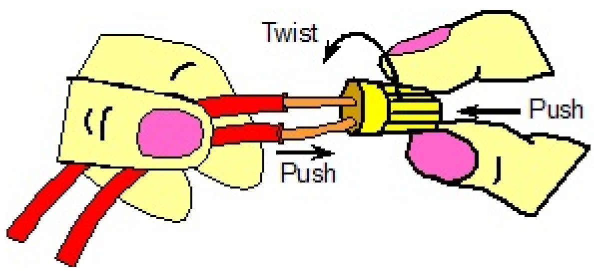

Figure 330.7 *Hold the ends of the wires even and then push the wire nut over the wires while twisting until the wire nut is tight.*

Electrical Code Terminology: There are three types of wires which you must understand if you are going to do maintenance wiring. One is called the ***ungrounded wire***, one is known as the ***neutral***, and the third is the ***equipment grounding*** wire. The types of electrical systems you will be working on will usually have one wire grounded. That means one wire has been connected to the earth. That connection was made at the transformer by the utility, and it was made again at the service entrance to each building by the electrician. This ***grounded wire*** is usually referred to as the neutral. The neutral wire carries electrical current just like the ungrounded or hot conductors. *A grounded wire is required to have white or gray insulation* or be marked at all places it is accessible with white tape.

At least one wire of a circuit will have a voltage when measured between it and the earth. That wire is the ***ungrounded wire*** or hot wire. This wire is dangerous to touch. You must also treat the neutral or grounded wire with care because sometimes when there is a problem in the electrical system the neutral can also become energized. There are usually two different ungrounded or hot wires in a typical single-phase house or farm electrical system. Each of these hot wires is about 120 volts between the wire and the earth where you are standing. Please remember that whenever the voltage is more than about 15 volts it can be dangerous to humans. When a motor or some other equipment operates at 240 volts, it takes two hot wires for the equipment. Between the hot wires is 240 volts, but from each hot wire to earth it is 120 volts. Ungrounded wires are required to have insulation that is any color other than white, gray, or green. But there are some exceptions to this rule.

The third type of conductor is not always a wire. This is the ***equipment grounding*** conductor. The purpose of this conductor is safety. If there was an accidental contact between the hot wire and the frame of some electrical equipment such as a motor, the equipment grounding conductor would conduct the electrical current safely back to the electrical service panel. The equipment grounding conductor connects to metal boxes, frames of motors, and the metal enclosure or frame of any electrically operated equipment with exposed metal. It is extremely important for ***safety*** that the equipment grounding wire be connected to the metal frame of all equipment. When electrical wires are run inside metal tubing or metal conduit the metal acts as the equipment grounding conductor. In other cases there is a wire run with the circuit wires that acts as the equipment grounding wire. *An equipment grounding wire is sometimes bare without insulation or it has green colored insulation or covering*.

Wire Color Code: The *National Electrical Code* is a set of rules for installing electrical wiring so as to minimize the chances of fires and shock due to the use of electricity. There is a color code that must be followed for some types of wires. Unfortunately some wiring gets installed by persons who are not familiar with Code rules. Never assume the purpose of a wire based upon the color on the wire insulation. Always verify that the wire color is correct for the application. The color code for wires within machines and appliances is not necessarily the same as for circuit wires installed within buildings. For wire sizes 4 AWG and larger, it is permitted to use colored tape or some other durable means to identify the purpose of a wire. The colored tape must be wrapped completely around the wire in a substantial quantity to make it obvious that it's purpose is to identify the wire.

Circuit wires that are used for ***equipment grounding*** are required to be ***bare*** without insulation, ***green***, or they may be green with yellow stripes. The equipment grounding wire is also permitted to be ***bare*** with no insulation or covering. The propose of this wire is to provide a safety path for fault current back to the electrical service panel. When circuit wires are run within metal conduit, the conduit acts as the equipment grounding conductor and an additional equipment grounding wire is generally not required. This is not true with agricultural wiring, however. Even though metal conduit may be used for a circuit, *in an agricultural building an insulated copper equipment grounding wire is required*. The color ***green*** is reserved for identifying equipment grounding wires. Green insulation is not permitted to be used for wires that have other purposes. Green tape is permitted to be used to identify a wire as an equipment grounding wire in sizes 4 AWG and larger if the insulation is of some other color. In the case of an equipment grounding wire, the insulation can be stripped off completely at the exposed ends to identify the wire as an equipment grounding wire.

Wires such as a ***neutral*** are grounded to the earth at the service panel of the building. Circuits that operate at 120 volts have an ungrounded wire and a grounded wire or neutral. Any circuit wire that is intentionally grounded to the earth, such as a neutral, is required to be identified with insulation that is ***white or gray***. All grounded circuit wires that are intended to carry circuit current are required to be insulated. In the past there were some exceptions to this rule, but today those exceptions no longer apply. The colors white or gray are reserved for grounded wires. These colors are not permitted for any other purpose. White tape is permitted to be used at the ends to identify a wire size 4 AWG and larger as a neutral if it has insulation of another color.

There is a type of 3-phase electrical system that is encountered for small businesses and farms that has one ungrounded wire with an unusual voltage between that wire and the neutral. Between the other two ungrounded wires and the neutral is 120 volts. *This wire with the higher voltage to neutral is sometimes called the high leg or wild leg.* You can learn more about 3-phase electrical systems by referring to Tech Note 220. This *high leg* wire is required to be identified with the color *orange*. Usually it will have orange tape near the terminations.

Ungrounded or hot wires are permitted to have insulation of any color other than white, gray, or green. The most common ungrounded wire colors are *black, red, blue, and yellow*. Sometimes wires may have the same basic color of insulation, but a colored stripe is added to make identification easier when may circuits are run together.

Installing Cable in Boxes: The proper way to insert cable into a box is to allow 6 inches of free wire inside the box. Insert the cable so that about ¼ inch of cable jacket is inside of the box. Tighten down the screws of the box connector or cable clamp so that the cable is held firmly, but it is not damaged or deformed from too much pressure. Install the box connector tightly into the box before inserting the cable. Figure 330.8 shows the proper method of installing cable into a metal box. A locknut secures the box connector to the metal box. In the case of some nonmetallic boxes in a dwelling the cable is permitted to be secured by another means and is not always secured to the box.

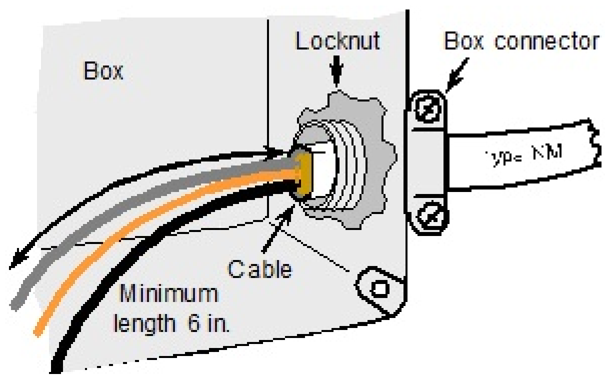

Figure 330.8 *Insert the cable into a metal box so that 6 inches of free conductor is inside the box and about ¼ inch of cable jacket is inside the box.*

Grounding Boxes and Receptacles: All metal boxes of an electrical system are required to be grounded. Figure 330.9 shows a grounding clip being used to ground a metal box. To install a grounding clip, lay the bare equipment grounding wire up against the inside of the box with the tip of the wire extending slightly above the edge of the box. Place the grounding clip over the wire and push it down onto the box with a flat blade screw driver. Grounding clips with a curved hook on the inside can be pressed down onto the box by placing the end of a flat blade screw driver into the hook and pushing down. Another way to connect an equipment grounding wire to a metal box is with a ***green*** *colored hex head screw* as shown in Figure 330.10. Most metal boxes come with a pre-tapped hole for the equipment grounding screw, but using the green grounding screw usually must be supplied and installed separately.

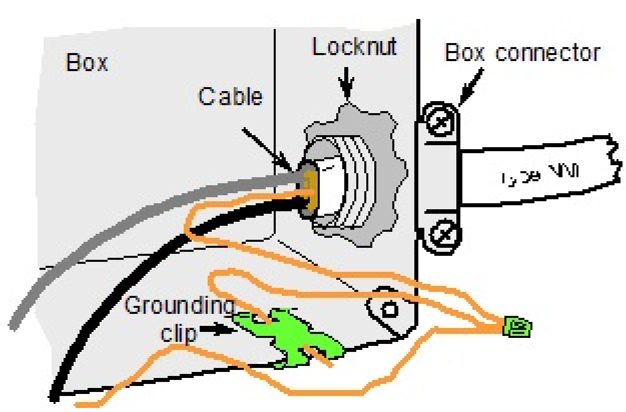

Figure 330.9 *An equipment grounding clip is used to connect the bare equipment grounding wire to the metal box.*

Frequently it is necessary to ground both a metal box and a receptacle outlet. This is done by splicing two short bare wires onto the equipment grounding wire of the cable entering the box. These short wires are usually 4 inches long and they are frequently called *pigtail* wires. A typical installation where both the box and a receptacle outlet are grounded is shown in Figure 330.10. Notice also that the box in Figure 330.10 has cable clamps inside the box. Install the cable so that all of the free wire is inside the box with about ¼ inch of cable jacket visibly extending beyond the cable clamp. Boxes such as the one in Figure 330.10 have holes in the bottom of the box already tapped for equipment grounding screws. Green hex head equipment grounding screws can be used to ground the metal box rather than a grounding clip.

It is very important to make sure the equipment grounding wire is continuous throughout the circuit. Grounding screws on devices such as switches and receptacles are only rated for one wire. *Never attempt to put more than one wire under a screw terminal.* The wire entering the box must also be connected directly to the wire leaving the box. Also it is important to make sure a metal box is also connected to this same equipment grounding wire. Sometimes it is not necessary to connect the equipment grounding wire to a receptacle or switch. Some receptacles and switches are of the self grounding type. They have a special clip at one of the mounting screws that makes adequate contact to a metal box. In those cases all that is required is to ground the box. The metal clip on the receptacle or switch will act as the grounding connection to the box. In the case of a nonmetallic box it is required to connect the incoming equipment grounding wire to the equipment grounding wire leaving the box, and run a short pigtail grounding wire to the receptacle or switch. Electricians refer to a short length of wire about 4 to 5 inches long used inside a box as a "pigtail."

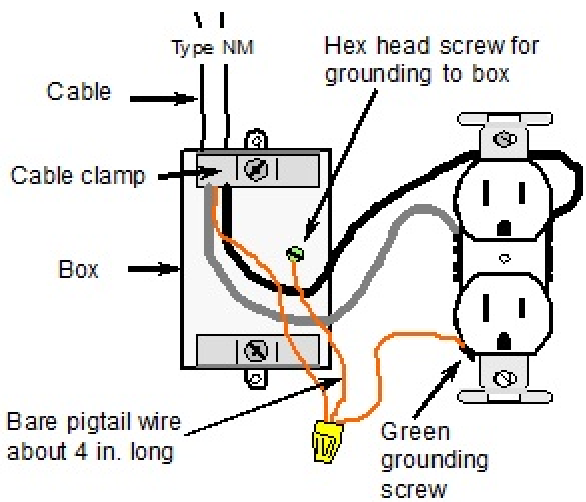

Figure 330.10 *Short wires called pigtails are used to ground the receptacle and metal box.*

Ratings of Switches and Receptacle: Switches, receptacles, and plugs have a maximum voltage and current rating. There are several reasons why different plugs and receptacles have different shapes for different voltages and current ratings. One reason is to prevent equipment from being plugged into a receptacle with the wrong voltage which will damage the equipment. A second reason is to prevent a fire because the plug, receptacle or switch will not handle the current of the equipment or load. Overheating will occur due to excessive current flow, and a fire may result. Finally, if the plug, receptacle, or switch is not adequate for the current or voltage, an electrical explosion may occur causing injury to persons nearby.

Voltage and current ratings are marked on the receptacle or switch. Figure 330.11 shows typical markings on a receptacle and switch. The receptacle shown in Figure 330.11 is only rated for use on circuits rated up to 125 volts and can supply a maximum of 15 amperes. A 125 volt receptacle rated to carry up to 20 amperes is shown in Figure 330.12.

The switch shown in Figure 330.11 is permitted to be used on circuits operating at up to 277 volts. That higher voltage is common in commercial and industrial buildings. The switch is also rated to supply loads up to a maximum of 15 amperes. The switch shown in Figure 330.11 is permitted to be used only on alternating current circuits. This means that it is not permitted to be used on a direct current circuit such as one supplied from batteries.

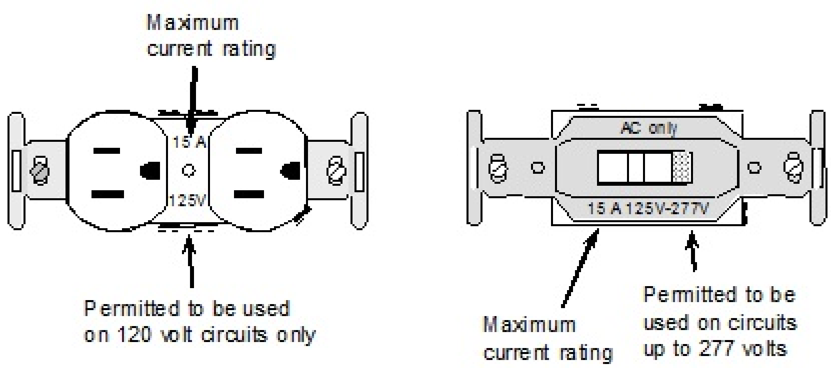

Figure 330.11 *Voltage and maximum current ratings are marked on switches and receptacle.*

Plugs and receptacles are designed to prevent accidental connection of equipment to the wrong voltage. It is important to only install receptacle outlets with the proper voltage and current rating for the circuit voltage and current requirements of the equipment and the circuit. Figure 330.12 shows a 20 ampere rated 125 volt receptacle with a 15 ampere and 20 ampere rated plug. Duplex receptacles with a “T” shaped neutral slot (center receptacle in Figure 330.12) are only permitted by the code to be supplied by a 125 volt, 20 ampere circuit. Also shown in Figure 330.12 is a receptacle rated at 15 amperes at 125 volts (left) and 15 amperes for 240 volt equipment (right). These special plugs and receptacles can be obtained from most any electrical supply distributor.

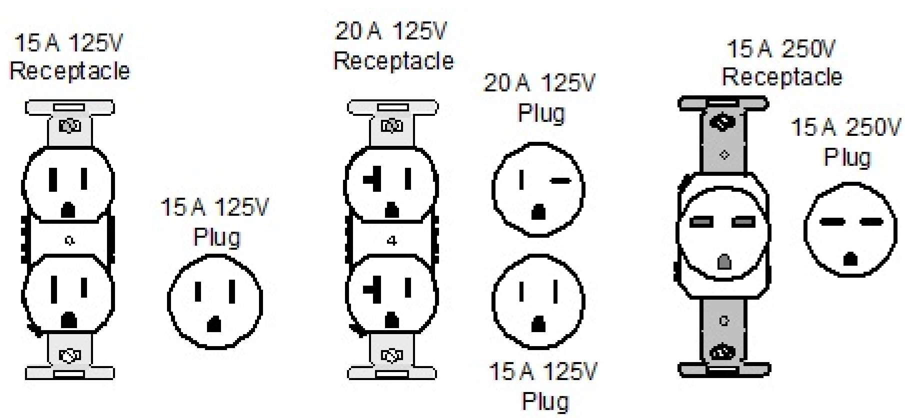

Figure 330.12 *The receptacle on the left is rated at 20 amperes, 125 volts and will accept both 15 ampere and 20 ampere rated plug. The receptacle on the right is for a 240 volt circuit.*

Basic Rules for Wiring Circuits: The white insulated wire in electrical cable is to be used for the neutral. It originates from the neutral terminal bus in the electrical service panel. Lighting fixtures, appliances, and equipment are frequently wired so that the neutral wire is connected to a particular wire in the fixture, appliance, or equipment. These are known as polarized devices and equipment. Such electrical devices and equipment will have either a white wire that is connected to the circuit white wire, or a silver colored screw terminal that is intended to be the neutral terminal. The other terminal for the ungrounded wire will more than likely be brass colored. A duplex receptacle will generally have two screw terminals on one side that are silver colored for the neutral wire and two brass colored screw terminals on the other side for the ungrounded hot wire.

When controlling a lighting fixture with a wall switch the purpose of the switch is to control the flow of 120 volt power to the fixture. When the switch is off there should be no live power at the fixture. So the Code rule is that the neutral wire connects directly to the fixture, but the hot ungrounded wire is interrupted by the switch on it's way to the fixture. *A neutral wire should never be connected to the switch* controlling a lighting fixture. A properly installed circuit for a wall switch controlling a lighting fixture is shown in Figure 330.13.

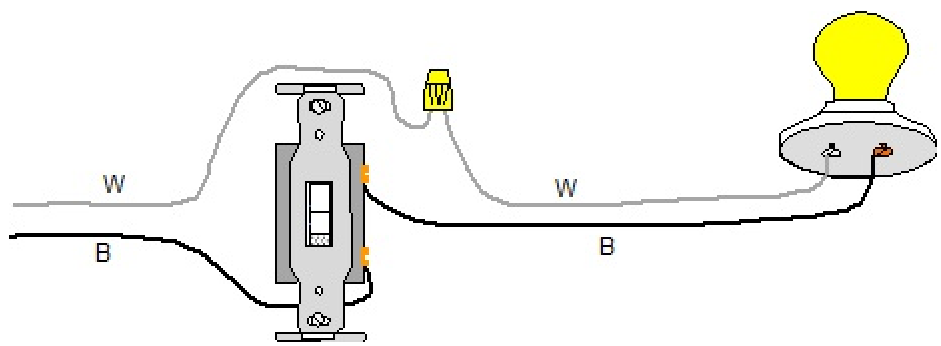

Figure 330.13 *Notice that the neutral wire is spliced at the switch so it will connect directly the lighting fixture uninterrupted. Only the ungrounded hot wire is connected to the switch.*

How 3-Way Switches Work: A 3-way switch is used when lights are to be controlled from two or more locations. This permits the light to be turned on or off from either location. It is possible to control lights from as many locations as desired with the use of two 3-way switches and 4-way switches. The 4-way switch will be explained later. A typical 3-way switch is shown in Figure 330.14. Note that there are three terminal screws on the 3-way switch. Two of the terminals are called traveler terminals and the other is called a common terminal.

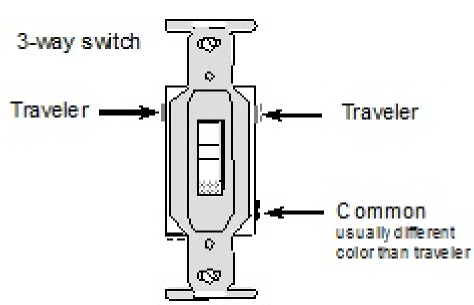

Figure 330.14 *A 3-way switch is used to control lights from more than one location and it has two traveler terminals and a common terminal. The common usually has a different appearance than the traveler terminals.*

The internal connection of the terminals of the 3-way switch is shown in Figure 330.15. The common terminal is either connected to one traveler terminal or to the other. Usually the common terminal is identified by making the head of the screw a slightly different color. This is actually known as a single-pole, double-pole switch. The common is either connected to one traveler terminal or to the other. Notice that OFF and ON are not marked on a 3-way switch as is the case with a single-pole switch.

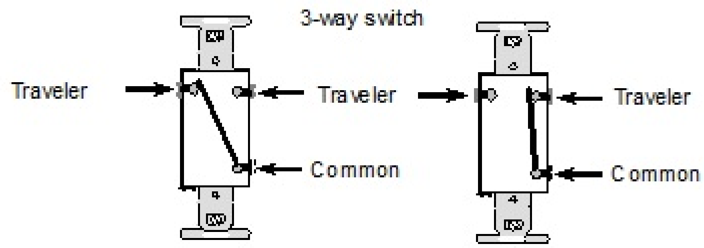

Figure 330.15 *The common terminal of a 3-way switch is either connected to one traveler terminal or to the other. The traveler terminals will have a different appearance than the common terminal.*

When connecting the wires to the 3-way switches it is important to connect to the correct terminals. If connected incorrectly, the lights will not work correctly. When wiring 3-way switches, the traveler terminals of one switch are connected directly to the traveler terminals of the other switch. This is shown in Figure 330.16. You must be sure to properly identify the traveler and common terminals on a 3-way switch before doing the wiring. The terminals may be located differently by some manufacturers. Older 3-way switches often have the common terminal in a different location than those manufactured in recent years.

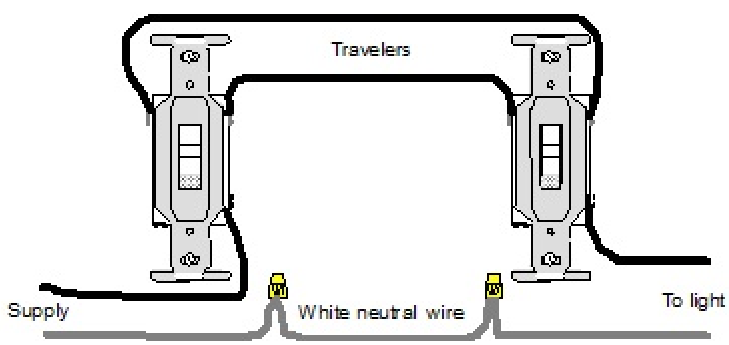

Figure 330.16 *The traveler terminals on one 3-way switch are connected directly to the traveler terminals of the other 3-way switch when lights are controlled from two locations.*

Wiring Circuits: Wiring a circuit can be confusing. It looks easy when observing an experienced electrician wiring a circuit. The trick is a clear understanding of how each device in the circuit works, and visualizing the circuit in your mind. Most experienced electricians see a mental image of the circuit in their minds as they wire the circuit. Here are some simple rules to follow which will help reduce the complexity of the circuit. In order to wire an electrical circuit it is essential that a person understand the purpose of each wire of the circuit. A 120 volt circuit that supplies power to lighting or receptacles in a dwelling will have an ungrounded wire connected to a fuse in the service panel or to a circuit breaker. When the circuit is wired using nonmetallic sheathed cable that wire will have black colored insulation. A diagram of a circuit breaker type electrical service panel is shown in Figure 330.17. The circuit will also have a neutral wire that connects to one of the terminals of the neutral terminal bus in the service panel. In a nonmetallic sheathed cable the neutral wire will have white insulation. Every circuit is required to have a safety equipment grounding wire. The circuit will work without that wire, but it is necessary to help prevent electrical shocks and to prevent a fire in the case damage occurs to the circuit. The equipment grounding wire either with green insulation or bare connects to the same neutral terminal bus as the neutral wire. The electrical code requires the neutral terminal bus to be grounded to the earth.

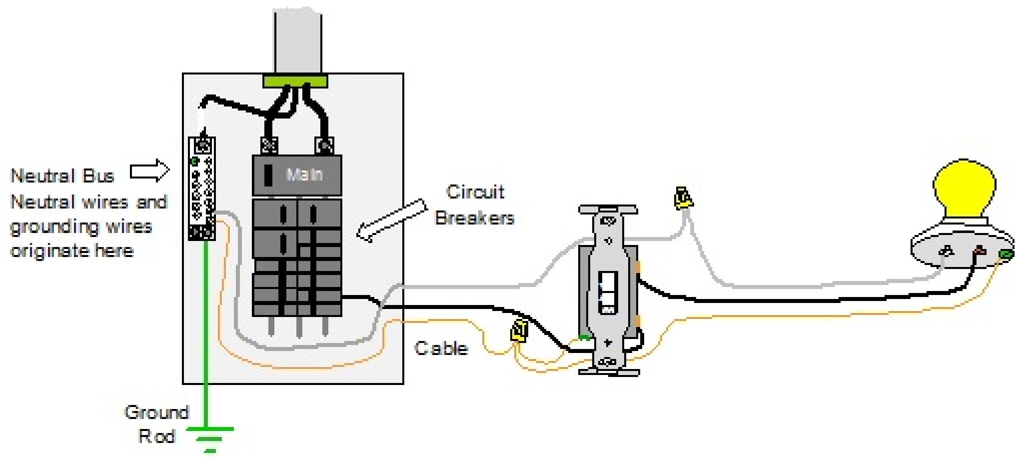

Figure 330.17*. A 120 volt lighting circuit originates from a dwelling electrical service panel with the black wire of a cable connected to a single-pole circuit breaker, the white neutral wire connected to the neutral terminal bus, and the bare equipment grounding wire also connected to the neutral terminal bus.*

Procedures for Wiring a Lighting Circuit with Two Switches: It is recommended at first to wire circuits systematically one step at a time. This may not be as fast at first, but in time you will be able to visualize the circuit and work much faster. Here are several steps to follow when wiring a circuit using nonmetallic-sheathed cable. This circuit first supplies a receptacle that is live all of the time then a set of 3-way switches that supply a light. In this case the light is just a porcelain receptacle that does not require grounding. Most lighting fixtures will have a green grounding wire or a green grounding screw.

First connect all of the equipment grounds as shown in Figure 330.18 and push the wires down into the boxes out of the way. All metal boxes must be grounded. Receptacles must be grounded. There are some self grounding receptacles which pick up the ground through one of the mounting screws. If you are not sure if the receptacle is self grounding, run a short pigtail to the green grounding screw on the receptacle. Many switches have a grounding screw. If there is a grounding screw, then the switch must also be grounded. Metal light fixtures, motors and other equipment will either have a green equipment grounding screw or lug, or they will have a green grounding wire present.

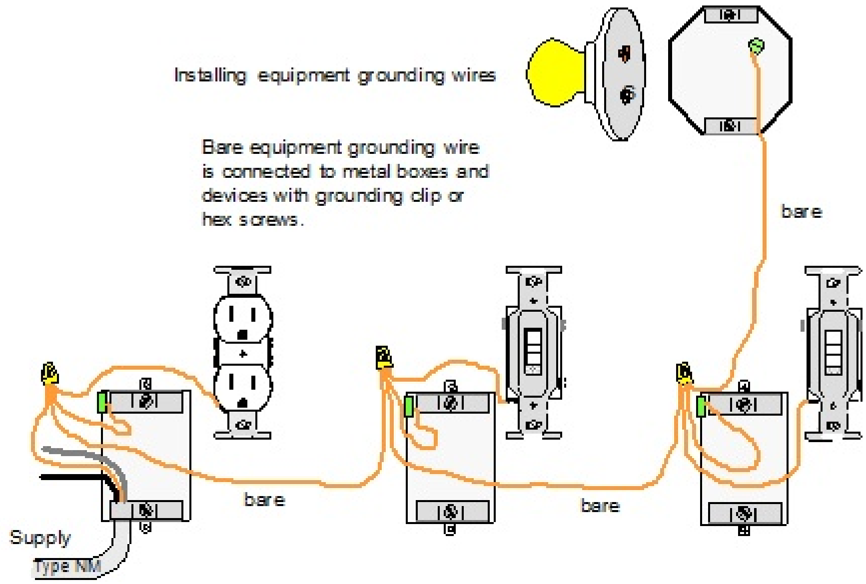

Figure 330.18 *First connect the equipment grounding wires at all boxes of the circuit and then push them down into the boxes out of the way.*

Second, run the neutral wires to all locations where power is used as shown in Figure 330.19 such as receptacle and lights. Never connect a neutral wire to a switch. All neutral wires are required to be white or gray. Keep in mind that sometimes when type NM cable is being used, a white wire must become used as an ungrounded wire and in those cases the ends of the white wire are required to be marked with tape such as black tape to indicate it is no longer a neutral wire.

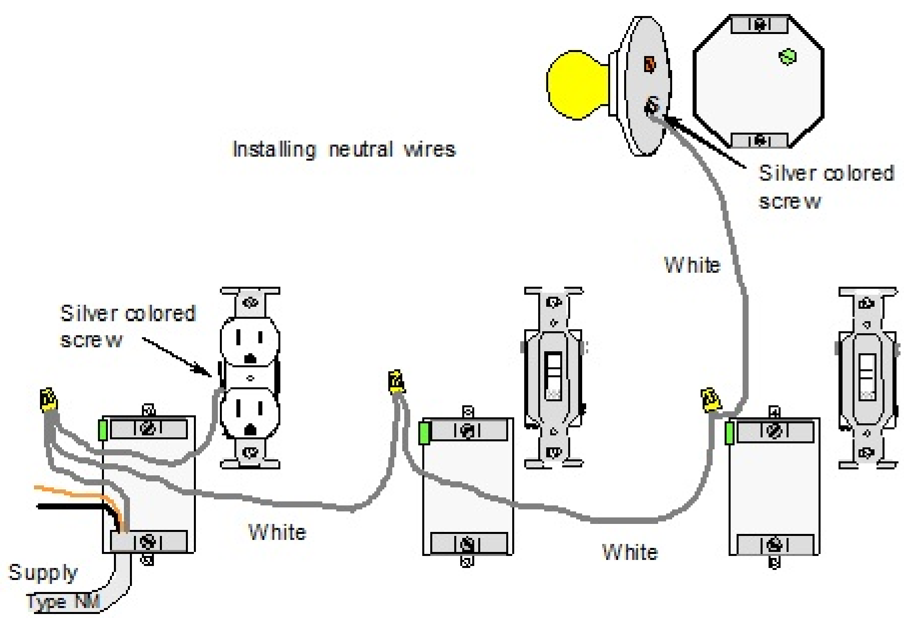

Figure 330.19 *Second, run neutral wires to places where power is used such as the receptacle and lights. The neutral wire never connects to a switch.*

The third recommended step is to run traveler wires from the traveler terminals on one 3-way switch to the traveler terminals on the other 3-way switch as shown in Figure 330.20. In most cases a 3-wire cable will be required between the boxes with the 3-way switches. The insulation colors for a 3-wire nonmetallic sheathed cable are white, black, and red. For this circuit the white wire is the neutral, thus leaving the black and red wires to be the traveler wires. Connect those wires to the traveler terminals of each switch. It does not matter which traveler wire connects to which traveler terminals. Just hook them up to either traveler terminal.

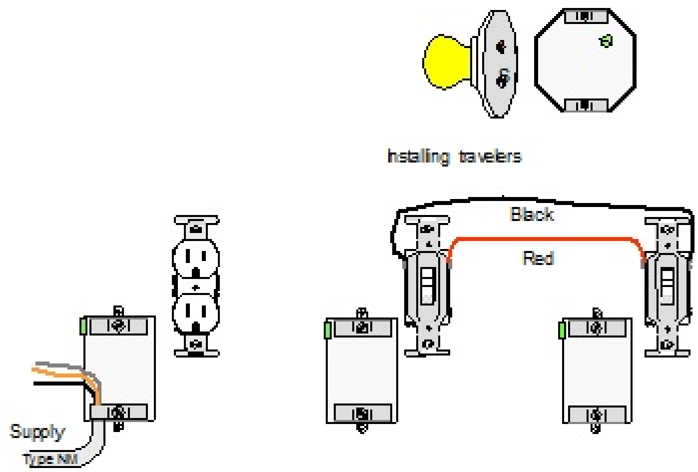

Figure 330.20 *Third, run the traveler wires between the traveler terminals of 3-way switches. In this case the traveler wires are black and red since the white wire is the neutral to the light.*

At this point the equipment grounding wires of the circuit have been connected, and the neutral wire has been run to the receptacle and the light. The traveler terminals have also been connected between the two 3-way switches. All that remains to complete this circuit is to run a live ungrounded wire (black) to the receptacle and to the first 3-way switch common terminal. And run a switched ungrounded wire (black) from the last 3-way switch common to the light. The 3-way switches control the hot wire that supplies the light. Once the travelers are connected, the switches have one input and one output. The input for this circuit is the common terminal of the first 3-way switch. The output wire is the common terminal of the last 3-way switch. The circuit is completed by connecting the wires as shown in Figure 330.21.

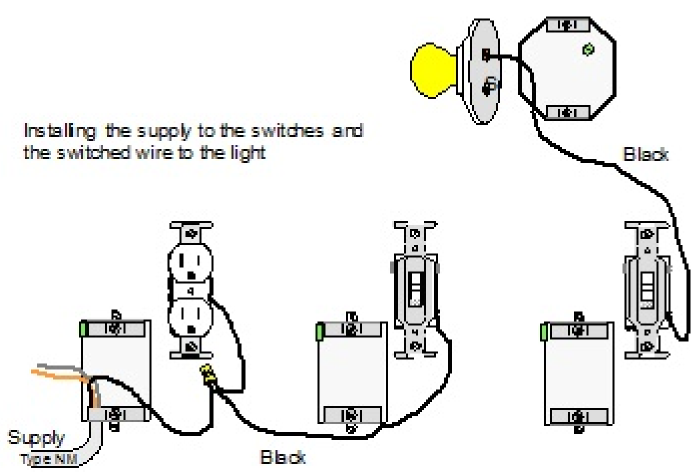

Figure 330.21 *Fourth, run hot wires to all locations where live power is needed which is the receptacle and the first 3-way switch and a switched wire from the last 3-way switch to the light.*

The wires in this circuit are shown as individual wires between the boxes. That was done to make it clear which wire goes to which device terminal. In an actual circuit nonmetallic-sheathed cable is run from one box to the other and only the ends of the wires are visible. When the walls of a building are open and there is no plasterboard in place it is easy to trace the circuit. But when the walls are covered, it is difficult to remember how the wires are run. It is a good idea to make a simple diagram to keep track of how a circuit is wired. For this circuit a 2-wire cable enters the receptacle box from the service panel. There is a 2-wire cable run from the receptacle box to the first 3-way switch box. A 3-wire cable is run between the 3-way switch boxes. Finally a 2-wire cable runs from the last 3-way switch box to the lighting box in the ceiling. The completed circuit is shown in Figure 330.22 except the equipment grounding wires are not shown. They are connected as shown in Figure 330.18.

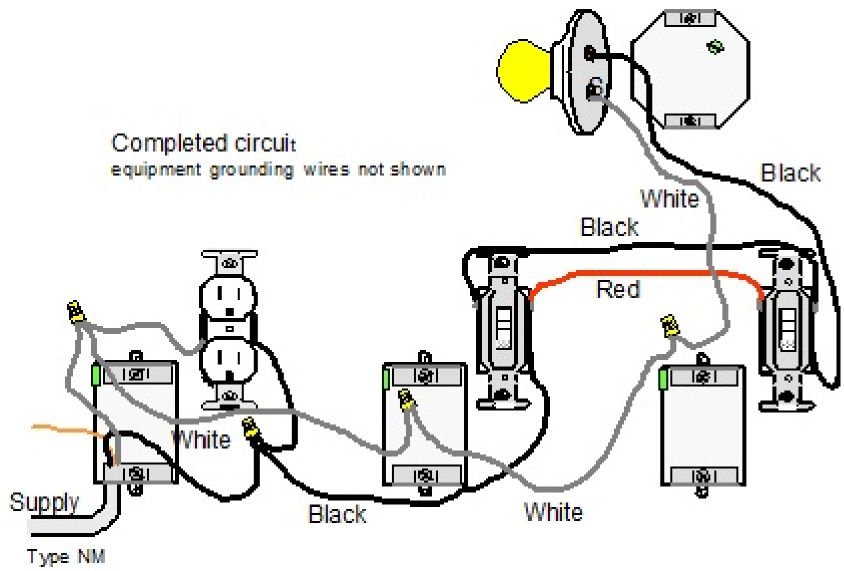

Figure 330.22 *Completed circuit where two wall mounted 3-way switches control a ceiling light.*

Controlling Lighting from Three Locations: Controlling lighting in a room of a dwelling from three for more locations requires the use of two 3-way switches plus a 4-way switch for each of the additional locations. A 4-way switch has four terminal screws and it's purpose is to switch the combination of traveler wires. How this is accomplished is shown in Figure 330.23. There are two sets of traveler terminals. Each set of traveler terminals will have a slightly different color. The traveler wires from one of the 3-way switches connect to one set of 4-way switch traveler terminals, and the other set of traveler terminals continue on to the other 3-way switch. Figure 330.23 shows two 4-way switches each with a different internal connection.

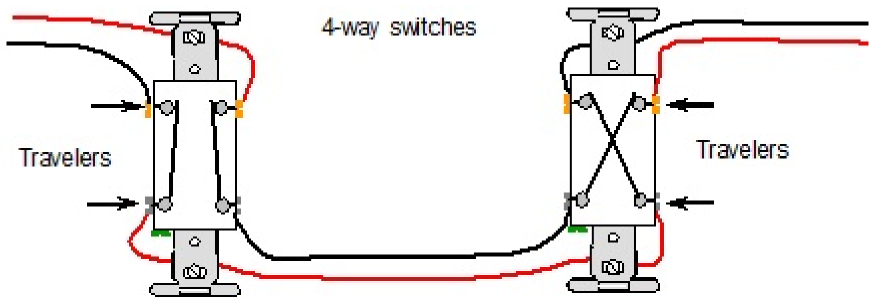

Figure 330.23. *Each of these 4-way switches shows a different internal connection. The travelers of each 4-way switch would connect to the traveler terminals of a 3-way switch not shown in this illustration.*

All of the screw terminals of a 4-way switch are traveler terminals. In recent years manufacturers identify each two terminal set of screws with a slightly different color. If the light is to be controlled from a third location, install a 4-way switch between the two 3-way switches. In this case, run traveler wires from the traveler terminals of one 3-way switch to one set of traveler terminals of the 4-way switch. Then run the traveler wires from the other set of traveler terminals of the 4-way switch to the traveler terminals of the other 3-way switch. Be careful not to mix up the traveler terminals on the 4-way switch. One set of travel terminals connects to one 3-way switch, and the other set of traveler terminals connect to the other 3-way switch. You can install as many 4-way switches as you desire between the two 3-way switches. An example of how a 4-way switch is installed is shown in Figure 330.24.

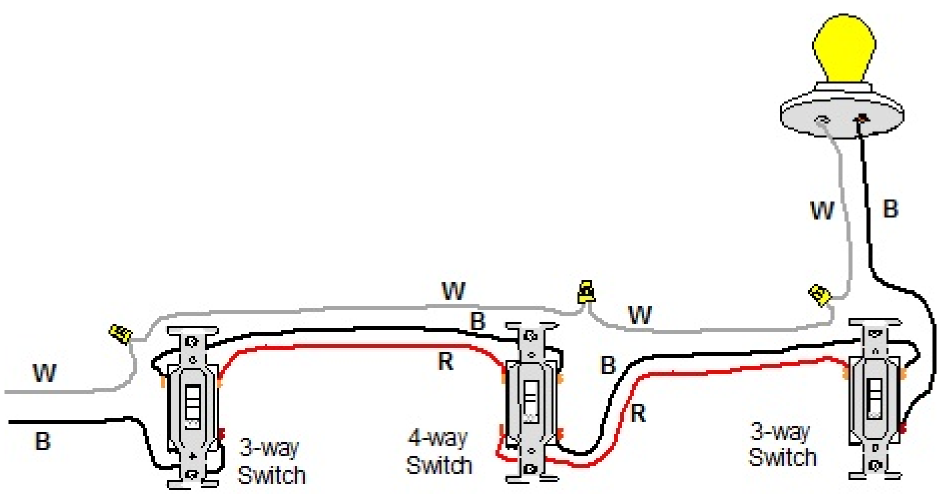

Figure 330.24 *To control a light from three locations requires a 4-way switch to be installed in the circuit between the two 3-way switches.*