

# **Tech-Design**

## Residential Wiring

Module Guide



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## INTRODUCTION

### Welcome to Residential Electrical Wiring!

Welcome to the new Tech-Design Residential Workshop Series. This series includes Residential Electrical Wiring, Residential Plumbing, and 3D Design and Construction Modeling. These modules offer hands-on experiences in residential design and demonstrate the techniques used to install the most common plumbing and electrical fixtures.

The skills that you will gain from these lessons are invaluable. Homeowners spend large sums of money to hire craftspeople to do the same jobs you'll learn in these lessons. Regardless of whether or not you pursue one of these fields professionally, you will benefit enormously from the skills you acquire in these hands-on experiences. You may someday have the ability to build an addition on your house or do all of your own electrical wiring. The possibilities are endless.

There are plenty of job opportunities relating to the areas covered in the Residential Workshop Series. For example, renovation is becoming an increasingly larger percentage of construction in the United States. Imagine the enormous satisfaction a carpenter gets after restoring the original details of a stylish Victorian home.

Electricians have a thorough understanding of electricity. They are very familiar with electrical equipment as well as the safety requirements for performing specific tasks. Electricians can receive some of the highest wages and best benefits of all the construction-related trades.

Whether you enroll in a union apprenticeship program or learn by doing, being a carpenter, plumber, or licensed electrician can be a very rewarding occupation. You may even decide to go into business for yourself. If you work hard and have patience and determination, your business can become very successful and lucrative.

## Introduction to Residential Electrical Wiring

It is difficult to imagine a world without lights, computers, stereos, or microwave ovens. A few hundred years ago, these items had not yet been invented. Even if they had, there wouldn't have been any place to plug them in!

When electricity was originally used for practical purposes, it was used for communication in the form of the electric telegraph and the telephone. Petroleum and paraffin lamps were still lighting homes until the late 1800s, when Thomas Edison developed the light bulb. Edison was also responsible for the first central power station and many power companies still bear his name.

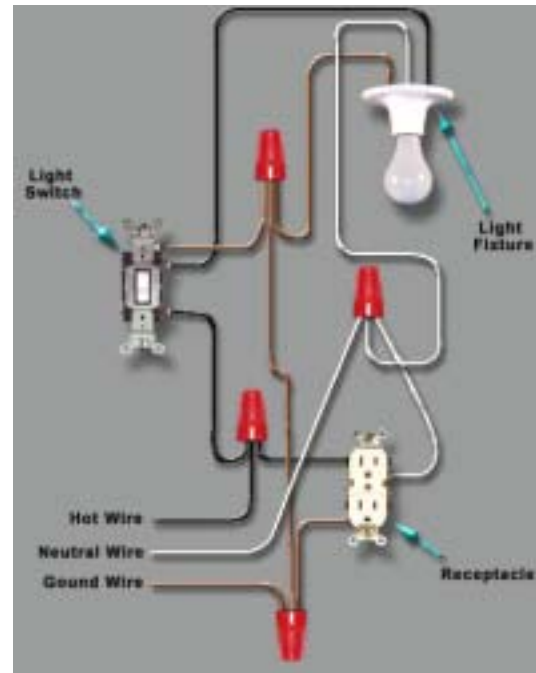
If you compared today's power requirements to what was needed 100 years ago, you would be shocked. Today, power plants located all over the country generate electricity with huge turbine generators that are driven mostly by fossil fuels, nuclear energy, or hydropower. There are many factors that contribute to our growing demand for electricity; but for now, let's get back to the subject of residential electrical wiring.



## Understanding Residential Electricity

Electrical systems can seem like a confusing mess of wires, connections, and hidden boxes. If you use common sense and take the necessary precautions, you can easily and safely handle most home wiring projects. Working with electrical wiring can be intimidating because of the potential for serious injury. As you learn more about electricity and wiring, you will become more confident. Let's begin by going over the fundamentals of electricity.

AC (Alternating Current) changes constantly from zero to 120 volts and then back down to zero to minus 120 volts. This cycle repeats itself 60 times every second. In terms of your electric service, this is referred to as 120VAC 60Hz.



The flow of electricity through a wire is comparable to the flow of water through a pipe. However, in order for electrical current to flow, a return path must be provided. Just as un-pressurized water is drained away from a house, current must flow back through a *neutral* wire, which carries no voltage.

Just as pipe with a large diameter can carry a greater volume of water than a narrow pipe, a large wire can carry more current than a small wire. The amount of current flowing in a circuit is called *amperage*. Most household circuits have a capacity of either 15 or 20 amps.

*Wattage* is a measurement of how much electrical power a device consumes. It is the rate at which current is converted into other forms of energy, such as light, heat, or motion.

Electricity travels at a rate that is close to the speed of light. No one has ever seen a volt or an amp, but when these forces interact, you can see their effect in a lit bulb.

**Volts – Amps – Watts**

The following equations may be used to determine the relationship between volts, amps, and watts.

Volts x amperes = watts

For example, if a device operates on 120V and draws 3 amps of current, the following equation is used to determine how much power is consumed.

$120V \times 3\text{amps} = 360W$

If you would like to determine the amount of power needed for a device to operate, you simply rearrange the equation.

Watts  $\div$  volts = amps

For example, if a 120V microwave oven uses 850 watts of power, use the following equation.

$850W \div 120V = 7.08 \text{ amps}$

The terms amp and volt are named after the two scientists who discovered them. Andre Marie Ampere was a French physicist who determined how to measure the amount of current in a circuit. Alessandro Volta was an Italian physicist who devised the first electric battery.

## The Basic Home Electrical System

The electric power we use is generated by power plants. Power is sent to a **power grid**<sup>1</sup>, starting with a substation where step-up transformers increase the power to extremely high voltages, which range from 300KV to 500KV (500,000 volts or more). High-voltage transmission lines are used to send the power to cities and towns that may be hundreds of miles away. At these power levels, transmission is quite easy.



Before the power can be used, it is stepped down to the distribution grid. There, power is prepared for distribution to substations where step-down transformers reduce the voltage to about 7,200 volts. Power is then sent along the street power lines to residential and commercial customers.

Transformers like the one you see here should be a familiar sight in your neighborhood. Their job is to reduce the 7,200 volts down to 240 volts, which is needed for normal household electrical service. There are three wires that run to every house. The bare wire is a ground and the two insulated wires each carry 120 volts. This arrangement allows a homeowner to use both 120-volt and 240-volt appliances.



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<sup>1</sup> *power grid* – a power grid consists of a network of transmission and distribution centers.



The service head is used to anchor the three service wires to the home. From there, the wires are directed down to the electric meter.



The wires from the service head are connected to an electric meter, which is usually mounted to the side of the house. It is used to register the consumption of electricity in kilowatt-hours. A kilowatt-hour equals 1,000 watts of electricity used per hour.

The meter is owned by your local power company and is protected by law. Tampering with the meter is prohibited and punishable by law.



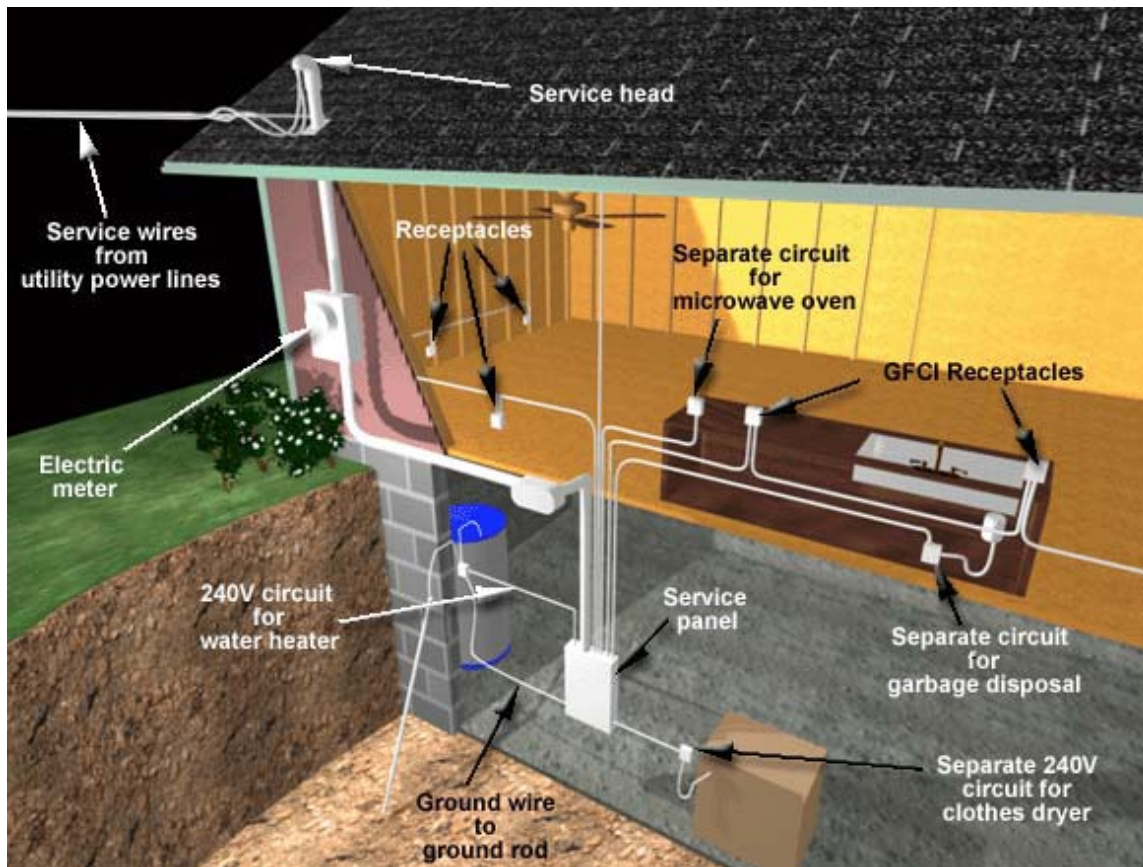
The service panel, also known as a fuse box or breaker box, is where power is distributed to individual circuits throughout the house. A circuit breaker or fuse is used to protect each circuit by opening it in the event of a short circuit or an overload. Each breaker or fuse should be identified so you can tell which circuit it protects. This makes it easier to shut off an individual circuit while repairs or modifications take place.

## Circuit Basics

Current flows along a path called a circuit. Each circuit that runs through the house originates at the service panel. The current flows through the circuit in a continuous loop and then returns to the service panel on a neutral wire. There can be any number of receptacles, switches, lights or other devices attached to each circuit. If an appliance requires large amounts of electricity, a separate circuit is run exclusively for that appliance.

As previously mentioned, each circuit is protected. If there is an overload or short, a circuit breaker or fuse in the service panel will cut off the power to that circuit.

The wires are identified by color. There are three wires in a 120V circuit, which includes a black or red for hot, white or gray for neutral, and bare copper or green insulated for ground. The ground wire is extremely important because it conducts current in the event there is a short or an overload. It also helps reduce the chances of a severe electrical shock.



*Residential Electrical System*

## The Service Panel

A service panel, or main breaker panel, is found in every home. It is usually located in the basement or garage and is easily identified by its metal casing. This is the heart of the electrical system and its purpose is to distribute power to each circuit in the home.

There are three main service leads that enter the service panel from outside the home. Two of the wires connect to two hot **bus bar**<sup>2</sup> lugs. Each bus bar carries 120 volts. For appliances such as an electric range or a large air conditioner, two bus bars are combined to get 240 volts. The wires above the main circuit breaker are always hot, even when the main circuit breaker is shut off.

A third wire is connected to a lug on the neutral bus bar. Neutral service lines are connected to the neutral leads of the branch circuits. Neutral leads carry current back to the power source (service panel) to complete the circuit. All branch circuit ground and neutral wires are connected to the neutral bus bar.

Before any type of work can be done, you must go to the service panel and shut off the power to the circuit on which you'll be working.

## Circuit Breakers and Fuses

Circuit breakers and fuses are designed to protect the electrical system from being damaged in case there is a short or overload. Most homes have circuit breakers. The circuit breaker is like a switch that “trips”, turning itself off if the amount of current is more than what the breaker can handle. A circuit breaker will trip when there are too many appliances and/or fixtures on the same circuit. Single-pole circuit breakers protect 120V circuits. Double-pole breakers protect 240V circuits.



Single-pole and double-pole circuit breakers

Inside of a circuit breaker, there is a metal strip that heats up and bends when current passes through it. If there is a short or overload, the metal strip bends and trips the circuit breaker. If this continues to happen even though the cause has been diagnosed and corrected, the breaker will have to be replaced. Each circuit breaker has an amperage rating, which indicates the maximum load it can handle. Circuit breakers are offered in a wide variation of amperage ratings.

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<sup>2</sup> *bus bar* – an uninsulated metallic conductor that provides a common contact area for supplying power to the circuit breakers.

GFCI (Ground Fault Circuit Interrupter) breakers offer protection against short circuits caused by water or moisture. The *National Electrical Code*<sup>1</sup> (see *National Electrical Code* below) requires them for outdoor wiring such as pools, spas, and hot tubs. Ground fault circuit breakers are also recommended for workshops and areas where power tools are in use.

The main advantage to using breakers is that when an overload or short occurs, a breaker can be reset but a fuse must be replaced. Fuses have a narrow zinc strip that melts when overloaded.

**NOTE:** This manual does not provide enough information for you to work on a service panel. **NEVER** touch any part of a service panel without proper training or supervision.

## Grounding

Although the neutral wire provides a path for current to return to the power source, a ground wire acts as a safety feature in case current tries to flow back using a path other than the neutral wire. This condition is known as a *short circuit*<sup>3</sup>, which can be very dangerous. If something metal becomes short-circuited and you touch it, current will flow through your body instead of the neutral wire in an attempt complete the circuit. This is because current always finds the easiest path to travel.

If you were to come into contact with some form of ground, whether it's a puddle of water or the kitchen sink, and then come in contact with a hot wire, you'll get zapped. If you touch a hot wire and you are grounded in any way, current will flow through the circuit. You may think that touching a ground wire cannot electrocute you, but this is not true. If you touch a ground wire and an appliance on that circuit is plugged in and turned on, you may be electrocuted. You will provide the earth ground that the ground wire is searching for. This is just another reminder that **you must find the right breaker, shut it off, and test the circuit before you begin working**. Remember that electrical work is quite safe if you are cautious and use good judgment.

Your local electrical codes require all wiring systems to be connected directly to the earth. This is accomplished by running a grounding wire from the neutral bus bar in a service panel to a grounding rod.

A ground wire should also be connected to a metal cold water pipe. If there is a short circuit or overload, electricity will travel along the ground wire and go into the earth where it's rendered harmless.

You may be familiar with polarized plugs and receptacles. A two-slot polarized plug and



<sup>3</sup> *short circuit* – an overcurrent condition due to a connection between both sides of a circuit or across a voltage source

receptacle is designed to insure that current flow travels along the black or red wires and the neutral current flows along the white or gray wires.



In new homes, code requirements call for three-slot receptacles. An additional ground wire is attached to all the receptacles and metal boxes, providing an additional path for current to travel in the event of a short. When a three-prong plug is plugged into a three-slot receptacle, appliances have added protection from shorts.

## NEC (National Electrical Code)

The NEC was devised and is currently published by the National Fire Protection Association. It is designed to protect people and property from electrical hazards and it covers the installation of electrical wiring and equipment in residential and commercial properties. Where any state or local government adopts the NEC, it becomes the law. The NEC is adopted and enforced in each of the 50 states. In Canada, the Canadian Electrical Code sets the guidelines for electrical wiring, but there are only minor differences between the two.

Local electrical codes conform to the national guidelines. Local codes govern the size and type of electrical equipment as well as the methods used for installation. Before you begin a project, you should check with the local building authority to see if a permit is necessary.

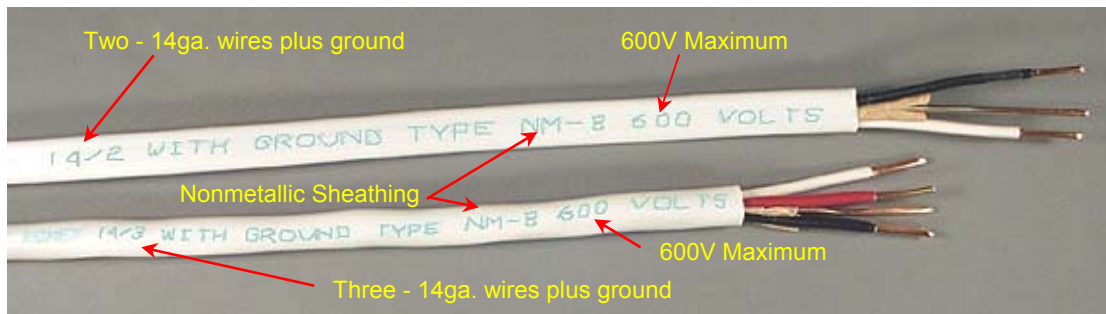
The *Uniform Plumbing Code* and the *Uniform Building Code* are also important in new home construction. All codes are enforced to protect you from injury and property loss.



## About Cables and Wires

When two or more wires are enclosed inside a plastic sheathing, it is called a cable. The most commonly used cable today is NM (nonmetallic), which is most frequently referred to by the brand name, Romex. Type NM-B is used for most indoor wiring applications.

NM cable is marked to indicate how many wires it has as well as the gauge (diameter). Wire sizes conform to the AWG (American Wire Gauge) system. As the gauge number lowers, the diameter and the current carrying capacity increase. For example, a 12-gauge wire is capable of handling 120 volts, 20 amps while a 14-gauge wire is capable of handling 120-volts, 15 amps. A 240-volt electric range or central air conditioner that draws 40 – 60 amps would require 8- or 6-gauge wire. If a wire is too small for the job, it can get dangerously hot and possibly cause a fire. Before you begin a job, determine the electrical requirements of the circuit and choose the wire accordingly.



A two-wire and three-wire cable is shown in the photo above. A cable marked 14-2 has two insulated 14-gauge wires plus a ground wire. A cable marked 14-3 has three insulated 14-gauge wires plus a ground wire. A strip of paper is included to protect the individual wires.

When a cable is stripped, you'll find different colored wires inside. Each color indicates the function of that wire.



The *hot* wire is covered with black or red insulation and carries current from the power source.



The *neutral* wire is covered with either white or gray insulation and returns current to the power source at zero voltage.



The *ground* wire is usually bare copper or green insulated and is used to carry current to the earth in case of a short circuit.

Wire Gauge, Capacity, and Use Chart		
6 - Gauge	240V, 60A	Electric Heat, Central Air Conditioner
8 - Gauge	240V, 40A	Electric Stove, Central Air Conditioner, Electric Hot Water Heater
10 - Gauge	240V, 30A	Clothes Dryer, Large Window Air Conditioner
12 - Gauge	120V, 20A	Light Fixtures, Receptacles, Microwave Oven, Window Air Conditioner, Refrigerator
14 - Gauge	120V, 15A	Light Fixtures, Receptacles, Small Appliances
16 - Gauge	Light-Duty Extension Cords	
18 - Gauge	Door Bells, Thermostats, Security Systems	

## Safety

As with any project, safety should always be your primary concern. Always use common sense and exercise caution whenever you work with electrical wiring. **Always remember to shut off the circuit breaker and test the circuit for power before you begin working.** Never turn the power back on until the job is completed.

Other safety precautions include:

- All switches, receptacles, metal boxes, and light fixtures should be connected to a ground. This allows any errant current to return to the service panel and then safely into the ground by way of the grounding rod.
- Never touch any metal fixtures, faucets or pipes while working with electricity. Electricity will find a path to ground, even if it has to go through you to get there.
- Use the correct wire. Wire too small for the job can get hot and melt, which could cause a fire.
- When working on electrical projects, wear sneakers rubber-soled shoes. Always make sure that you're standing on a dry surface.
- If you are unsure about what is correct and safe, consult the advice of a qualified electrician.



## RESIDENTIAL ELECTRICAL WIRING TRAINER



The Residential Electrical Wiring trainer is used to provide an introduction to electrical wiring techniques. The knowledge and skills you'll gain from these activities will enable you to identify and demonstrate proper wiring of common electrical fixtures as well as the skills to wire some of the most common electrical circuits. You'll also learn how to work safely with electricity. Safety should always be your primary concern and it will be emphasized in each of the activities.

This manual includes illustrations to help guide you step-by-step through each procedure. Using the trainer, you will be able to demonstrate the operation of a service panel and how it is used to distribute power and protect branch circuits. In this manual, you will perform the following activities:

- Wire a subpanel
- Wire a 30amp 120/240V receptacle
- Wire a switch-controlled light fixture
- Wire a switch-controlled receptacle

- Wire two receptacles in sequence
- Wire a switch-controlled split receptacle
- Wire three-way switches and light fixture
- Wire a doorbell
- Install a coaxial cable jack
- Install a phone jack

Since the Residential Electrical Wiring Trainer operates at 24VAC, there are few dangers associated with its use, however, you should always exercise the same precautions that you would follow if you were working with standard household electricity (120/240VAC). You will learn more about these precautions as you perform the activities.

For your protection, the Residential Wiring Trainer comes equipped with a transformer. This is prewired to the panel and steps down the voltage from 120VAC to 24VAC. The switch on the transformer box should be turned off whenever the trainer is not in use.

There are three front panels; each is attached to the trainer with posts and clips. Across the top of the trainer, you will see three notches. Each notch allows you to get a firm grip on that panel for easy removal. Place your fingers behind the panel wherever there is a notch and pull towards you. The panel will unsnap from the posts and come off.

Replacing a panel is also easy. Line up the upper and lower clips with the matching posts. Then, hit the panel gently on the top and bottom with the palm of your hand. If there are wires protruding, make sure that they don't cause any obstructions.

Each opening is labeled, indicating the type of fixture that will be installed. As you go through the lessons, another type of fixture may be installed in its place. It will be common for a box labeled "Switch" to house something different, such as a receptacle.

**WARNING: The lessons in this Module Guide are designed as an overview of several aspects of residential wiring. The purpose of these lessons is to improve your understanding of residential electrical wiring. Completion of these lesson activities does not qualify you to do this type of work in your home. Remember that wiring can be extremely dangerous if you are not careful and don't follow the rules. Never attempt any type of residential wiring project without supervision by a licensed electrician.**

## Lesson 1 – Wiring a Subpanel

### **Material List**

Roll of 14-2 cable

15A single-pole circuit breaker

Yellow wire nuts

### **Tools You'll Need**

Cable ripper

Slotted screwdriver

Wire stripper

Lineman's pliers

Diagonal cutters

Needle nose pliers

Pencil

Multimeter

When you have completed this lesson, you will be able to:

- test a subpanel for voltage.
- wire a subpanel for a new circuit.
- install a single-pole breaker.
- determine the differences between a main service panel and a subpanel.

You may view a video of this activity by going to Lesson 1 on your computer. Click on the graphic for the video titled "Wiring a Subpanel." This video can be paused or repeated as often as necessary to complete this lesson.

The Residential Wiring Trainer comes with a maximum 100-amp 120/240V **subpanel**<sup>4</sup> rather than a standard main service panel. The method used to connect a circuit breaker is the same on both types of panels. However, branch circuit ground and neutral connections are made slightly differently. Subpanels have separate ground and neutral bus bars whereas on main panels, ground and neutral wires are both connected to a neutral bus bar. The neutral in a subpanel is kept physically and electrically isolated from the metal panel; the ground is attached to the metal frame. Also, there is no main breaker in a subpanel because it is connected to a feeder breaker in the main panel.

Because of the low voltage being sent from the transformer, the subpanel is connected with cable consisting of 14-gauge feeder wires. This is the same wire that is normally used on a 15A (amp) circuit.

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<sup>4</sup> *subpanel* – any panel connected downstream to a main panel.

This feeder cable consists of two hot leads. One is red and the other is black. There is also one white neutral wire and one bare copper wire (ground). A 30-amp 240V subpanel requires a 10-3 feeder cable. If you were using a 50-amp 240V subpanel, a 6-3 cable or individual 6-gauge **THHN**<sup>5</sup> stranded cables would be necessary. The National Electrical Code requires you to run all stranded cable through **conduit**<sup>6</sup>.

The service panel divides and distributes power to the branch circuits in the home. A circuit breaker is installed after the hot, neutral, and ground wires are connected. The main circuit breaker must be shut off and tested for power before any work is started.

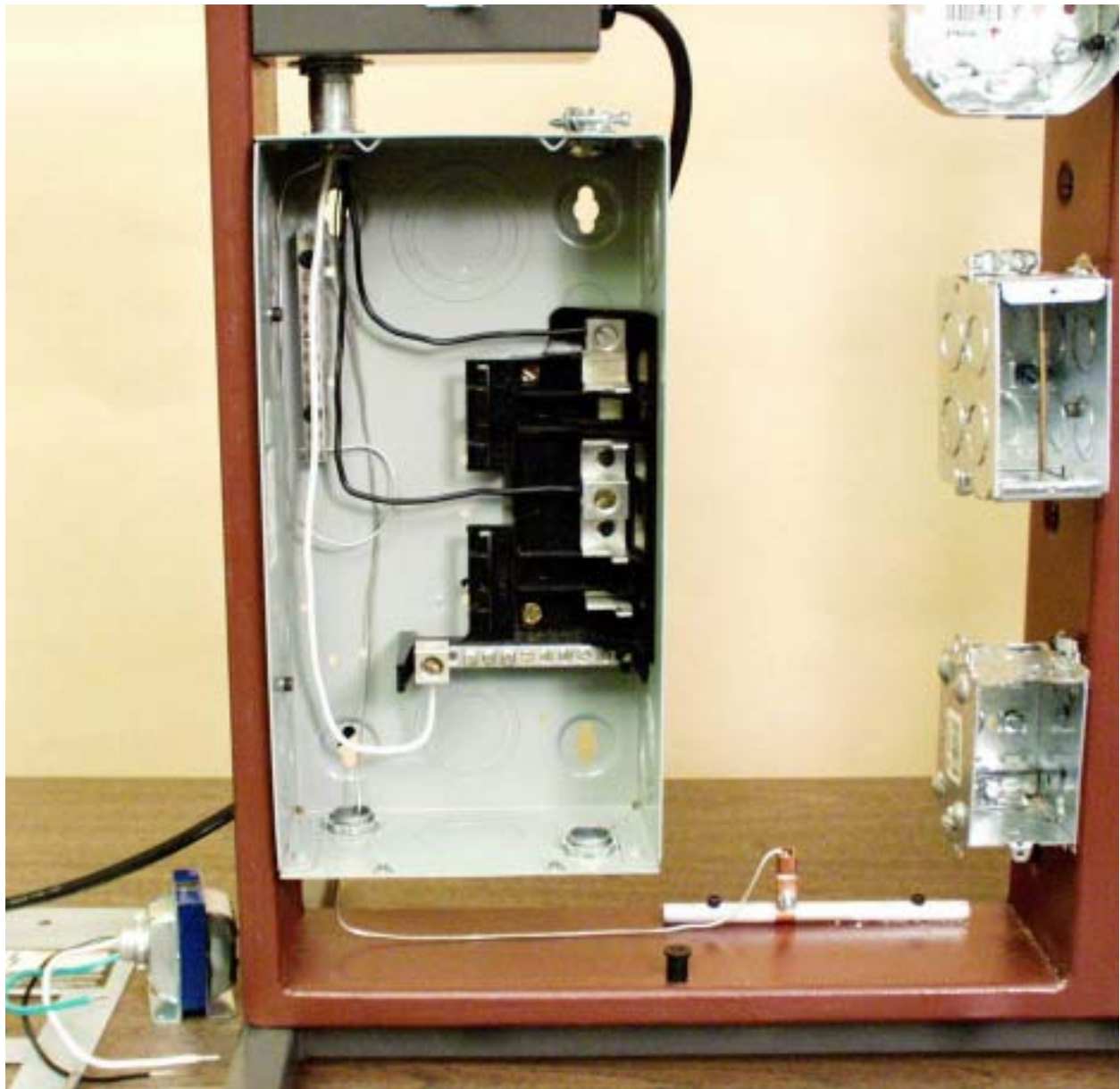
Before you begin to work on any panel, it is important that you don't touch any of the parts until you've verified that the power has been turned off at the main service panel. In this case, the switch on the transformer should be in the OFF position. If the left and middle panels on the trainer have not been removed, then remove them now.

Using the slotted screwdriver, remove the four (4) panel cover screws and then place them where they will not get lost.

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<sup>5</sup> *THHN* – Stranded wire similar to wire in NM cable; but each color (red, black, white, and green) wire is purchased separately.

<sup>6</sup> *conduit* – a metal or plastic pipe or tube used to protect electric wires or cables.



Look at the top of the panel. You should find two preinstalled cable clamps. If they aren't already installed, then ask your instructor for assistance.

In this lesson activity, you will run 14-2 cable from a junction box to the panel. Although this will not be a complete circuit, the wires in the junction box will be used for circuits you'll be wiring in future activities.

Before you begin, you should set up the multimeter.

1. Take the black lead and plug it into the jack marked COM. Take the red lead and plug it into the jack marked VΩmA. Now set the multimeter at 200VAC
2. If the trainer is not plugged into a wall outlet, then you should plug it in now. Turn the switch to the ON position.
3. Place one multimeter lead on the upper hot bus bar and the other lead on the neutral bus bar. Look at the meter display to determine how much voltage is being carried by one of the hot bus bars. This is the amount of voltage that will be supplied to a circuit when a single-pole breaker is installed.
4. Place one lead on the upper hot bus bar and place the other lead on the bus bar below it. Notice that each of the hot feeder wires is connected to a separate bus bar lug. Once again, look at the meter display to determine how much voltage is being carried by the combination of both hot bus bars. This is the amount of voltage that will be supplied to a circuit when a double-pole breaker is installed. Turn off the multimeter.



**Warning:** Never attempt to do this test in a service panel energized with high voltage. Never attempt to do any work inside a service panel unless the main breaker is shut off. Any voltage tests should be done at the other end of the circuit after the wiring has been completed.



You will now begin to wire the service panel using the same precautions that you would use if this were a panel in the home. The switch on the transformer box will represent the main breaker and should therefore be turned off.



5. Measure 3 ft. (91.44 cm) of 14-2 cable and mark it with a pencil. Use the lineman's pliers to cut the cable from the roll.
6. Strip 6-inches (15.24 cm) of the cable on one end. If necessary, refer to "How to Strip Nonmetallic (NM) Cable" in Reference B of this manual. Cut the excess sheathing off with the diagonal cutters.
7. Using the wire stripper, strip approximately  $\frac{3}{4}$  inch (1.91 cm) of insulation from the ends of the black and white wires. Use the opening on the stripper that is marked with the same gauge wire that you are using. In this case, use the opening marked "14."
8. On top of the junction box, there are two knockouts. The knockout on the left side should already be removed. If it hasn't, remove it now by placing the slotted screwdriver in the slot of the knockout, bending the knockout up, and then rocking it from side to side until it falls off.
9. Loosen the center screw for the cable clamp, and then run the wires behind the clamp and down into the junction box. Tighten the clamp against the unstripped portion of the cable, not the wires.



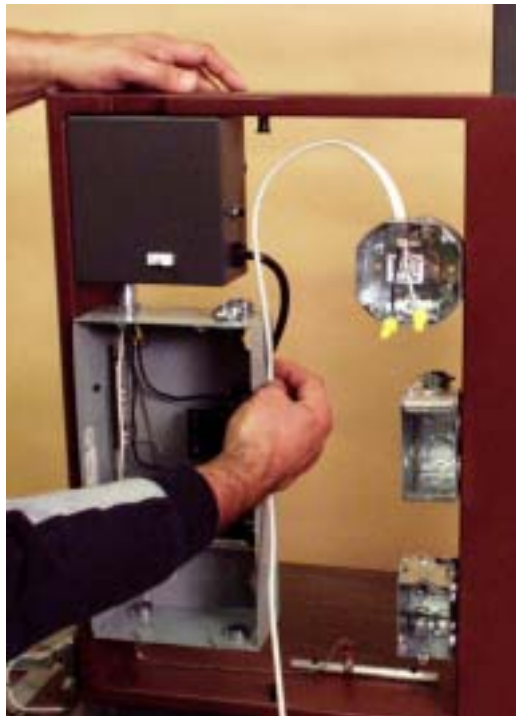
When you wire a circuit, the first wire to connect is always the ground wire.

10. Peel back and remove the paper wrapping from the ground wire. Loosen the ground screw on the back of the box. Wrap the ground wire around the ground screw and if necessary, use the needle-nose pliers to close the loop around the screw. Always wrap a wire in a clockwise direction around a screw, so the wire is pulled tighter as the screw is tightened. Tighten the screw until you are sure the wire can't come off. You never want a wire to become loose. Do not cut the remaining tail of the ground wire. Tighten a wire nut onto the ends of the hot and neutral wires.



**NOTE:** Normally, you would connect a fixture to these wires *before* running wire to wire the panel. However, they will be used for wiring circuits in future activities.

11. Take the cable and form a loop over the rear cable clamp located on the top of the panel. Hold the cable alongside the clamp and mark the cable with a pencil.



12. Strip the cable starting from the pencil mark and continuing all the way down to the end of the cable. Cut off the excess plastic sheathing with the diagonal cutters.
13. Run the wires down through the cable clamp until the unstripped cable portion is through the clamp. Tighten the clamp screws.



14. Connect the ground wire to the ground bus bar. Run the ground wire neatly along the side of the panel and then loop it up and around to the ground bus bar. If the ground wire is too long, then cut it to size with the diagonal cutters. Loosen the first available setscrew above the lower ground bus bar mounting bolt. Push the wire into the opening until it is all the way through and starting to protrude through the other side. Then, tighten the setscrew.



When wiring a panel, you should follow the same loops and bends as the preinstalled feed wires. A panel should never look like a bird's nest. Wires should be run in an orderly fashion so that, in the future, they can be easily traced or removed.

15. Connect the white neutral wire to the neutral bus bar. Run the neutral wire neatly along the left portion of the panel, alongside the preinstalled neutral feed wire. Loop it up to the neutral bus bar. If the neutral wire is too long, then shorten it with the diagonal cutters.
16. Using the wire stripper, strip off approximately  $\frac{1}{2}$  inch (1.27 cm) of the insulation. Use the opening on the stripper that is marked "14."
17. Loosen the first available setscrew to the right of the neutral bus bar lug. Push the wire into the opening until it stops. Then, tighten the setscrew.



18. Pick up the circuit breaker and examine the configuration of the contacts to determine how it makes contact with the bus bar. Also, look at the switch to determine the amperage rating. The amperage rating of a circuit breaker is always indicated on the switch. In this case, you are installing a 15 amp single-pole breaker. Before you install the breaker, make sure it is in the OFF position. Then, place one end onto the bottom guide hook and push the other end into the bottom bus bar. The breaker should be installed in the lowest possible position.



19. Run the black hot wire neatly along the left portion of the panel. Bend the wire and run it to the breaker setscrew terminal. If the hot wire is too long, then shorten it with the diagonal cutters.
20. Strip approximately  $\frac{1}{2}$  inch (1.27 cm) of insulation from the end of the wire.
21. Loosen the setscrew with a slotted screwdriver, and then insert the wire. There should be no bare wire visible when the wire is fully inserted. If there is, then remove the wire and cut off the excess with the diagonal cutters.
22. Insert the wire and tighten the setscrew.



You have completed wiring the panel and installing a 15A breaker.

Turn off the trainer, clean your area, and put your tools back in their proper place.

Go to the next section in the presentation, **Exercise**. When you have completed the exercise, read the **Review** and then complete the **Lesson Quiz**. When you have completed the quiz, you may move on to Lesson 2.

## Lesson 2 – Wire a 30-Amp 120/240V Receptacle

### **Material List**

Roll of 10-3 NM cable  
30 Amp 120/240V receptacle  
double-pole breaker

### **Tools You'll Need**

Cable ripper  
Slotted screwdriver  
Wire stripper  
Diagonal cutters  
Needle nose pliers  
Pencil  
Multimeter

When you have completed this lesson, you will be able to:

- install a 3-pole receptacle.
- determine how a 3-pole receptacle can provide dual voltages.
- wire a subpanel for a dedicated circuit.
- install a double-pole breaker.
- use a multimeter to test a circuit.

You may view a video of this activity by going to Lesson 2 on your computer. Click on the graphic for the video titled “Wire a 30 Amp 120/240V Receptacle.” This video can be paused or repeated as often as necessary to complete this lesson.

In this lesson activity, you will run a dedicated 240V, 30A circuit from a 3-pole receptacle to the subpanel. A double-pole circuit breaker will be installed in the panel.

This type of receptacle is commonly used for appliances such as air conditioners and clothes dryers. The method you will use to wire this receptacle permits each hot wire to carry 120V. Therefore, 240 volts are supplied to the appliance. If the appliance requires 120V to operate a light or a timer, it will split the voltage to create both 120V and 240V circuits.

Each bus bar in your subpanel carries 12VAC. When a double-pole breaker is installed, power is transferred from both bus bars to the red and black hot wires. These wires carry a total of approximately 24 volts.

In a real-life scenario, each bus bar would carry 120 volts between the two terminals; the double-pole breaker would be carrying a total of 240 volts.

1. Measure 3 feet (91.44 cm) of 10-3 cable and mark it with a pencil. Cut the wire at the mark using the diagonal cutter. This is heavy gauge wire and it will require cutting in two or three steps. Try working your way around while cutting into each wire as you go.
2. Strip 6 inches (15.24 cm) of the cable on one end. The cable stripper is actually designed for flat cable, therefore, you will need to make a few passes until the cable casing is finally cut. Cut off the excess plastic sheathing with the diagonal cutters.
3. Run the wire down into the top rear opening of the box, using the same technique you used in the previous lesson. Remember that the clamp should be tightened against the uncut portion of the cable and not the wires.
4. Use the wire strippers to remove approximately  $\frac{3}{4}$  inch (1.91 cm) of insulation from the red (hot), black (hot), and white (neutral) wires. You should use the opening on the stripper marked "10."
5. Using the needle nose pliers, form an open loop at the end of the ground wire and attach it to the ground screw inside the box. Close the loop with the pliers and then tighten the ground screw.



This receptacle is designed to connect to two hot wires, each carrying 120 volts. The center terminal connects to a white neutral wire.

6. Loosen the three terminal setscrews on the back of the receptacle.
7. With the setscrews loose, connect the white neutral wire to the center terminal. If any bare wire is showing, remove the wire and trim the excess with the diagonal cutters. Make sure the screw is contacting the bare wire and not the insulation. Tighten the setscrew firmly.

- Whenever you connect wire to a terminal, it is important that the screw is tight and that there is no chance of the wire becoming loose. Otherwise, it is possible for the wire to come off and create a short circuit.

- Connect the red and black wires to each of the outer terminals.

- Run the cable over to the access point located on the top of the panel. There should be no sharp bends in the cable. The knockout should be removed and a cable clamp should already be installed. Once you have determined how much cable is needed, mark it with a pencil.



- Strip the cable starting from the mark and going all the way to the end. Then, cut off the excess plastic sheathing with the diagonal cutters.

- Run the wires down through the clamp until the unstripped portion of the cable is inside the clamp. The clamp should be tightened against the cable and not the exposed wires.

- As in the previous lesson, starting with the ground wire, connect the ground and neutral wires to the appropriate bus bars. Remember that like wires should be grouped together and should run in a neat and orderly fashion.

- Install the double-pole breaker at the uppermost position on the panel. Notice the two slotted contacts on the breaker. These contacts should be positioned so that the breaker can be pushed onto the two separate bus bar contacts. Be sure that the breaker is switched to the OFF position.





**NOTE:** In a real-life scenario, this double-pole breaker should be rated 30A. The breaker you installed is rated 15A.

15. Run the black and red wires neatly along the left portion of the panel. Bend the wires and run them to the breaker setscrew terminals. If the wires are too long, shorten them with the diagonal cutters.
16. Strip approximately  $\frac{1}{2}$  inch (1.27 cm) of insulation from the end of each wire.



17. Loosen the setscrews with a slotted screwdriver and then insert the wires. It does not matter if the red or black wire is connected to the upper or lower terminal. Remember that there should be no bare wire visible when the wires are fully inserted. If there is, remove the wires and cut off the excess with the diagonal cutters.

18. If necessary, reinsert the wires and then tighten each of the setscrews.
19. Turn the switch at the transformer to the ON position.
20. Turn the circuit breaker to the ON Position.
21. Turn on the multimeter and set it at 200VAC (or 750 VAC, depending on your multimeter).



22. Place one lead on the center neutral contact on the back of the receptacle. Place the other lead on one of the hot terminals. The hot terminals are where the black and red wires are connected. What is the voltage reading?
23. With one lead remaining on the center neutral terminal, place the other lead on the opposite hot terminal. What voltage reading are you getting now? Is it the same?
24. Now, place a lead on each of the hot terminals. What is the voltage reading?



You've just determined that the voltages between the neutral and hot leads on each side of the receptacle are equal. The voltage across the two hot leads is double. As mentioned earlier in this lesson, the appliance that is plugged into this receptacle has the option to split the current to draw single or combined voltages.

25. Turn the circuit breaker to the OFF position.
26. Fold the wires and neatly tuck them into the box. Then, attach the receptacle to the box.

Turn off the trainer, clean your area, and put your tools back in their proper place.

Go to the next section in the presentation, **Exercise**. When you complete the exercise, read the **Review** and then complete the **Lesson Quiz**. When you have completed the quiz, you may move on to Lesson 3.



## Lesson 3 – Wire a Switch-Controlled Light Fixture

### **Material List**

Roll of 14-2 NM cable

Light fixture

25-watt 12V bulb

Single-pole switch

Yellow wire nuts

Green wire nuts

### **Tools You'll Need**

Cable ripper

Slotted screwdriver

Wire stripper

Diagonal cutters

Lineman's pliers

Needle nose pliers

Pencil

Voltage tester

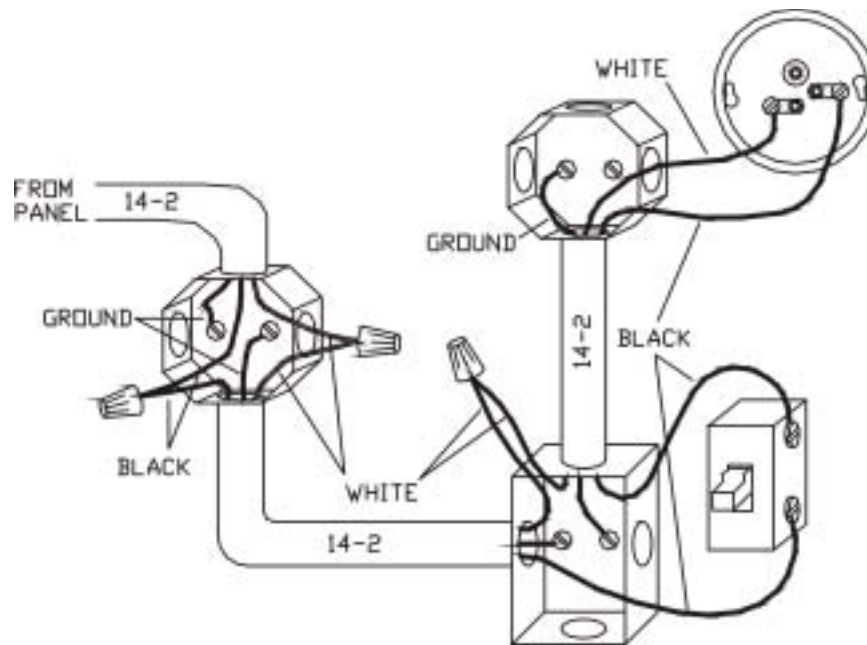
When you have completed this lesson, you will be able to:

- install a 2-pole switch.
- install a light fixture.
- wire a connection in a junction box.

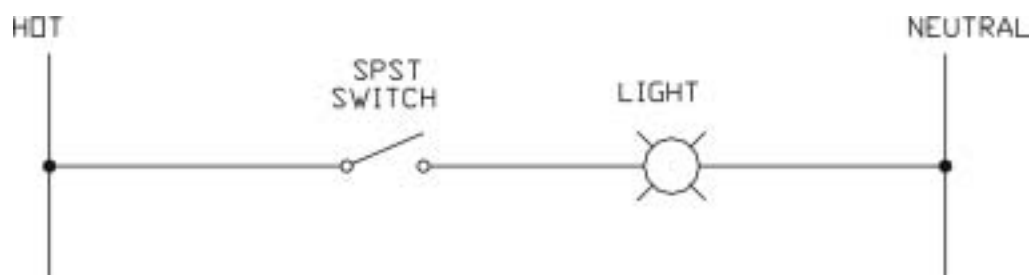
You may view a video of this activity by going to Lesson 3 on your computer. Click on the graphic for the video titled "Wire a Switch-Controlled Light Fixture." This video can be paused or repeated as often as necessary to complete this lesson.

The diagrams shown below represent the same circuit in two different formats. The pictorial diagram uses pictures or sketches to show each component in the circuit. It also shows the wiring between the components and how the components are connected.

Schematic diagrams use graphic symbols to represent the components and functions of a circuit. Schematic diagrams are ideal for tracing circuits for troubleshooting; however, the sizes and shapes of components are not represented as they are in a pictorial diagram.



*Pictorial Wiring Diagram*



*Schematic Wiring Diagram*

In this lesson, you will wire a simple circuit consisting of a single-pole switch and a light fixture. Power will be derived from the junction box leads that you installed in Lesson 1.

Junction boxes are used for housing connections to one or more electric circuits through the use of non-permanent splices. The non-permanent splices you will make consist of wires twisted together and covered with wire nuts. The National Electrical Code states that a junction box must be located where it can be accessed at any time.

1. Before you begin, make sure the transformer switch is in the OFF position.
2. Make sure the breaker for this circuit is in the OFF position.
3. Attach the voltage tester leads to the hot and neutral wires to verify that there is no voltage present. You may also use the multimeter.



Refer to the right cover panel to determine which box is designated to house a switch and a light fixture. All cover panels should be removed before you begin wiring.

4. Measure and cut 42 inches (106.68 cm) of 14-2 cable.
5. Strip 6 inches (15.24 cm) of casing from one end of the cable. Cut off the excess plastic sheathing with the diagonal cutters.

6. Route the unstripped end of cable from the switch box to the junction box. The photo below shows you an example of how this is done. You may route the wire any way you'd like, provided that there are no sharp bends in the cable.



7. The bottom left knockout on the switch box should already be removed. If it wasn't, remove it now. If necessary, refer to Lesson 1, step 7.
8. Run the wires into the switch box and then tighten the cable clamp against the cable.



9. Attach the ground wire to one of the ground screws. Let the other wires hang out for now.

10. Measure and cut another 18 inches (45.72 cm) of 14-2 cable.
11. Run the cable from the switch box to the light fixture box. Since you've run enough cables to understand the technique, you may begin now. When you are finished, the ground wires should be attached to the boxes. The additional ground wire in the switch box should be connected to the other ground screw. Make sure there are at least 6 inches (15.24 cm) of the remaining wires left protruding. Strip about  $\frac{3}{4}$  inch of insulation from all of the wires.



12. Connect the ground wires to each of the ground screws located inside the box.
13. Now twist the neutral (white) wires together clockwise and cap them with a yellow wire nut. Tuck them neatly into the back of the box. Make sure no bare wire is exposed outside the wire nut. If there is, remove the wire nut, cut off the excess wire, and replace the wire nut.



In the following step, the neutral wires will not be connected to the switch. Since the hot wires are switched, the neutral wires will be connected together, bypassing the switch entirely.

- Using the needle nose pliers, form an open loop on the end of each of the black (hot) wires and then attach them to the upper and lower switch terminals. Remember that when you connect wires to screw terminals, they should always be bent in a clockwise direction. If the switch is unmarked, try connecting it so that the terminals are located on the right side. Otherwise, make sure the words ON and OFF are right side up.

Look at the back of the light fixture. Notice that there are silver and brass terminal screws. The silver terminal is used for connecting the neutral (white) wire and the brass terminal is used for connecting the hot (black) wire.



- With the insulation stripped from the ends of the hot and neutral wires, bend loops on the ends of the wires and connect them to the back of the light fixture.



- Determine how much of the remaining cable is needed. Remember, it should be routed into the junction box and have at least 6 inches (15.24 cm) of wire remaining inside the box to complete the circuit. Cut the cable to the proper length, strip the end of the cable, and run the wires into the box. Then, tighten the cable clamp against the cable.



17. Connect the ground wire to the box.
18. Strip about  $\frac{3}{4}$  inch of insulation from the hot and neutral wires. Then, use the lineman's pliers to twist each pair of wires together. Screw a yellow wire nut onto each pair of wires. Tuck these wires inside the box.
19. Screw a 12V light bulb into the lamp socket. These bulbs look identical to a standard 120V light bulb and many of them are not labeled. If this is the case, then you should make sure the bulb is placed back in the original box at the end of the day or labeled in a way that makes it easy to identify.
20. Turn the transformer switch to the ON position.
21. Turn the appropriate circuit breaker to the ON position.
22. Turn the light switch to the ON position. The bulb should light.



If the bulb does not light, go back to the beginning of this lesson activity and retrace your steps. Make sure the transformer switch is on, the correct circuit breaker is on, and the trainer is plugged in.

Turn off the trainer, clean your area, and put your tools back in their proper place.

Go to the next section in the presentation, **Exercise**. When you complete the exercise, read the **Review** and then complete the **Lesson Quiz**. When you have completed the quiz, you may move on to Lesson 4.

## Lesson 4 – Wire a Switch-Controlled Receptacle

### **Material List**

Roll of 14-2 NM cable

Single-pole switch

Receptacle

Yellow wire nuts

Green wire nuts

### **Tools You'll Need**

Cable ripper

Slotted screwdriver

Wire stripper

Diagonal cutters

Lineman's pliers

Needle nose pliers

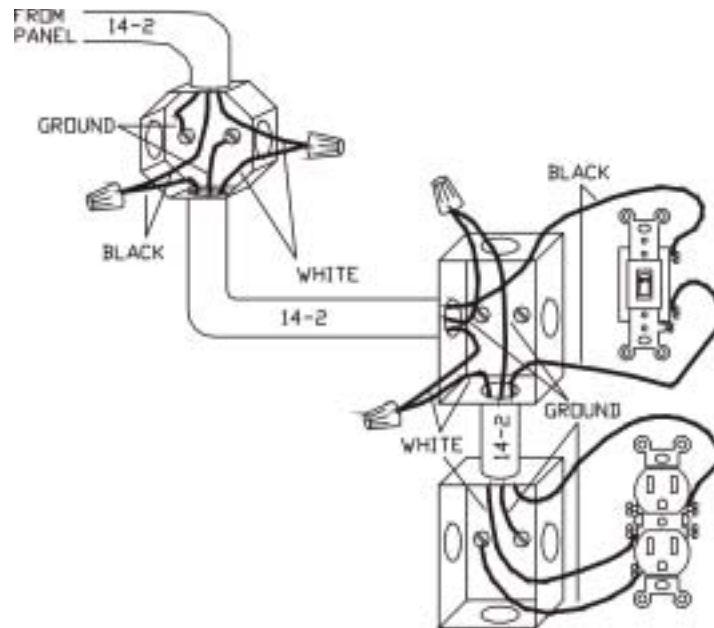
Pencil

Voltage tester

When you have completed this lesson, you will be able to:

- install a 2-pole switch.
- install a receptacle.

You may view a video of this activity by going to Lesson 4 on your computer. Click on the graphic for the video titled "Wire a Switch-Controlled Receptacle." This video can be paused or repeated as often as necessary to complete this lesson.



In this lesson, you will wire a simple circuit consisting of a single-pole switch and a receptacle. The circuit will be connected to the junction box you wired in Lesson 1.

1. Before you begin, make sure that the transformer switch and the appropriate circuit breaker are in the OFF position.
2. Use the voltage tester to make sure there is no voltage in the circuit. Do this by first removing the wire nut from the neutral wires in the switch box. Then, attach one of the tester leads to the neutral wires while touching the other tester lead to the hot wire coming from the power source. If the tester shows that there is no voltage, then you may proceed.

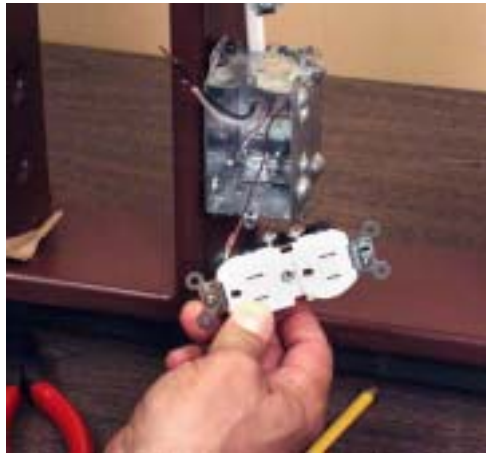


3. Use the lineman's pliers to untwist and separate the neutral wires.
4. Loosen the ground screw and detach the ground wire that comes from the lamp.
5. Trace the hot wires entering the switch box and determine which one is coming from the lamp. Disconnect that hot wire from the switch.
6. With any type of pliers, straighten the ends of the wires. This will make it easier to pull them out of the box.
7. Loosen the cable clamp that anchors the cable going up to the lamp box. Then, pull the wires out of the switch box. The only wires remaining in the box should be the ones coming from the power source.



8. Measure and cut 17 inches (43.18 cm) of 14-2 cable. Then, strip 6 inches (15.24 cm) of casing from each end of the cable. Cut off the excess plastic sheathing.
9. Loosen the upper cable clamp in the receptacle box, which is located below the switch box. If necessary, remove the appropriate knockout so that the new cable can run straight up and into the switch box.
10. Loosen the lower cable clamp in the switch box.

11. Run the new wire into the receptacle box, and then into the switch box. Make sure the cable is running behind the cable clamps in both boxes before tightening them.
12. In the switch and receptacle boxes, connect the ground wire to the ground screw.
13. Twist and cap the neutral wires. Remember that no bare wire should be showing beyond the wire nut.
14. Connect the hot wire to the switch terminal. There should be only one vacant terminal.
15. Attach a 6-inch **pigtail**<sup>7</sup> ground wire to the back of the receptacle box. Do this by taking a separate piece of ground wire and twisting it clockwise around the ground screw. Tighten the screw, and then connect another 6-inch pigtail ground wire to the green screw terminal on the receptacle. Notice that the receptacle is oriented so that the U-shaped holes are located on the bottom.

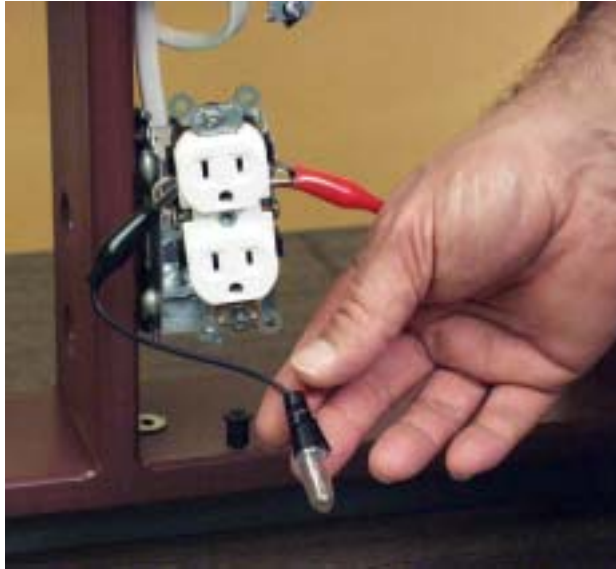


Looking at the receptacle, notice that the terminal screws on the left are silver and the terminal screws on the right are brass. The silver terminals are for neutral wires and the brass terminals are always hot.

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<sup>7</sup> *pigtail* –a piece of wire used to connect other wires to a single terminal.

16. Go ahead and connect the hot and neutral wires to the appropriate terminals on the receptacle. When you are done, it should appear as shown in this photo.



17. Turn the transformer switch to the ON position.
18. Turn the appropriate circuit breaker to the ON position.
19. Turn the switch powering the receptacle to the ON position.
20. Connect the leads on the voltage tester to the hot and neutral terminals on the receptacle. The tester light should turn on. If it didn't, check your work by retracing your steps. Check the transformer switch and circuit breaker, and make sure the trainer is plugged into a receptacle.

Turn off the trainer, clean your area, and put your tools back in their proper place.

Go to the next section in the presentation, **Review**. Read the review then take the **Lesson Quiz**. When you have completed the quiz, you may move on to Lesson 5.

## Lesson 5 – Wire Two Receptacles in Sequence

### **Material List**

Roll of 14-2 NM cable

2 receptacles

Yellow wire nuts

Green wire nuts

### **Tools You'll Need**

Cable ripper

Slotted screwdriver

Wire stripper

Diagonal cutters

Lineman's pliers

Needle-nose pliers

Pencil

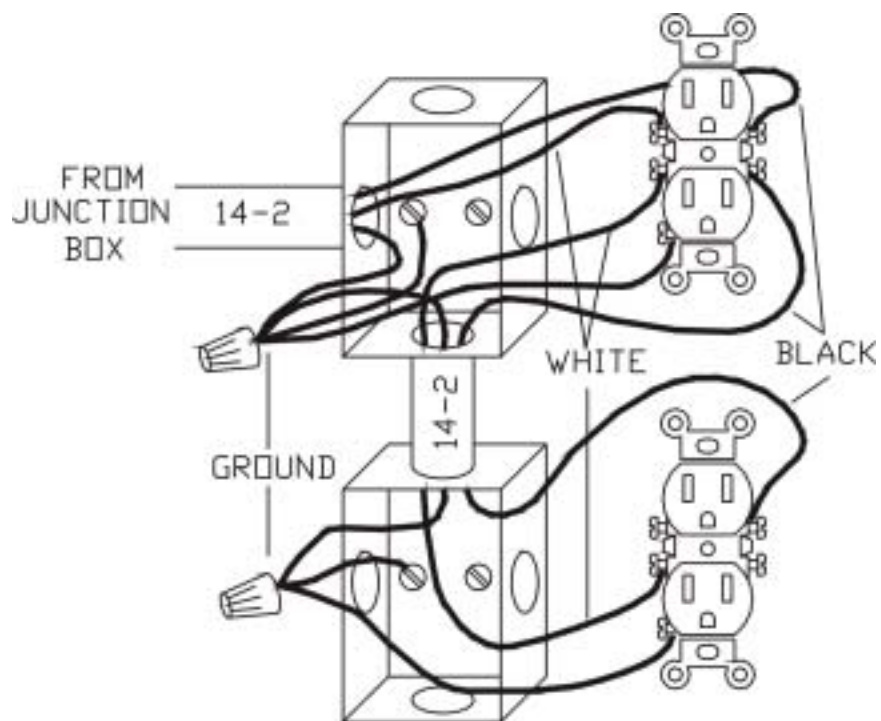
Voltage tester

When you have completed this lesson, you will be able to:

- wire two receptacles in sequence.

You may view a video of this activity by going to Lesson 5 on your computer. Click on the graphic for the video titled "Wire Two Receptacles in Sequence." This video can be paused or repeated as often as necessary to complete this lesson.

The circuit you are about to wire is configured so that the receptacles are continuously energized unless the circuit breaker is turned off. Most receptacles in the home are wired in this way.



1. Before you begin, make sure that the transformer switch is in the OFF position and also that the appropriate circuit breaker is in the OFF position.
2. Use the voltage tester to make sure there is no voltage in the circuit. Since you will be using the same wires from the previous lesson, do this by attaching the voltage tester leads to the hot and neutral terminals of the receptacle.





3. Disconnect the switch and receptacle and remove them from the boxes. Straighten the wires and separate them into two groups.
4. Attach a pigtail ground wire to the back of the switch box. In this lesson, you will temporarily use this box for a receptacle.
5. Attach a pigtail to the ground terminal on one of the receptacles.

This receptacle will be middle-of-the-run wired, meaning that there are two cables entering the box, one of which continues to the next receptacle.

6. You now have three ground wires protruding from the box and one pigtailed ground connected to the receptacle ground terminal. Using the lineman's pliers, twist the four ground wires together until they are tight. Then, screw on a green wire nut.
7. You are now left with four wires; two hot and two neutral. Attach the two neutral wires to the silver terminals on the left side of the receptacle. Remember to bend the loops in a clockwise direction.
8. Attach the hot wires to each of the brass screw terminals on the right side of the receptacle. The wiring of this receptacle is now complete.



9. Attach a pigtail to another receptacle's ground terminal. A ground pigtail has already been attached to the back of the box, leaving you with a total of three ground wires. Group the three ground wires and twist them together clockwise with the lineman's pliers. Then, screw on a green wire nut.



10. Connect the hot and neutral wires to the receptacle following the same procedure as you did in steps 7 and 8.



11. Turn the transformer switch to the ON position.
12. Turn the appropriate circuit breaker to the ON position.
13. Connect the leads on the voltage tester to the hot and neutral terminals on each of the receptacles. The tester light should turn on for each receptacle. If it didn't, check your work by retracing your steps. Check the transformer switch and circuit breaker, and make sure the trainer is plugged into a receptacle. You can also refer to the wiring diagram to check your wiring.

Turn off the trainer, clean your area, and put your tools back in their proper place.

Go to the next section in the presentation, **Review**. Read the review then take the **Lesson Quiz**. When you have completed the quiz, you may move on to Lesson 6.

## Lesson 6 – Wire a Switch-Controlled Split Receptacle

### **Material List**

Roll of 14-2 NM cable  
Roll of 14-3 NM cable  
Receptacle  
Single-pole switch  
Yellow wire nuts  
Green wire nuts

### **Tools You'll Need**

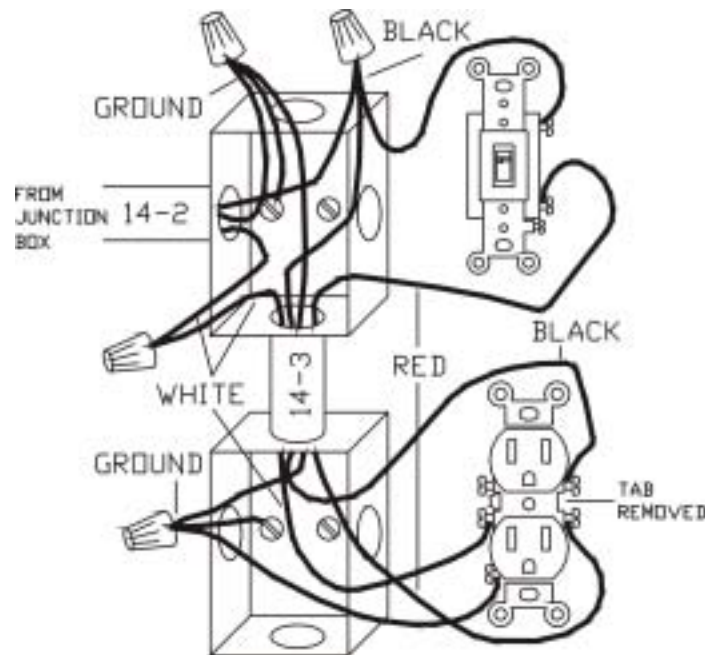
Cable ripper  
Slotted screwdriver  
Wire stripper  
Diagonal cutters  
Lineman's pliers  
Needle-nose pliers  
Pencil  
Voltage tester

When you have completed this lesson, you will be able to:

- wire a switch-controlled split receptacle.
- wire a switch.

You may view a video of this activity by going to Lesson 6 on your computer. Click on the graphic for the video titled “Wire a Switch-Controlled Split Receptacle.” This video can be paused or repeated as often as necessary to complete this lesson.

The NEC requires you to install a split receptacle in any room that does not have a switch-controlled ceiling light fixture. In the circuit you are about to wire, the top half of the receptacle will always be hot while the bottom half will be switched. If a lamp is plugged into the bottom receptacle, it can be controlled by a wall switch.



1. Before you begin, make sure that the transformer switch and the appropriate circuit breaker are in the OFF position.
2. Use the voltage tester to make sure there is no voltage in the circuit. Since you will be using the same wires coming from the power source (junction box), do this by attaching the voltage tester leads to the hot and neutral terminals on either of the receptacles installed in the last lesson.
3. In the box for the upper receptacle, remove the green wire nut and untwist the four ground wires. Then, separate them so that you can see where each of them goes.
4. Remove the receptacles from both boxes and set them aside.

5. Group together the hot, neutral, and ground wires coming from the power source and move them up and out of the way.



6. Remove the cable running between the switch and receptacle boxes. Begin by loosening the appropriate cable clamps. Then, pull the wires out of both boxes. It may be easier if you cut off the ends of the wires first so they can pull through the clamps more easily. In the bottom box, be careful not to cut the pigtail ground wire attached to the box.



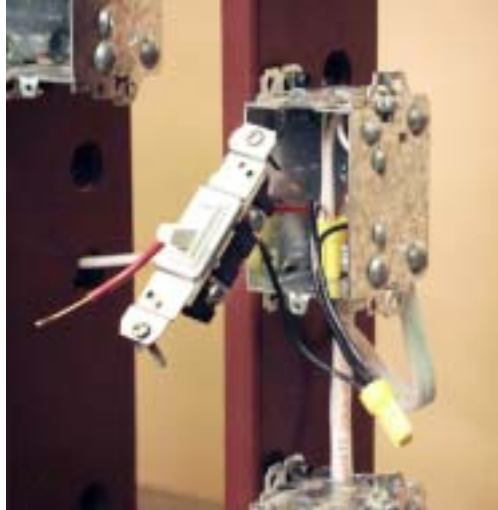
In the next step, a three-wire cable will be installed to run separate and identifiable hot wires to each half of the receptacle. The red wire will energize the lower receptacle while the black wire will be used to energize the upper receptacle.

7. Measure and cut 17 inches (43.18 cm) of 14-3 cable. Then, strip 6 inches (15.24 cm) from each end of the cable. Cut off the excess plastic sheathing.
8. Run the wires into both boxes. Make sure the cable is running behind the cable clamps before they are tightened. You should now have two-wire and three-wire cable running into the switch box. The other end of the three-wire cable should run down into the receptacle box.



9. Strip about  $\frac{3}{4}$  inch of insulation from all the hot and neutral wires.
10. Twist the ground wires together and cap them with a green wire nut. Then, tuck them inside the box.
11. Twist the neutral wires together and cap them with a yellow wire nut. Then, tuck them inside the box.

12. From a scrap piece of cable, cut off a pigtail for the black hot wire. Strip  $\frac{3}{4}$  inch of insulation from both ends. Then, connect it to the lower terminal on the switch. Make sure the terminals are on the right side of the switch.
13. Group the other end of the black hot pigtail, the feed hot wire (coming from the power source), and the black hot wire coming from the receptacle box. Twist the three wires together and cap them with a yellow wire nut.



14. Connect the red hot wire to the upper switch terminal. The switch is now completely wired.
15. Hold the receptacle so that the brass screw terminals are facing you. They should be located on the right side of the receptacle. Notice the brass connecting tab between the screws. If the tab is removed, there will no longer be conductivity between the top and bottom receptacles. The side of the receptacle that the black hot wire is connected to remains hot whether the switch is in the ON or OFF position. This is because the black hot wire is connected directly to the power source. The red hot wire is switched.



- Using the needle-nose pliers, bend the tab back until it breaks off. The terminals should now appear as shown.

**NOTE:** If a receptacle is available with the tab already removed, you may use it to complete the following steps.



- Connect a ground pigtail to the ground terminal on the receptacle.
- In the receptacle box, connect the ground pigtail (attached to the box) to the ground wire connected to the receptacle and the ground coming in from the switch box. Then, twist the three ground wires together and cap them with a green wire nut.
- Connect the neutral wire to one of the silver terminals on the receptacle.
- Connect the black hot wire to the upper brass terminal. Remember that this is the side that will remain hot regardless of the switch position.
- Connect the red hot wire to the lower brass terminal.

Your circuit is now completely wired and ready for testing. In the following steps, you will use the voltage tester to verify that your wiring was done correctly.

- Turn the transformer switch to the ON position.
- Turn the appropriate circuit breaker to the ON position.



24. Turn the switch to the ON position. Then, place the voltage tester leads on the top receptacle neutral and hot terminals. Is the receptacle energized? Turn the switch to the OFF position and try again. What are your results?

The top receptacle is connected to the black hot wire and should remain hot regardless of the switch's position.

25. Once again, turn the switch to the ON position. Then, place the voltage tester leads on the bottom receptacle neutral and hot terminals. Is the receptacle energized? Turn the switch to the OFF position and try again. What are your results?

Since the bottom receptacle is connected to the (red) hot wire, it should respond to the position of the switch. When the switch is in the ON position, the bottom receptacle should be energized. When the switch is in the OFF position, the light on the voltage tester should be off.

If you do not get the results as described above, use the diagram and the steps in this lesson as a reference to retrace your steps.

26. Carefully tuck the switch and receptacle wires into their boxes and screw them to the boxes.

Turn off the trainer, clean your area, and put your tools back in their proper place.

Go to the next section in the presentation, **Exercise**. When you have completed the exercise, read the **Lesson Review** then take the **Lesson Quiz**. When you are finished with the quiz, you may proceed to Lesson 7.



## Lesson 7 – Wire Three-Way Switches and Light Fixture

### **Material List**

Roll of 14-2 NM cable  
Roll of 14-3 NM cable  
2 Three-way switches  
Circuit breaker  
Light fixture  
12V light bulb  
Yellow wire nuts  
Green wire nuts  
Electrical tape

### **Tools You'll Need**

Cable ripper  
Slotted screwdriver  
Wire stripper  
Diagonal cutters  
Lineman's pliers  
Needle-nose pliers  
Pencil  
Voltage tester

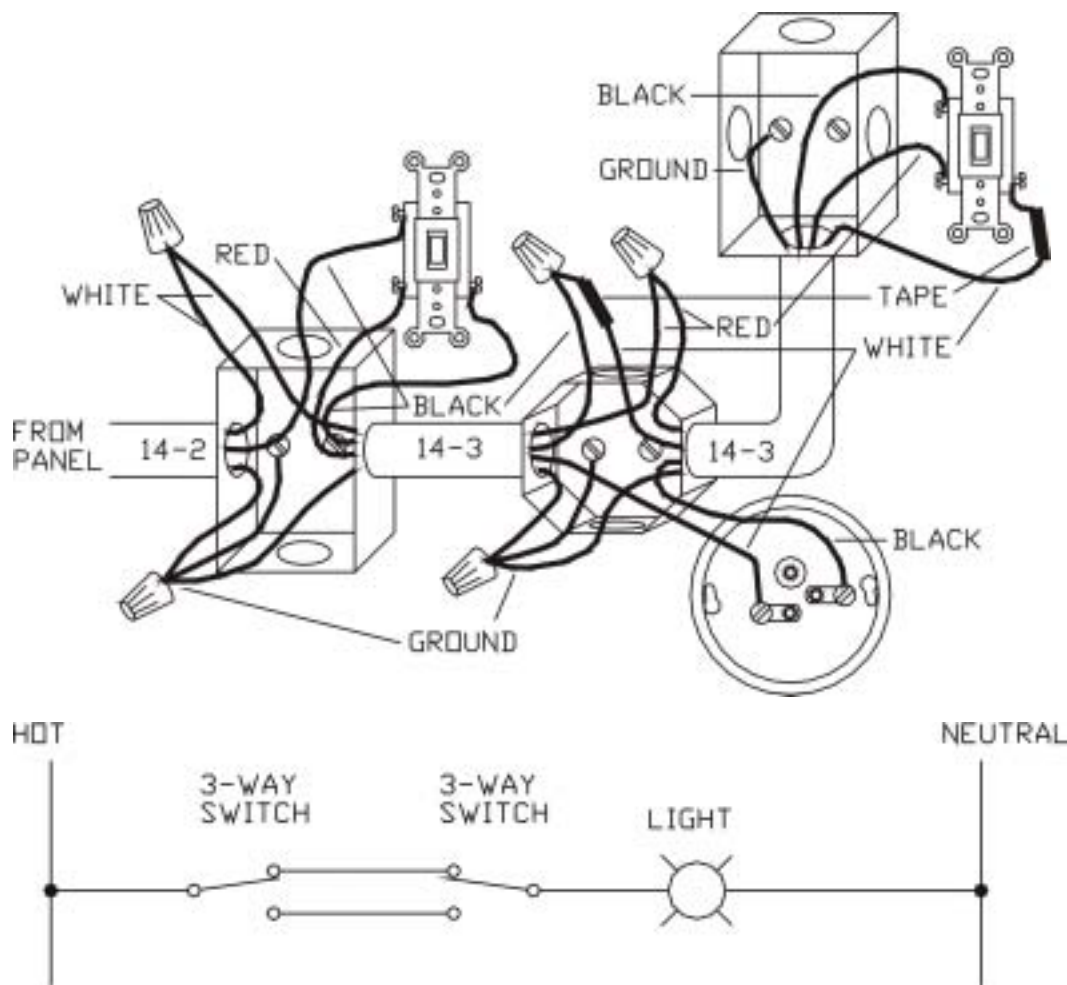
When you have completed this lesson, you will be able to:

- wire three-way switches with the light fixture located between the switches.

You may view a video of this activity by going to Lesson 7 on your computer. Click on the graphic for the video titled “Wire Three-Way Switches and a Light Fixture.” This video can be paused or repeated as often as necessary to complete this lesson.

In this lesson, you will wire two three-way switches and a light fixture to demonstrate how a light fixture can be controlled from two locations. For example, this would be a common system in residences where a light is controlled from either end of a long hallway or from the top and bottom of a stairway. The ON position of a switch can either be up or down, depending on the position of the other switch.

Since this will be on a separate circuit, you will be wiring the subpanel and adding another circuit breaker. In a real-life scenario, this does not necessarily need to be on a separate circuit.

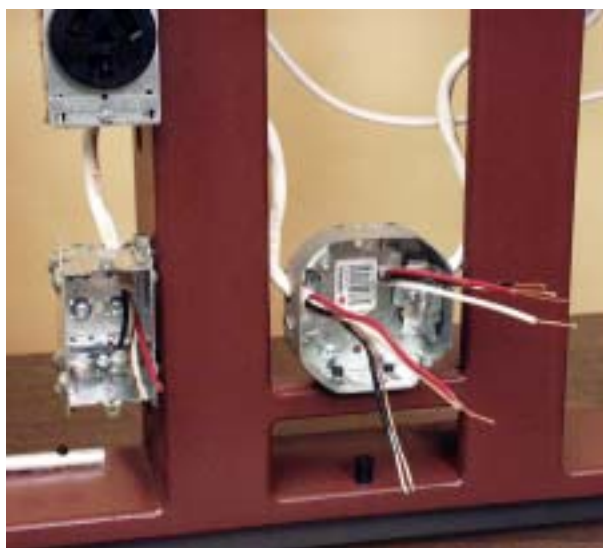


1. Before you begin, make sure that the transformer switch is in the OFF position.
2. Measure and cut 24 inches (60.96 cm) of 14-3 cable. Then, strip 6 inches (15.24 cm) from both ends of the cable. Cut off the excess plastic sheathing.

3. Run the cable from the upper three-way switch box to the lower light fixture box (located between the two switch boxes). When you are done, make sure the cable clamps are tightened in both boxes.
4. Strip approximately  $\frac{3}{4}$  inch of insulation from all the wires.



5. In this step, you need to run 14-3 cable from the light fixture box to the lower three-way switch box. Determine how much cable you'll need and proceed until this step is complete. Remember that 6 inches (15.24 cm) of sheathing should be stripped from each end of the cable and  $\frac{3}{4}$  inch of insulation should be stripped from all the wires. When you are done, the cable clamps in both boxes should be tightened.

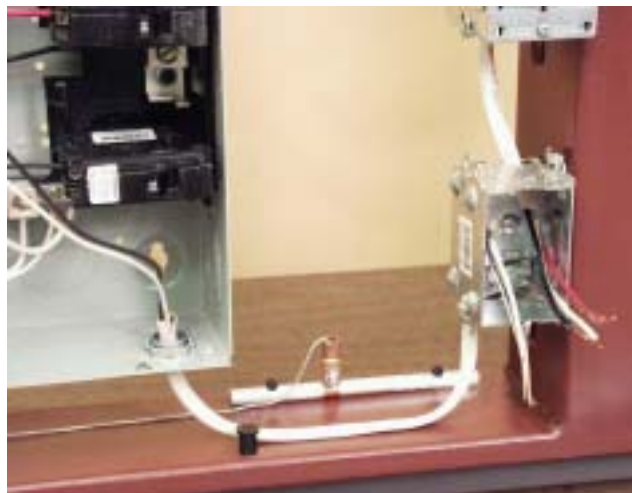


In the following steps, you will run 14-2 cable to the subpanel.

6. Measure and cut 36 inches (91.44 cm) of 14-2 cable. Then, strip 6 inches (15.24 cm) from one end of the cable. Cut off the excess plastic sheathing.
7. Run the stripped end of the cable into the bottom of the lower three-way switch box. Tighten the cable clamp.



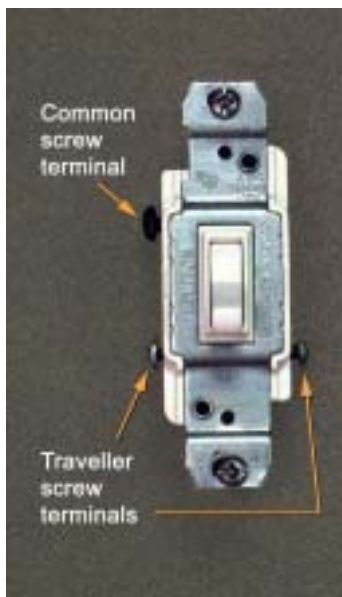
8. Run the other end of the wire along the bottom of the trainer and up to the opening located on the bottom right side of the panel. Mark the cable at the opening with a pencil. Starting from the mark, strip the cable all the way to the end.
9. Run the wire into the panel. Then, tighten the cable clamp. Do not connect the wires inside the panel until the rest of the circuit is completed.



10. In the lower switch box, you should have a 2-wire feed entering on one side and on the other side, a 3-wire cable running to the lamp box. From the lamp box, another 3-wire cable should run to the upper switch box.



Before you begin wiring the circuit, let's take a closer look at a three-way switch so that you have a better understanding of how it operates.



Three-way switches are designed to work in pairs. They are commonly used any time two switches are needed to operate one or more light fixtures. Three-way switches have no ON or OFF markings because they can turn a light on or off in either position, depending upon the position of the second switch.

Notice that the three-way switch has three screw terminals. The two lighter-colored terminals on the bottom are called *traveler screw terminals*. The term *traveler wires* are given this name because they run between the two switches and are connected to the traveler screw terminals (see the diagram at the beginning of this lesson).

The dark-colored terminal is a *common screw terminal*. A hot wire is connected to the common screw terminal so that current can be carried from the power source to the light fixture.

As previously mentioned, the lower switch box has two sets of wires; the 2-wire cable houses the feed wires that carry voltage from the power source. The wires housed in the 3-wire cable will be used as traveler and common wires, which are necessary for connecting the rest of the circuit.

11. In the lower switch box, connect a ground pigtail to the ground screw on the box. If necessary, cut the ground wires so that they are all the same length. Group all three ground wires, twist them together, and cap them with a green wire nut. Tuck the ground wires into the back of the box.

Tucking wires in a box should always be done neatly, otherwise the job will not be done properly. If the wires aren't arranged neatly, it can be difficult to fit the switches in their boxes.

12. Twist the neutral wires together and cap them with a yellow wire nut. Then, tuck them into back of the box.
13. Connect the hot (feed) wire to the common screw terminal. Remember that the feed wires are from the 2-wire cable running into the panel.
14. Connect the red hot wire to the bottom left traveler screw terminal.
15. Connect the black hot wire to the bottom right traveler screw terminal.



16. Connect a ground pigtail to the lamp box. Then, twist all three ground wires together and cap them with a green wire nut. Tuck them into the back of the box.
17. Take the neutral wire coming from the lower switch box and connect it to one of the *silver* screw terminals on the back of the light fixture.

18. Take the white wire that runs to the upper switch box and twist it together with the black wire that runs to the traveler screw terminal on the switch you just installed. Then, cap the wires with a yellow wire nut.
19. Take the two red hot wires, twist them together, and cap them with a yellow wire nut.

Although the white wire is usually considered the neutral wire, it will now act as a traveler wire. It will be connected to a traveler screw terminal on the other switch and used to power the lamp from the other side of the circuit. When a white wire is used in a circuit as a hot wire, you must label it by wrapping it with a band of electrical tape. This is specified in the National Electrical Code.

19. Wrap a band of electrical tape around the both ends of the white wire.



20. Connect the remaining black hot wire to the brass terminal on the light fixture.
21. In the upper switch box, connect the ground wire to the ground screw.
22. Connect the white traveler wire (coded as hot) to the bottom right traveler screw terminal. Be sure that a band of electrical tape has been wrapped around both ends of the wire.
23. Connect the red traveler wire to the bottom left traveler screw terminal.
24. Connect the black wire to the common terminal screw (dark colored screw).



This part of the circuit is now complete. To complete the circuit, you need to wire the panel. If you need help, refer to the diagram and/or steps in Lesson 1. Install the third breaker in the last remaining slot. This should be between the other breakers already installed. When the panel is completely wired, complete the following steps.



25. Screw the 12V bulb into the lamp socket.
26. Turn the transformer switch to the ON position.
27. Turn the appropriate circuit breaker to the ON position. Make sure the trainer is plugged into an outlet.

Your circuit should work perfectly. Either switch should turn the light on and off. If they do not work properly, refer to the wiring diagram in the beginning of the lesson and retrace your wires.

28. Turn the appropriate breaker to the OFF position.

Tuck the remaining wires into the switch and lamp boxes. The lamp fixture and the wires connected to it should remain out of the box until the end of the last lesson.

29. Install the switches in the boxes. If the switches don't fit easily, do not use the screws to draw them into the box. If necessary, rearrange the wires and try again.
30. Disconnect the wires connected to the light fixture. Then, install all three panels on the trainer.
31. Reconnect the light fixture and mount it to the box.
32. Install the cover on the subpanel. The cover should be supplied to you with the knockouts removed. If they weren't, then remove them now.



33. Turn the appropriate breaker back to the ON position and retry the switches to make sure everything still works.

Turn off the trainer, clean your area, and put your tools back in their proper place.

Go to the next section in the presentation, **Exercise**. When you are finished with the exercise, read the **Review** and then take the **Lesson Quiz**. When you have completed the quiz, you may move on to Lesson 8.

## Lesson 8 – Wire a Doorbell

### **Material List**

Yellow wire nuts

Doorbell wire

### **Tools You'll Need**

Phillips screwdriver

Allen wrench

Wire stripper

Diagonal cutters

Needle-nose pliers

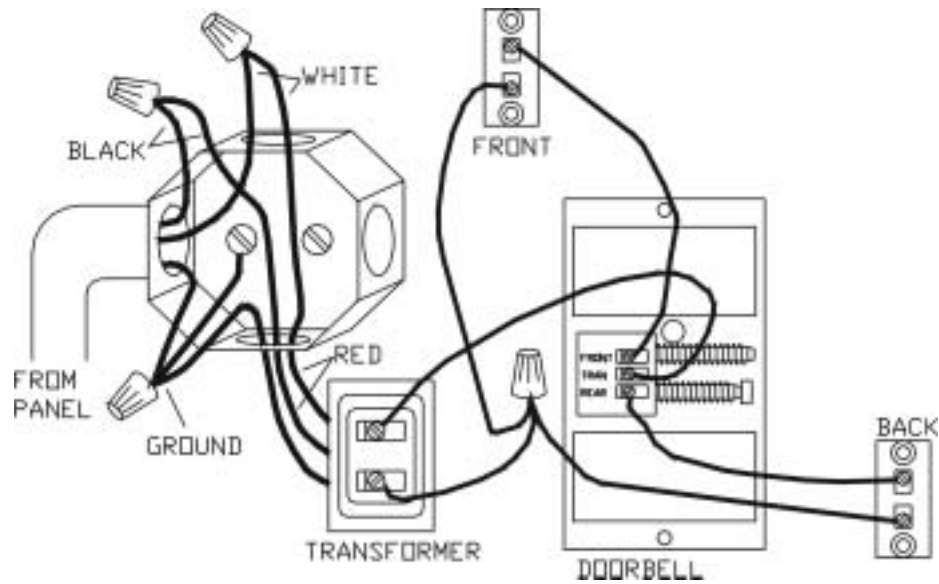
Lineman's pliers

When you have completed this lesson, you will be able to:

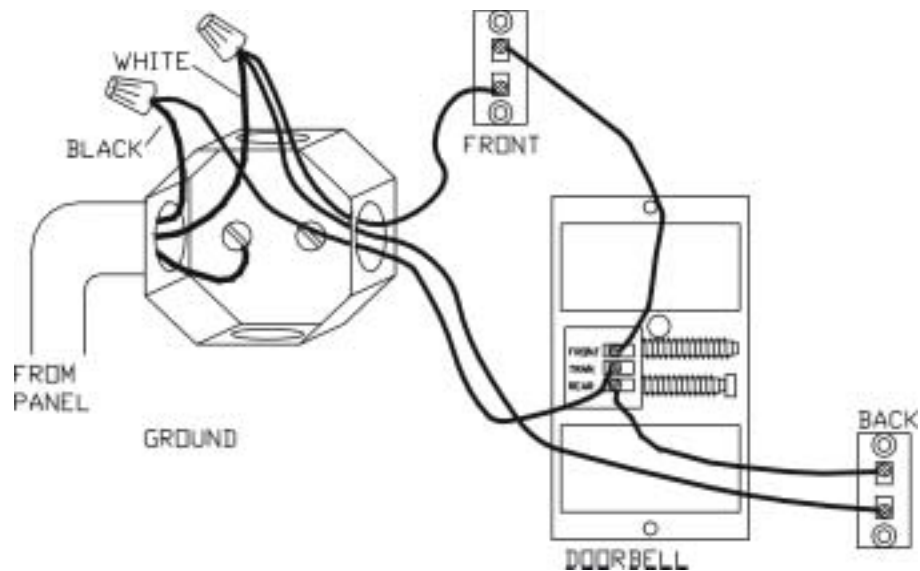
- wire a front and back door doorbell.

You may view a video of this activity by going to Lesson 8 on your computer. Click on the graphic for the video titled “Wire a Doorbell.” This video can be paused or repeated as often as necessary to complete this lesson.

In this activity, you will wire a doorbell system with front and back door doorbell switches. Doorbell systems are normally powered by a transformer, which is used to reduce 120V to a lower voltage of 20V or less to the chime. Since the Residential Wiring trainer supplies a low voltage, an additional transformer won't be necessary. You should, however, look at the wiring diagram and inspect the transformer that is supplied with the trainer to understand how a doorbell system is installed in a real-life scenario. Notice the three transformer wires colored black, white, and green. These wires are normally connected to the hot, neutral, and ground wires, respectively. A doorbell transformer is often mounted near the service panel, but it can be mounted to a junction box or wherever there is an existing 120V circuit. In our case, the doorbell wires will be connected directly to the existing wires in the junction box without using the transformer.



*Standard Wiring Diagram With Transformer*



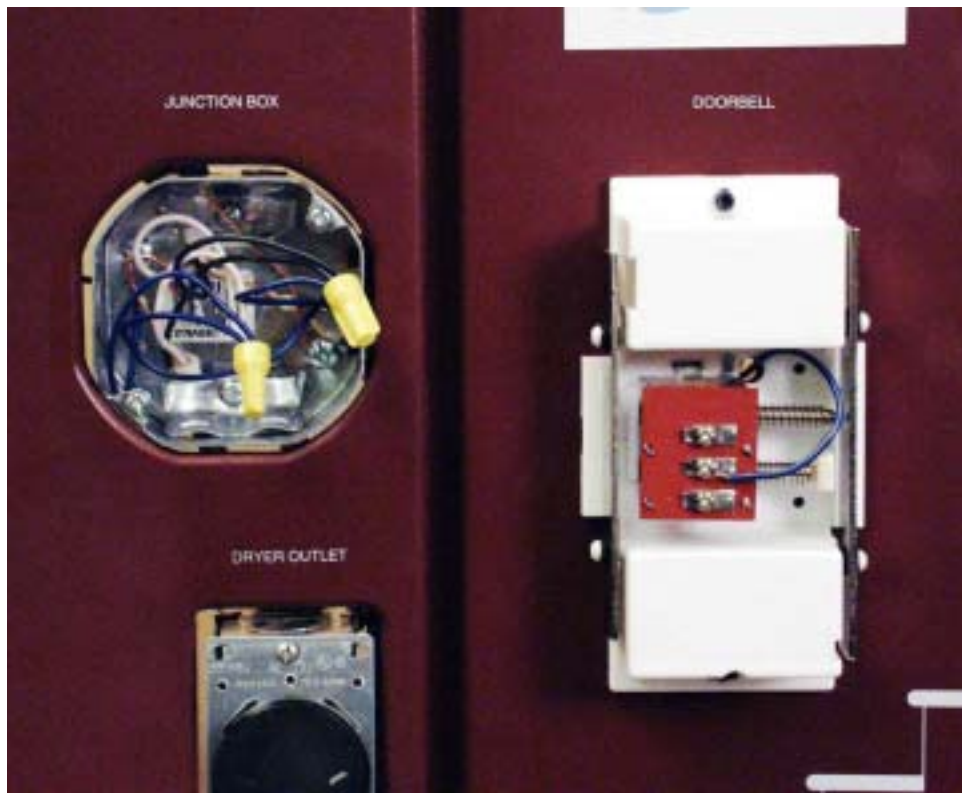
*Wiring Diagram for Residential Wiring Trainer*

Remove the cover from the doorbell chime. Look at the terminal screws and you will see that they are labeled “Front”, “Trans”, and “Back”. There may be a slight variation in these terms, depending on the manufacturer. When you are instructed to connect wires to the doorbell chime, these terms will be used to identify the terminals.

1. Before you begin, make sure the circuit breaker for the junction box is in the OFF position. Use the voltage tester on the junction box wires to verify that the correct breaker is turned off.
2. Remove the covers from the front and back doorbell switches. Then, using the 9/64 Allen wrench, remove them from the panels.
3. Cut a doorbell wire long enough to run from the hole behind the front doorbell switch to the junction box. Be sure that there will be plenty of slack left in the wire before it is cut.
4. Repeat the same process for the rear doorbell switch.
5. Strip approximately  $\frac{3}{4}$  inch of insulation from the ends of both wires. Run each wire out through the hole behind each of the doorbell switches. Connect the end of each wire to one of the terminals on front and back doorbell switches. In the junction box, twist together the two doorbell wires and the neutral wires and cap them with a yellow wire nut.



6. Cut another wire long enough to run from the junction box to the center terminal on the doorbell chime. The wire will run behind the panels and then out through the hole behind the chime unit. Strip both ends of the wire.
7. Twist together the doorbell wire and the hot wires in the junction box. Cap them with a yellow wire nut. Tuck all the wires into the junction box.
8. Run the other end of the wire through the hole behind the doorbell chime and connect it to the center terminal marked “Trans.”



9. Cut two more wires, each of them long enough to run from the holes behind the doorbell switches to the other terminals on the doorbell chime. There should be plenty of wire so that they can run through the hole behind the chime unit and connect to the appropriate terminals. Strip the ends of both wires.

10. Run one end of the wire out through the hole behind the front doorbell switch and connect it to the terminal on the switch. Run the other end of the wire behind the panels then out through the hole behind the doorbell chime. Connect it to the doorbell terminal marked "Front."



11. Repeat the process for the back doorbell switch. Run one end of the other wire out through the hole behind the back doorbell switch and connect it to the terminal on the switch. Run the other end of the wire behind the panels and out through the hole behind the doorbell chime. Connect it to the doorbell terminal marked "Back."



12. Turn on the circuit breaker. Make sure the trainer is turned on and that it is plugged into an outlet.
  
13. Test the doorbell switches. In most doorbell systems, the front and back doorbells sound different. For instance, the front doorbell may ring twice whereas the back doorbell may only ring once.
  
14. Reinstall the doorbell switches and replace the cover on the doorbell chime.

Turn off the trainer, clean your area, and put your tools back in their proper place.

Go to the next section in the presentation, **Review**. Read the review then take the **Lesson Quiz**. When you have completed the quiz you may move on to Lesson 9.



## Lesson 9 – Install a Phone Jack

### **Material List**

Telephone wire

TV/phone jack

### **Tools You'll Need**

Phillips screwdriver

Wire stripper

Diagonal cutters

Needle nose pliers

When you have completed this lesson, you will be able to:

- connect telephone wire to a modular telephone jack.

You may view a video of this activity by going to Lesson 9 on your computer. Click on the graphic for the video titled “Install a Phone Jack.” This video can be paused or repeated as often as necessary to complete this lesson.

In this lesson, you will connect a four- or six-wire telephone cable to a modular telephone jack. The most common type of telephone cable is the four-wire, which consists of a yellow, black, red, and green wire. These wires are paired together to get two separate telephone lines. Red and green are paired together for line one. Black and yellow are paired together for line two. If you have one telephone line, only two (red/green) wires are necessary. If your telephone cable has six wires, it is capable of handling three telephone lines. Almost all homes have four-wire telephone cables.

The most common modular jack, which you are undoubtedly familiar with, is called the RJ-11 telephone jack. This jack uses only two of the wires in a four- or more wire telephone cable. You have been supplied with an RJ-11 jack.

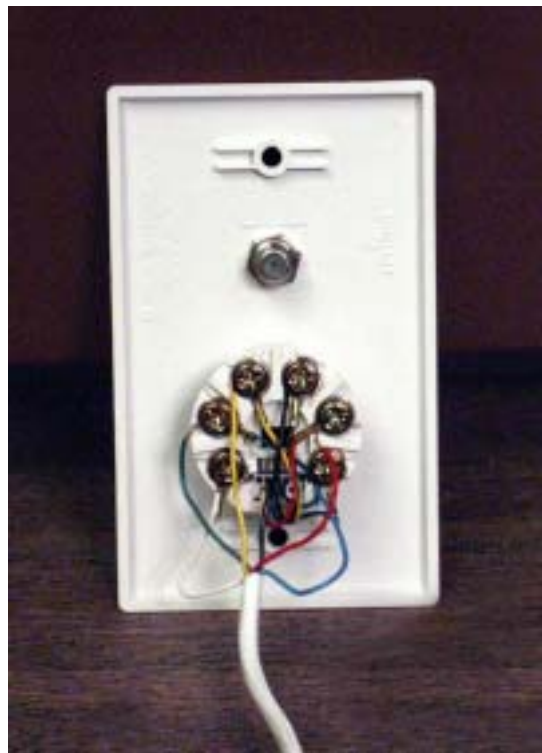
To prevent unwanted static interference, a telephone jack should never be installed less than 6 inches (15.24 cm) from an electrical circuit.

Connecting telephone wires is very easy. If you are color-blind, don't hesitate to ask your partner or your instructor for assistance.

1. Cut off approximately 1 ft (30.48 cm) of telephone cable.
2. Using the wire stripper, remove 2 inches (5.08 cm) of sheathing. You can use the largest opening (#10). Use care not to cut too deeply or you may need to start over.
3. Strip approximately  $\frac{3}{4}$  inch of insulation from the end of each wire. You can use the #20-22 opening on the wire stripper. It is very likely that you'll be working with 22-gauge wire.

Examine the back of the CATV/phone jack. You will see six terminals, each terminal is pre-wired to the modular jack and each terminal wire is color-coded. When you are connecting wires to the screw terminals, match each color wire as closely as possible with the color of the terminal wire.

4. Loosen the first terminal screw (starting from your left or right) and begin connecting similarly colored wires to the terminals. If there are fewer wires than there are terminals, disregard the extra terminals.



5. When you are done, run the other end of the wire into the CATV/phone jacks box and attach the cover plate to the box. That's it! A very simple job that you can do any time at home.

In a real-world scenario, the other end of the cable is connected to a telephone junction and the wires are connected to color-coded screw terminals.

Clean your area and put your tools back in their proper place.

Go to the next section in the presentation, **Exercise**. Complete the exercise then read the **Review**. After you have read the review, take the **Lesson Quiz**. When you have completed the quiz, you may move on to the final lesson.

## Lesson 10 – Install a Coaxial Cable Connector

### **Material List**

Coaxial cable

### **Tools You'll Need**

Needle nose pliers

Wire stripper or diagonal cutters

Coaxial cable stripper

Coaxial crimping tool

When you have completed this lesson, you will be able to:

- install a jack on a coaxial cable.

You may view a video of this activity by going to Lesson 10 on your computer. Click on the graphic for the video titled “Install a Coaxial Cable Connector.” This video can be paused or repeated as often as necessary to complete this lesson.

In this lesson, you will strip the end of a coaxial cable and install a connector. Coaxial cable is a type of copper cable used in the home primarily to receive cable television (CATV) and also for faster Internet connections using cable modems.

The coaxial cable has two main components: the inner conductor that carries the signal and the outer shield that serves as a ground. The cable is called “coaxial” because both components run along the same axis. Coaxial cable is used for computer networking, audio and video signal transmission, telecommunication, and many other applications.



Coaxial connectors come in various sizes and shapes, depending upon the manufacturer and the application in which it is used. The connector you will use is in a category called F connectors.

**NOTE:** The design of the coaxial cable stripper may vary, depending on availability. If your coaxial cable stripper is different from that which is represented in this manual, follow the directions supplied by the manufacturer.

Ultimately, the coaxial cable stripper cuts the cable to the dimensions described in the following three steps. The steps that are not numbered are for information purposes only and are not part of the activity.

Strip off  $\frac{1}{2}$  inch of the outer sheathing while being careful not to cut into the underlying shield.



Carefully pull back the strands of the shield and fold it back onto the outer cable.



Strip  $\frac{1}{4}$  inch of the inner insulation away from the inner conductor. The cable can now be fastened to a connector.

1. Cut approximately 1 ft (30.48 cm) of coaxial cable. Use the cutter portion of the wire stripper or the diagonal cutters.
2. Squeeze together the handles of the coaxial cable stripper. Then, slip one end of the coaxial cable into the cutting jig as far as it will go. Let go of the handles and the cutting jig will close against the sides of the cable.



The cutting jig has two blades. One is shallow and the other is deep. As the stripper is twisted around the cable, the shallow blade cuts into the outer sheathing while the deeper blade cuts through the insulation of the inner conductor.

3. Twist the stripper around the cable a few times until the outer and inner portions of the cable have been cut to the appropriate depth. Then, remove the stripper from the cable.
4. Remove the cut portions of the cable. Use the needle-nose pliers if necessary.



5. Carefully pull back the strands of the shield and fold it back onto the outer cable.
6. Push the end of the cable all the way into the connector. The connector should make full contact with the outer shielding.



7. Use the crimping tool to permanently fasten the connector to the cable.



You have successfully installed a connector on a coaxial cable. You may screw it onto the cable jack to see how the connection is made.

Congratulations! You have completed the final lesson in the Residential Electrical Wiring Module. In the following sections, you will choose an independent study project and read about different career possibilities relating to electrical wiring. Clean your area and put your tools back in their proper place.

Go to the next section in the presentation, **Exercise**. When you are finished with the exercise read the **Lesson Review**, and the **Module Conclusion**.

## Independent Study Projects

Choose one of the Independent Study Projects from the list below. When you have completed your project, give it to your instructor for review.

1. Using the trainer, reconnect the light fixture to the switch that is presently connected to a receptacle. If necessary, you can refer to the wiring diagram in Lesson 3. Be sure to follow the safety rules that were described in each lesson.
2. In Lesson 3, you wired a switch-controlled light fixture. To vary the intensity of the light, you would need a rheostat. Write at least 150 words about how a rheostat works and what types are available.



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Holt, Michael. Journeyman Electrician's Exam Preparation: Electrical Theory, National Electrical Code, NEC Calculations: Contains 1,800 Practice Questions.

Brickner, Dale and John Traister. *Electrician's Exam Preparation Guide*. Based on the 1999 NEC.

Miller, Rex. *Electrician's Pocket Manual*.

## REFERENCE A HOW TO STRIP WIRE AND CABLE



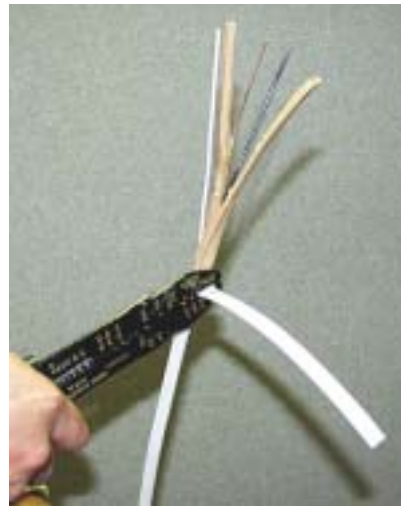
1. Place the cable inside the cable ripper, leaving at least 8-inches from the end of the cable.



2. Slice the cable by squeezing the cable ripper tightly and pulling it down toward the end of the cable.



3. Peel back the sheathing until all the wires are exposed.



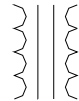
4. Using a combination wire cutter and stripper, cut off the excess sheathing and protective paper wrapping.



5. Cut each of the wires to the desired length and then strip the insulation off.



Fuse



Transformer



Pushbutton Switch  
(normally open)



Light



ON/OFF Switch



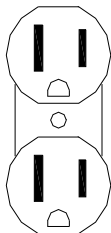
Motor



3-Way Switch



Resistor



Duplex AC Receptacle



Ground



Earth Ground

