AP Physics

Residential Wiring

Part 1: Safety

Household wiring provides an alternating potential difference of 110 V (or 220 V) to appliances. The potential difference creates an electric field, which, in turn, applies a force to an electron, causing it to travel through an electrical device. The energy imparted in these charge carriers is transferred to the appliance, resulting in the desired appliance behavior.

Our primary concern at this time is safety. If you become part of the circuit, you will experience a potential difference resulting in a flow of charge through you. Whether the current is fatal or not depends on the path it takes and magnitude of the current. It is our goal to survive this lab experience.

In 110 V residential wiring, the two wires that supply the current are designated as the *hot* wire, typically color coded with black insulation, and the *neutral* wire, coded with white insulation. The neutral wire is actually connected to the earth through the power distribution panel, typically a breaker box. For this reason, the neutral wire is said to be *grounded*. You can consider current flow to go from the hot wire through the appliance to the neutral wire. In actuality, current flow changes direction 60 times each second, but the path is still through the hot and neutral wires. This is why the nameplate on an appliance may read 110 V, 60 Hz.

You may have noticed that there is often a third wire accompanying the hot and neutral wires. This wire is the *ground* wire, and is color coded green. The ground wire is connected to the chassis of an appliance and returns to the earth. If for some reason, a current path becomes possible in which the hot wire is in contact with the chassis of the appliance, the current path will go directly to ground through the green wire, and not through you. In the apparatus we will be using, all the electrical boxes and conduit parts are electrically grounded through the ground prong of the power cord. In residential wiring, all the conduit runs and outlet/switch boxes are grounded through the breaker box, and an independent ground wire is usually never run.

In this lab we will be dealing almost exclusively with the higher voltage, high potential current of normal household power distribution systems. All electrical equipment is protected by a fuse or circuit breaker either in the equipment or in the circuitry leading to the equipment. In general, the fuse or breaker is sized to protect the rest of the system if there is a failure in the protected load device. The amount of current required for electrocution is substantially less than the rating of the fuse or breaker, and so the protection device cannot be depended upon to protect you against shock.

Electrical circuits are potentially dangerous even when workers use a great deal of care in their work.

The more aware you are of good safety habits and practice them, the less the chance of accidental electrocution. Electricity must be respected. Work on electrical circuits can be performed with safety to the workers and to those who will use the equipment when safeguards and common sense are used.

- Never take chances that will endanger yourself or others. Consider the results of each act.
- Always be careful. Work in a position that will allow you enough room to avoid moving against live parts.
- Exercise caution. Always work under safe conditions. Consider every circuit to be alive. All power sources and power circuits are potentially dangerous.
- Never work with finger rings, jewelry, metal watchbands, or metal chains; these items can come in contact with electrical circuits.
- Do not work alone on power circuits.
- Dead circuits should be treated as if they were alive. Someone may turn the circuit on by accident. Take nothing for granted.

Table 1. Estimated Effects of 60 Hz AC Currents[1]

1 mA	Barely perceptible
16 mA	Maximum current an average man can grasp and "let go"
20 mA	Paralysis of respiratory muscles
100 mA	Ventricular fibrillation threshold
2 Amps	Cardiac standstill and internal organ damage
15/20 Amps	Common fuse or breaker opens circuit*
* Contact with 20 milliamps of current can be fatal. As a frame of reference, a common household circuit breaker may be rated at 15, 20, or 30 amps.	

Electrical injuries may occur in various ways: direct contact with electrical energy, injuries that occur when electricity arcs (an arc is a flow of electrons through a gas, such as air) to a victim at ground potential (supplying an alternative path to ground), flash burns from the heat generated by an electrical arc, and flame burns from the ignition of clothing or other combustible, non electrical materials. Direct contact and arcing injuries produce similar effects. Burns at the point of contact with electrical energy can be caused by arcing to the skin, heating at the point of contact by a high-resistance contact, or higher voltage currents.

[1] NIOSH Publication No. 98-131: Worker Deaths by Electrocution

Contact with a source of electrical energy can cause external as well as internal burns. Exposure to higher voltages will normally result in burns at the sites where the electrical current enters and exits the human body. High voltage contact burns may display only small superficial injury; however, the danger of these deep burns destroying tissue subcutaneously exists. Additionally, internal blood vessels may clot, nerves in the area of the contact point may be damaged, and muscle contractions may cause skeletal fractures either directly or in association with falls from elevation. It is also possible to have a low-voltage electrocution without visible marks to the body of the victim.

Flash burns and flame burns are actually thermal burns. In these situations, electrical current does not flow through the victim and injuries are often confined to the skin.

Contact with electrical current could cause a muscular contraction or a startle reaction that could be hazardous if it leads to a fall from elevation (ladder, aerial bucket, etc.) or contact with dangerous equipment.

The presence of moisture from environmental conditions such as standing water, wet clothing, high humidity, or perspiration increases the possibility of a low-voltage electrocution. The level of current passing through the human body is directly related to the resistance of its path through the body. Under dry conditions, the resistance offered by the human body may be as high as 100,000 Ohms. Wet or broken skin may drop the body's resistance to 1,000 Ohms. The following illustrations of Ohm's law demonstrate how moisture affects low-voltage electrocutions. Under dry conditions, Current=Volts/Ohms = 120/100,000 = 1 mA, a barely perceptible level of current. Under wet conditions, Current=Volts/Ohms = 120/1,000 = 120 mA, sufficient current to cause ventricular fibrillation. Wet conditions are common during low-voltage electrocutions.[2]

The equipment we will be using is protected by a 15 A circuit breaker. Although this breaker is sufficient to prevent a fire, a short circuit in the apparatus may still result in a flash that may eject hot metallic particles. For this reason, safety glasses are required when first applying power after making a wiring revision.

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[2] NIOSH Publication No. 98-131: Worker Deaths by Electrocution; Part I. Electrocution-Related Fatalities

Part 2: Getting to know the equipment

The apparatus we are using consists of a breaker box, a split-wired duplex receptacle, lamp holders, lamp dimmer, standard and 3-way switches, and a ground fault circuit interrupter. A line cord is prewired through the circuit breaker. There are no other prewired circuit components.

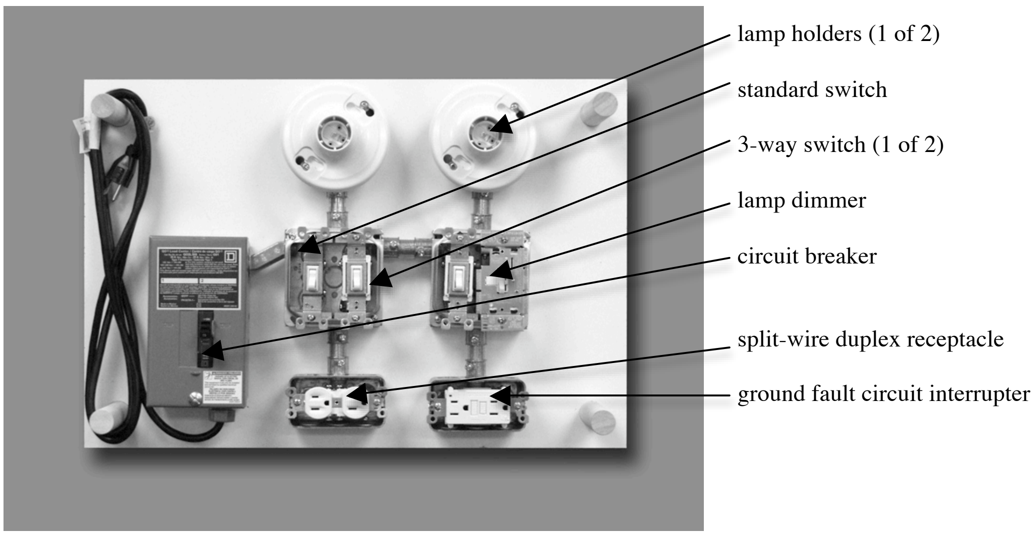


Fig 1: Residential wiring circuit board, components installed

1. Open the circuit breaker box and examine the way the line cord is wired. Observe that the green wire is connected to the chassis of the breaker box – this is the ground wire. The black wire (hot) is connected to the top of the breaker. The white wire (neutral) is connected to the ground bus bar.

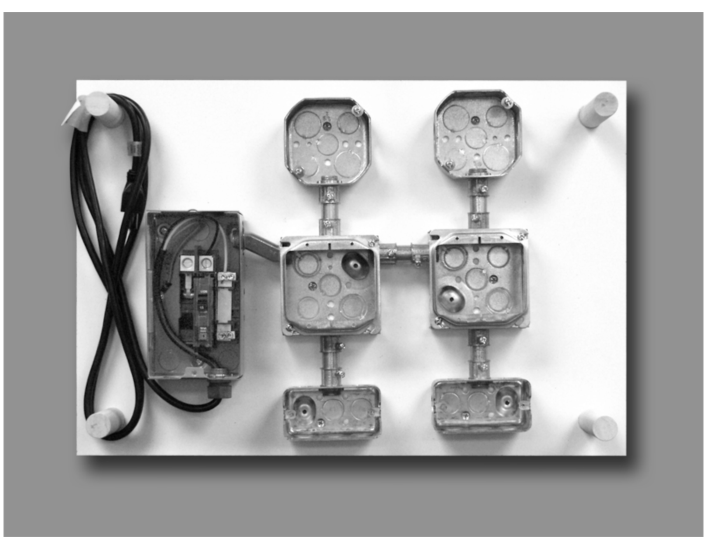


Fig 2: Residential wiring circuit board, components removed and breaker box uncovered

2. Remove the standard light switch. Notice that there are two brass screws and one green screw.

Fig 3: Standard light switch

   a. Use a multimeter to examine the operation of the switch. Set the meter on a low ohms scale. With the meter probes separated from each other, what does the meter reading tell you? Now touch the meter probes together. How did the reading change? What does this tell you about the circuit you created with the meter probes? When a meter is used in this fashion, it is called "testing for continuity."

   b. Speculate on the function of the green screw. Does it have continuity to either of the brass screws?

   c. Notice any markings on the switch. Do these markings tell you anything about the appropriateness of using this switch in a particular application?

3. Remove one of the 3-way switches. Observe the number of screw connections on this device.

Fig 4: 3-way switch

   a. Check continuity on this switch. How does the position of the switch handle affect the internal connections? Draw a schematic diagram of the internal structure of this switch, taking care to indicate which external screws are represented in your drawing.

   b. Is the green screw connected to any internal structure of the switch?

4. Remove the duplex receptacle and examine it carefully. Note that there are two sets of screws, one set nickel-plated, and the other set brass. This is where you will make your connections – the hot wire to the brass, the neutral wire to the nickel. Notice that each pair of screws has a connecting bridge. The bridge on the nickel side is intact; the bridge on the brass side has been broken. This allows us to independently power each side of the receptacle.

Fig 5: Duplex receptacle

   a. Sketch a drawing of the internal connections of your duplex receptacle. How are the ground connections (D-shaped openings) wired? If you are unsure, check for continuity.

   b. Speculate on why you think there are two different size slots on each of the receptacles.

   c. Notice any markings on the device. Do these markings tell you anything about the appropriateness of using this receptacle in a particular application?

5. Remove the ground fault circuit interrupter (GFCI). The purpose of the GFCI is to act as a fast switch and remove power from any appliance that is plugged into or otherwise wired into the GFCI in the event that the current through the hot wire and neutral wire become unbalanced. The GFCI can detect an unbalance of greater than 5 mA and disconnect the load within 0.03 seconds.

Fig 6: Ground fault circuit interrupter with outlet plate

    a. What does it mean to say that the hot and neutral wires are unbalanced? Why would they become unbalanced? Discuss this in terms of current paths.
    b. Where would a GFCI be used in a residence? Why?
    c. Notice the screw terminals. Compare them to the duplex receptacle. Note similarities and differences.
    d. What is the maximum current that the GFCI can accommodate?
    e. Speculate on the internal construction of the GFCI. What makes it work? (Hint: draw on your physics knowledge – there is nothing tricky here.)

6. Remove the dimmer and study the connection terminals. This particular model is called a toggle dimmer, as it incorporates an on-off toggle switch and the dimmer function as a small slider. Although there are many kinds of dimmers, just about all of them perform the same function, and are wired into the lighting circuitry the same way.

Fig 7: Toggle dimmer with switch plate

    a. Speculate on the way the dimmer should be wired. Should the dimmer be wired in series or parallel with a lamp circuit? Why?
    b. Look for markings on the dimmer. What do those markings tell you about this device's appropriateness for a specific application?
    c. The dimmer control for a car's dashboard lights is nothing more than a variable resistor. Discuss the suitability of using a variable resistor in a residential lighting circuit with a maximum load of 600 W.

7. Remove the lamp holder fixture and note the connections on the underside. Note any similarities to the duplex receptacle.

Fig 8: Lamp holder

    a. If a light bulb were screwed into the fixture, which terminal would connect to the outside portion of the bulb's base? Why is the lamp holder constructed in this way?

Task 1: Wiring a switch-controlled light fixture

In this exercise, you will wire a standard light switch to turn on a bulb screwed into one of the lamp holders. Below are a few rules to follow for this task and the tasks to follow.

1. A maximum of two wires may be connected to the protected side of the circuit breaker.
2. The hot side of the circuit is switched.
3. Although the neutral side may be spliced (multiple wires joined together with a wire nut), the neutral side must retain its integrity. Simply stated, the neutral wire is never broken by a switch.
4. Neutral wires are white.
5. Hot wires are color coded black. Hot wires interrupted by a switch may be another color as long as that color is not white or green.

Fig 9: Wire nut joining two neutral wires.

On the Task 1 Worksheet, draw the way you will route and connect the wires for this task. Indicate the color of the wire you will be using. Have your instructor check this before you actually wire the circuit.

After you have wired your circuit and confirmed that it works properly, remove all the wires. The switch and light fixture will be wired differently in the tasks that follow.

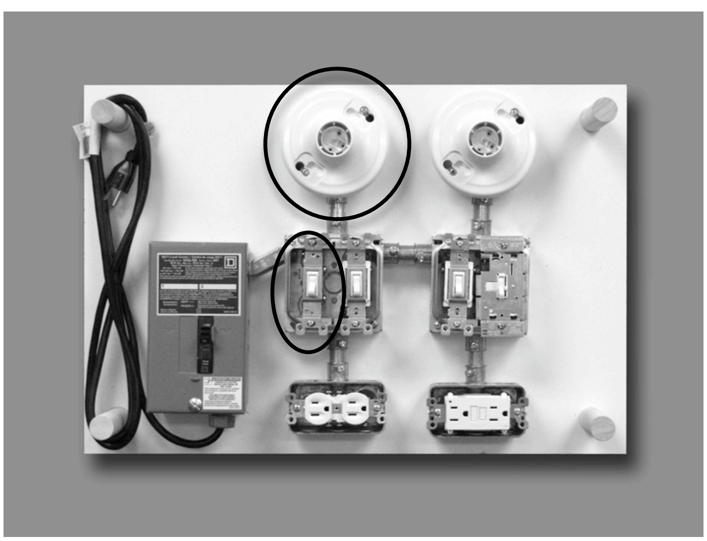


Fig 10: Wire these components to turn on a light with a standard light switch.

Task 2: Wiring a split-wire duplex receptacle and GFCI

In this exercise, you will wire a duplex receptacle in a way that will provide uninterrupted power to the GFCI and one side of the duplex receptacle, and switched power to the other side of the duplex receptacle.

Because you will be wiring multiple outlet circuits, bring a hot wire into the box from the circuit breaker and use a wire nut to make a branch circuit that feeds the switch, the constant-on side of the receptacle, and the GFCI. In a similar fashion, do the same for the neutral wire.

On the Task 2 Worksheet, draw the way you will route and connect the wires for this task. Indicate the color of the wire you will be using. Have your instructor check this before you actually wire the circuit.

After you have wired and proven this circuit, verify that it works properly by testing it with a multimeter. Set your meter to AC voltage, 200 V or greater. Make sure the probes are connected to the voltage terminals on the meter.

1. Was there a potential difference between the hot side of the receptacle and the neutral side? How did the operation of the switch affect the meter reading?
2. Was there a potential difference between the hot side and the metal box? What does this tell you if you touched the hot wire and the box at the same time?
3. What are the functions of the buttons on the face of the GFCI?
4. Can you think of a way to test the operation of the GFCI?

When you are finished with this task, do not remove the wiring.

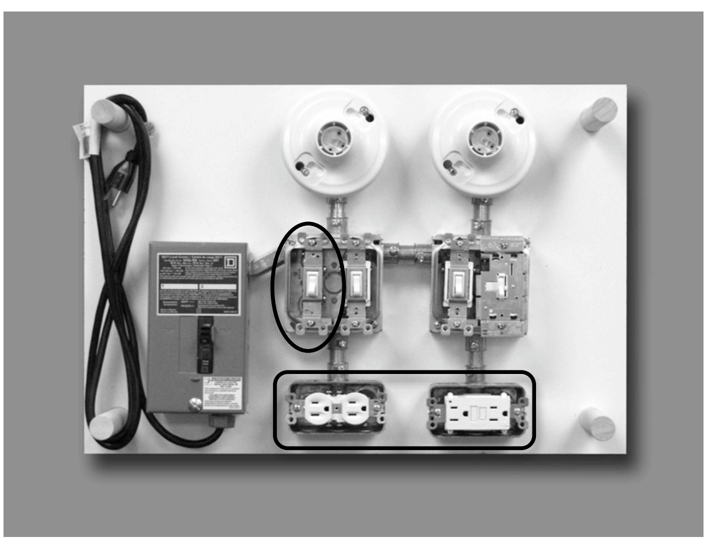


Fig 11: Wire these components to control a split-wire duplex receptacle and GFCI.

Task 3: Wiring a light dimmer

In this exercise, you will wire a light dimmer to control an incandescent lamp in one of the lamp fixtures.

Because you will be wiring multiple lighting circuits, bring a hot wire into the box from the circuit breaker and use a wire nut to make a branch circuit that feeds the dimmer. Other branch wiring will be added later. In a similar fashion, do the same for the neutral wire. You should now have two black wires on the protected side of the circuit breaker and two white wires on the neutral bus in the breaker box.

On the Task 3 Worksheet, draw the way you will route and connect the wires for this task. Indicate the color of the wire you will be using. Have your instructor check this before you actually wire the circuit.

After you have wired and proven this circuit, verify that it works properly by testing it with a light bulb. In addition, check the operation of the dimmer with a multimeter. Set the meter on AC volts, 200 V or greater. Observe the meter reading as you vary the dimmer setting.

When you are finished with this task, do not remove the wiring.

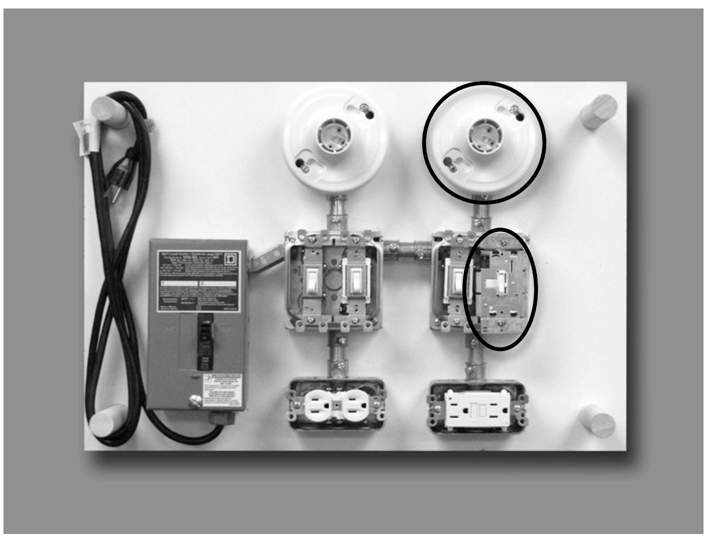


Fig 12: Wire the dimmer and light fixture.

Task 4: Wiring three-way switches and a light fixture

In this exercise, you will wire a pair of three-way switches to control a light fixture.

Three-way switches are used in situations where there are two entrances to a room and lighting needs to be controlled from each entrance. Another common use is at the top and bottom of a staircase.

Think about the schematic diagram you made of the three-way switch. Devise a way to control one light fixture with two of these switches. Sketch out a schematic of the circuit. Have your instructor check the circuit before attempting to build it.

On the Task 4 Worksheet, draw the way you will route and connect the wires for this task. Indicate the color of the wire you will be using. Have your instructor check this before you actually wire the circuit.

After you have wired and proven this circuit, verify that it works properly by testing it with a light bulb.

When you are finished with this task, REMOVE ALL THE WIRING except for the line cord in the breaker box.

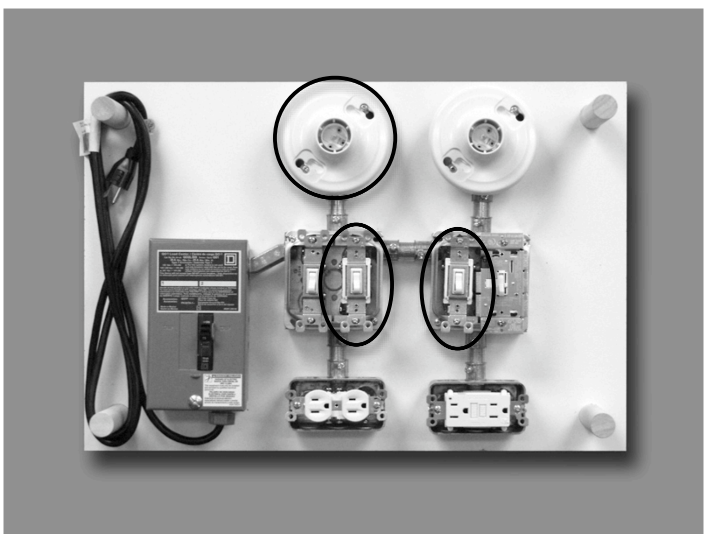
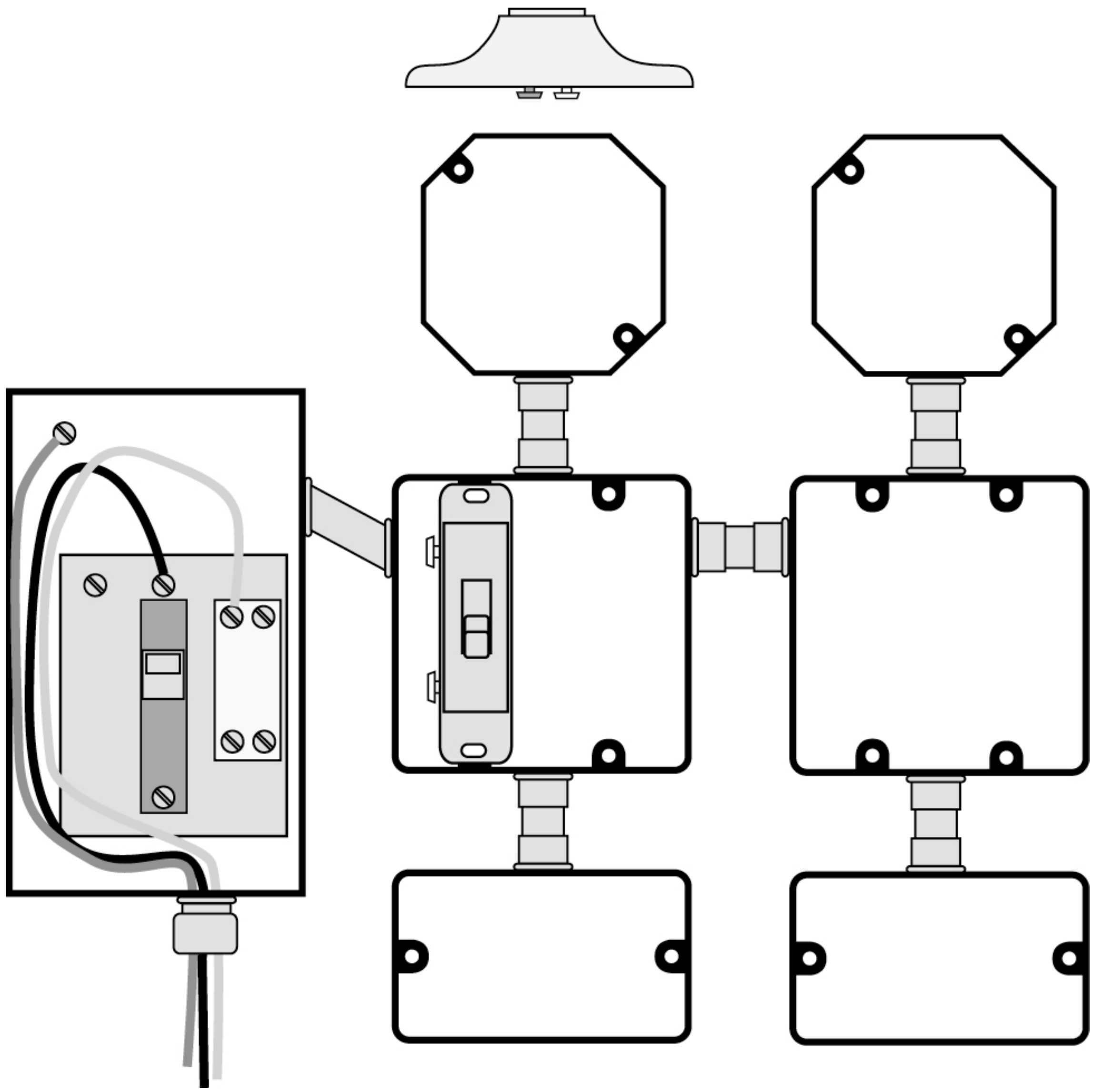


Fig 13: Wire the three-way switches to the light fixture.

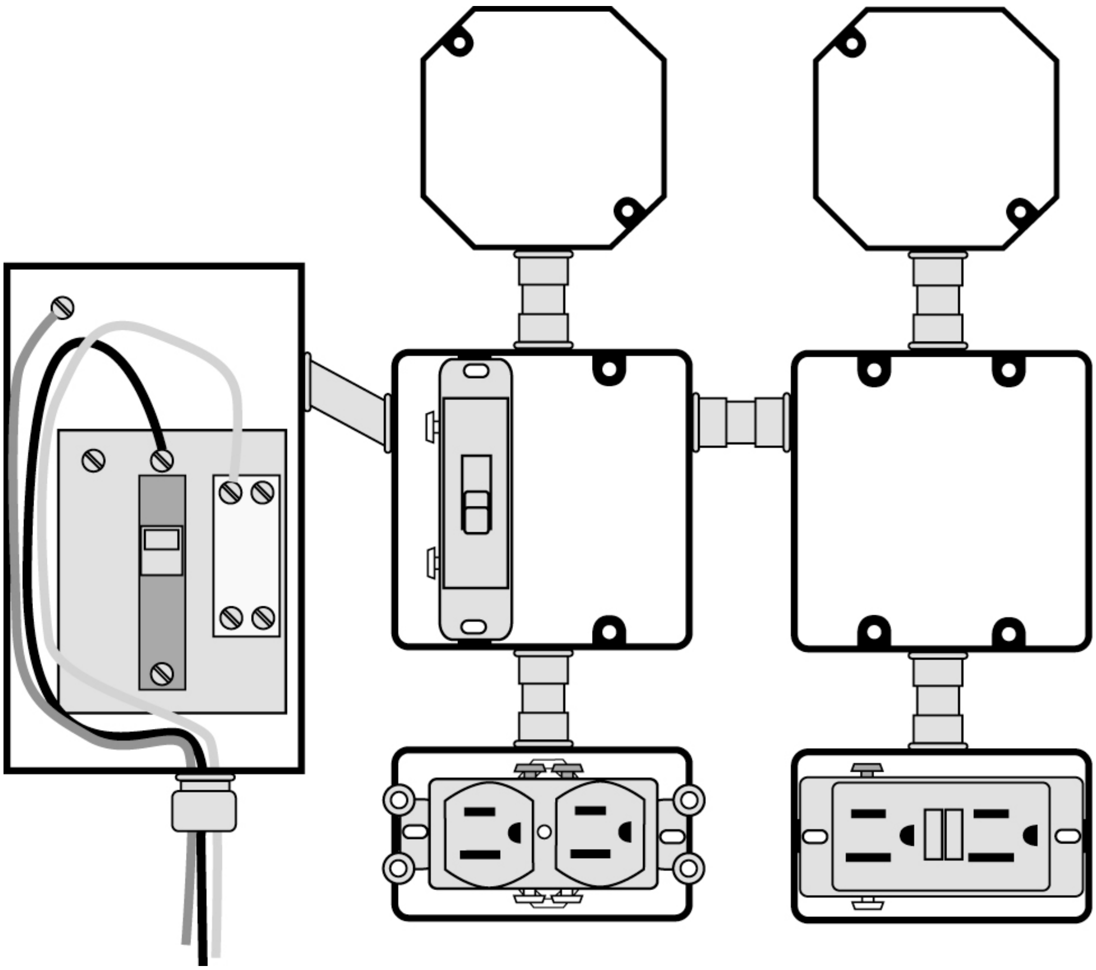
Task 1 Worksheet

Wiring a switch-controlled light fixture



Task 2 Worksheet

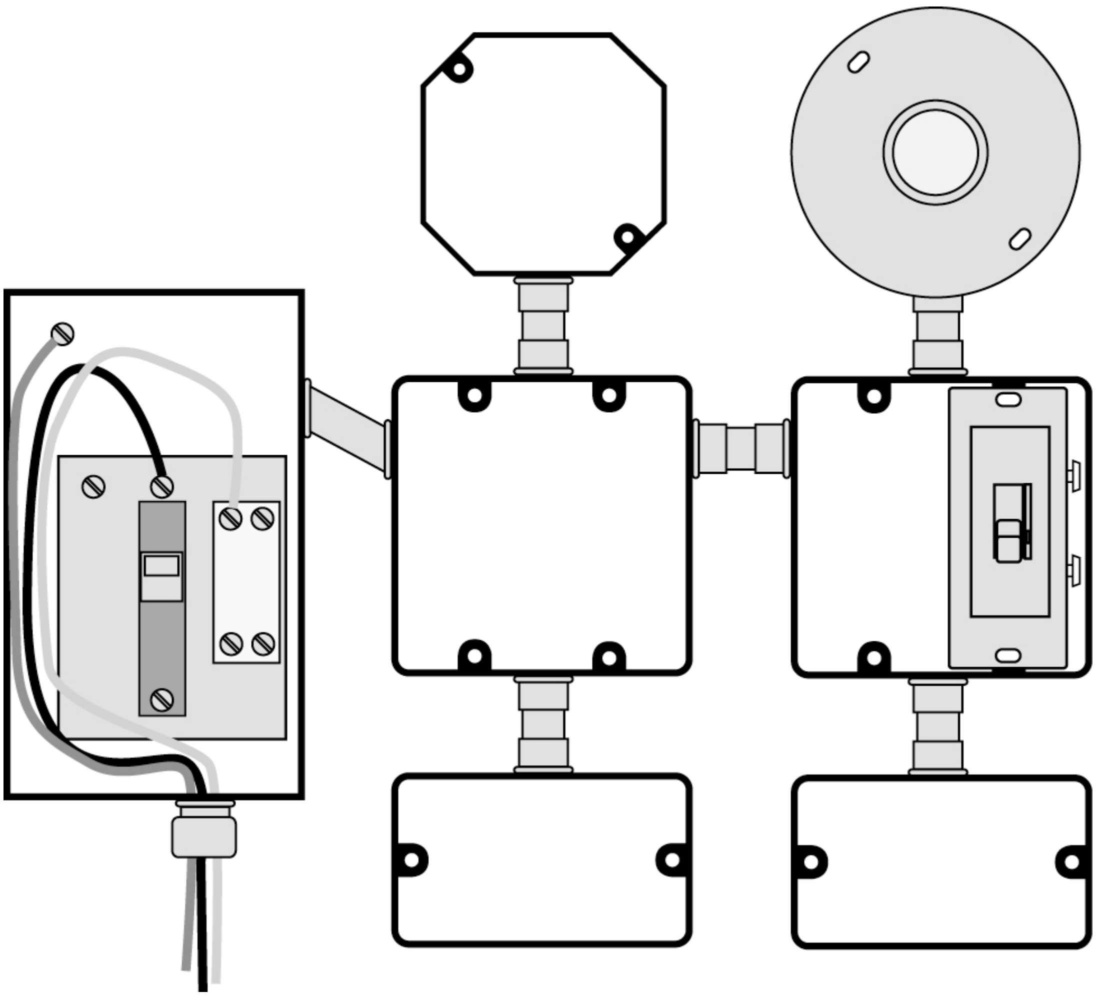
Wiring a split-wire duplex receptacle and GFCI



Note: be sure to indicate where wires are joined together with wire nuts.

Task 3 Worksheet

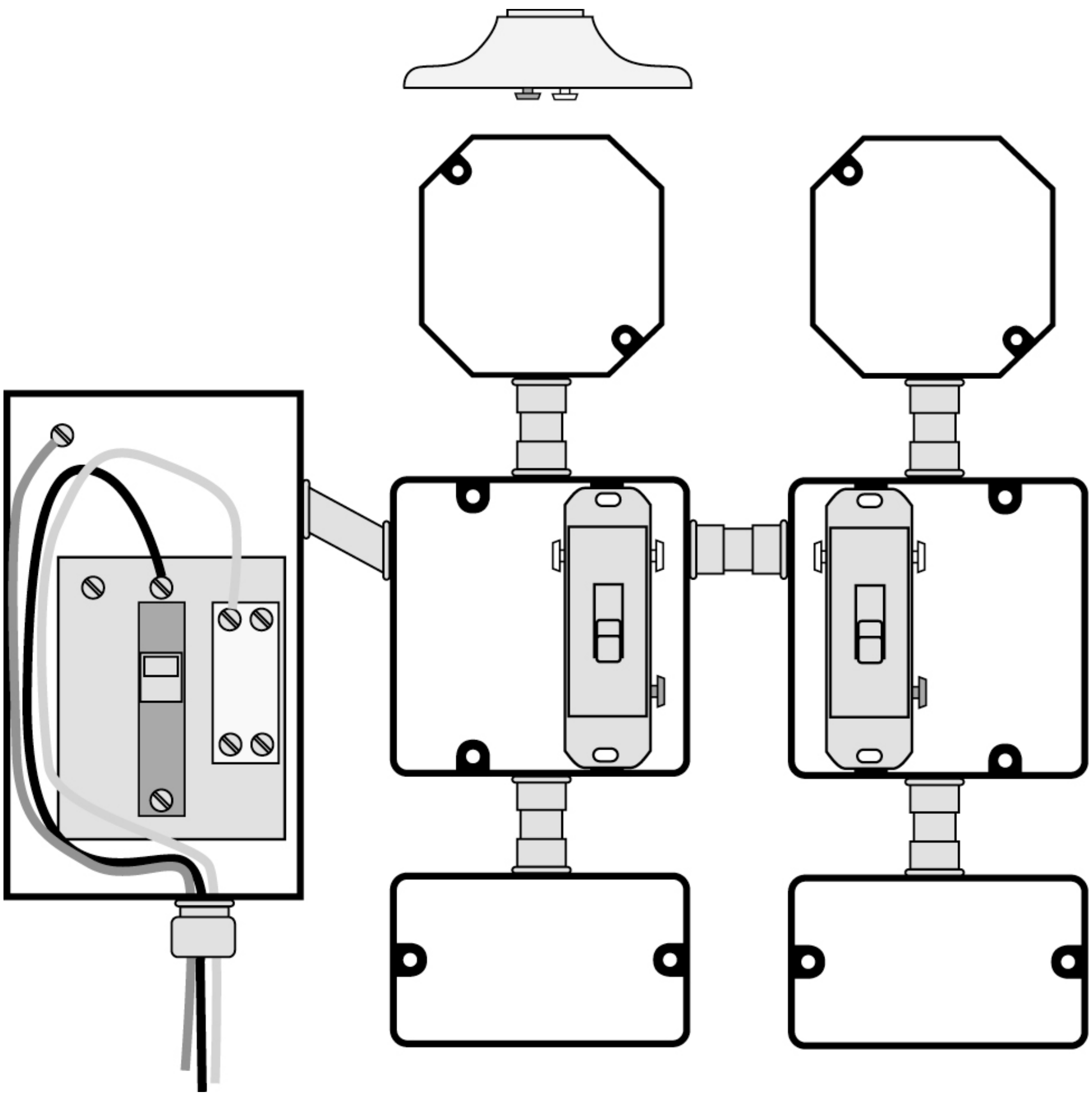
Wiring a light dimmer



Note: be sure to indicate where wires are joined together with wire nuts.

Task 4 Worksheet

Wiring three-way switches and a light fixture



Note: be sure to indicate where wires are joined together with wire nuts.