Wiring Devices

Description
Once a house has been roughed in and has passed an electrical inspection, it’s time for the electricians to do the final job of wiring and installing devices. Most trades have a finishing process to their specific areas in residential construction. Finishing carpenters usually come to add doors, trim, and moulding, plumbers connect fixtures such as taps and sinks, kitchen cabinets get installed, flooring and carpets get installed, and painters finish it all by doing their job. The time it takes from electrical rough in to finishing varies depending on the pace and timing of all trades. Ultimately, when the electricians arrive to install devices such as switches, receptacles, and light fixtures, all other trades are finishing their areas as well.

Wiring devices is the finishing touch and a chance to test all branch circuits for proper operation. This is the point in a job where if mistakes were made in the rough-in stage, they could be very costly to the contractor, in both time and material. Wiring devices properly is relatively easy if the rough in is done accurately. If device and wire connections are done poorly during the finishing process, it can create a very real safety hazard. High-resistance faults from poor wire connections in switch, light, and receptacle boxes are the most likely areas for fire hazards, so proper wiring skill and technique at this stage are imperative. Responsibility for people’s safety should be an electrician’s number one priority in all work performed.

Lesson Outcomes
The student will be able to:

- Wire a switch, light, and receptacle
- Produce a wiring diagram for wiring a switch, light, and receptacle
- Correctly strip plastic-sheathed cable and insulated wire inside a device box
- Understand how to make pigtailed
- Know how to properly ground a device box and the device within it
- Make proper hooks for terminal connections
- Understand the safety concerns around proper wiring methods regarding short circuits, shock hazards, and high-resistance faults inside device boxes

Assumptions
Students will:

- Understand basic electrical theory
- Know about electrical safety and shock hazards
- Know how to draw a basic wiring diagram
- Have knowledge of electrical terminology and equipment
- Have some practice with electrical hand tools and know how to strip wire and sheathing
**Terminology**

**Bonding**: the permanent joining of metal parts together to form an electrically conductive path that has the capacity to conduct safely any fault current likely to be imposed on it.

**Device box**: a box that holds a device (e.g., switch, receptacle, or cover) and associated wiring.

**Device connections**: *line* and *load* refer to the power connections coming into or out of electrical devices in the scheme of an electrical system, commonly a ground fault receptacle. The incoming feed from the supply comes into the *line side* of a device. It leaves the device from the *load side* and then feeds the load.

**Electrical device**: anything that can use electricity to perform a task using electricity, such as a switch or receptacle.

**Non-metallic sheathed cable (NMSC)**: a common plastic-sheathed cable used for wiring wood frame construction buildings. Also known by trade names Romex (USA) and Loomex (Canada). The most common cable type used in residential wiring is non-metallic dry (NMD) 90 cable. “Dry” refers to the cable’s use in dry areas.
Pigtail: a short wire used to connect an outlet or switch to a splice.

**Wiring diagram or schematic:** a simplified pictorial representation of an electrical circuit. It shows the components of the circuit as simplified shapes, and the wiring connections between the devices. A wiring diagram usually gives more information about the relative position and arrangement of devices and terminals on the devices, to help with installing the wiring.

![Figure 2—Cable types](image)

![Figure 3—Wiring diagram](image)
**Estimated Time**

2–4 hours

**Recommended Number of Students**

20, based on *BC Technology Educators’ Best Practice Guide*, working in pairs or larger groups depending on hand tools and material available. Students could carousel through activities if hand tools are scarce. Half the students could do wiring diagrams while the other half wires devices.

**Facilities**

Technology education shop with benches and vises

**Tools**

- Lineman pliers
- Wire strippers
- Utility knives
- Robertson® #1 and #2 screwdrivers
- Needle-nose pliers
- Side cutters

**Materials**

- 14/2 plastic-sheathed cable (Loomex)
  
  *Note:* The teacher should purchase a roll of wire 75 or 150 m for all activities based on the number of students. Any leftover wire can be used for future classes.
- Wire connectors, yellow, 10 per group
- Device boxes: two single gang and one octagon per group (metal or plastic).
  
  *Note:* Boxes should ½” offset for drywall as shown.
- Single-pole switches (one per group) (Figure 4)
- Duplex receptacle (one per group) (Figure 5)
- Medium base lamp holder and 40 or 60 W bulb (one each per group) (Figure 6)
- Wood screws (#8 × 1” or 2.5 cm, 6 per group)
- Small cuts of 2 × 4” stud roughly 24” (60 cm), not smaller than 18” (45 cm), 1 per group.
  
  *Note:* The lumber is for students to practise attaching boxes to wood and for wiring. Do not cut full lengths of material for this exercise if it is going to be used for framing, etc.; offcuts of material will work for this activity. If using larger pieces of material, group boxes within 24” (60 cm) of each other to save wire.

*Youth Explore Trades Skills*
**Optional**

Cordless drill with Robertson #1 and #2 bits

**Resources**

*Understanding the wiring in an electrical receptacle*

http://www.youtube.com/watch?v=bDhYDY9A4TI

Activity

Students should produce a wiring diagram of the circuit before commencing this activity. The circuit should include a receptacle with a power source feeding a single-pole light switch, which then feeds a light. Students will have produced a wiring diagram for the circuit used in this activity during Circuit Drawings and Wiring Diagrams. They may use this wiring diagram for reference during this activity.

Note: The teacher should make sure the wiring diagram is accurate before commencing this activity.

Wire one duplex outlet and one switch controlling one light, fed from the outlet.

Figure 7—Wiring diagram of circuit

This activity is designed to teach students how to attach device boxes to studs and how to wire devices. How to correctly run and strap wire between device boxes is explained in Wiring a Wall Section.
Mounting Boxes

The teacher should demonstrate how to attach a receptacle, switch, and light device box to a section of 2 × 4" stud (18–24", or 45–60 cm in length) or to a larger piece of material with the boxes spaced closely together to save wire.

1. Secure the stud into a bench vise for stability.
2. Screw the octagon box close to one end of the stud using 1" (2.5 cm) wood screws.
   
   **Note:** Make sure the boxes are screwed with tabs flush against the stud to allow for drywall.
3. Screw the two single gang boxes spaced evenly below the octagon box.

![Figure 8—2 × 4" secured in vise with boxes attached](image)
Entering Cables

1. Measure the 14/2 cable to run from the octagon box to the closest single gang box. (Figure 9)

   **Note:** Allow 8" (20 cm) of cable to run past each box to allow for wire length inside the boxes.

   **Code requires at least 6" (15 cm) of free wire in a box plus enough wire to wrap the ground wire around the ground screw.**

   ![Figure 9](image_url)

   Figure 9—Two boxes showing wire measurement

2. When cutting sheathing, hold the wire firmly and place the blade in the middle of the sheathing. Draw the blade away from your hand to split the sheathing open (Figures 10a and 10b). The reason for placing the blade in the middle of the sheathing is to run the blade beside the ground wire inside, and to not nick the insulation on the two conductors running on the outside of the 14/2 cable.

   **Safety concern:** Make sure hands are clear from the blade.

3. Strip 8" (20 cm) of sheathing (Figure 10c). Push one end of the 14/2 cable into the octagon box and guide the wire out of the box until 6–8" (15–20 cm) of wire is protruding from inside the box (Figure 11). Allow $\frac{1}{2}$" (1 cm) of sheathing to be visible in the box entrance so the conductors do not get damaged. Do the same with the first single gang box.
Figures 10a, 10b, 10c—Stripping sheathing
4. Repeat this procedure to run cable between the two single gang boxes (Figures 7 and 12).

5. Cut a piece of 14/2 cable to 12” (30 cm), or use a piece of scrap 14/2, and bring it into the last device box to simulate incoming power. (Figures 7 and 12)
Grounding the Boxes

The next step is to bond the boxes to ground, starting at the first single device box.

The first single gang box is going to be a receptacle with incoming power, the second single gang box will be a single-pole switch, and the octagon box will be a light.

1. Starting at the receptacle box, loosen the grounding screw in the box (counter-clockwise). Then loop the base of one ground wire around the grounding screw (clockwise) and tighten the screw (Figure 13).

![Figure 13—Box showing the ground wire looping around the grounding screw](image1)

2. Make black, white, and bare pigtail wires for splicing outlets.

3. Cut a piece of 14/2 Loomex 6” (15 cm) long and strip off the jacket. Scrap wire could be used for this task. Save the black and white pigtails for later splicing.

4. Join the two ground wires along with a pigtail grounding wire by twisting and putting a wire connector on them (Figure 14). If the receptacle was the last device in a wiring configuration and there was only one 14/2 entering the box, the ground wire could simply loop from the ground screw to the receptacle without making a pigtail.

![Figure 14—Ground wire pigtail](image2)
5. Now run the ground wire around the grounding screw in the single-pole switch box. Switches are not connected to the grounding wires, so join the two grounding wires and put on a wire connector (Figure 15).

**Note:** The switch will be bonded to the ground when the device is secured to the box.

![Figure 15—Switch box grounding](image)

6. The octagon box has only one 14/2 cable entering it, so in this case the grounding wire gets wrapped around the grounding screw and pushed into the box (Figure 16).

**Note:** This light fixture has no grounding connection; any light fixtures that do have a green or bare wire would be connected to the bond wire in the octagon box. In this case, the fixture will be bonded to ground when the fixture is attached to the box.

![Figure 16—Grounding wire in octagon box](image)

The grounding is now complete.
Splicing and Pigtailing

Outlet Box

1. Match up the white (neutral) wires in the box and cut them to the same length. Leave 4” (10 cm) protruding, measured from the front edge of the box.

2. Strip the white wires, attach a 4” (10 cm) white pigtail to the other two white wires, twist, and put a wire connector on them (Figure 17).

   **Note:** A pigtail is required by code for the white (neutral) cable with three conductors (14/3, 12/3, etc.), but not for two-wire cables. However, most electricians will use a pigtail for all receptacles and lamp holders as it will reduce the strain on receptacle and lamp holder termination points and a spliced connection will carry current more reliably.

3. Cut and strip the black (hot) conductors in the receptacle box and make a pigtail connection for them as was done for the white wires (Figure 17).

![Figure 17—Completed pigtails in receptacle box](image-url)
Switch Box

1. Cut, strip, and twist the two white conductors and join with a wire connector in the switch box (Figure 18).

![Figure 18—White wires connected in switch box](image)

Light Box

No splices required.

Terminating and Mounting Devices

Outlet Box

The devices are now ready to be installed to the wires.

1. Starting at the receptacle, strip the pigtail’s insulation on the neutral (white) and hot (black) wires to ¾” (roughly 1 cm) for termination.
2. When terminating wire to devices with terminal screws, making a hook at the end of the conductor allows for a secure connection (Figures 19–22). This type of connection will reduce the chance of a high-resistance fault from a wire coming loose in the future.

3. With ¼” (roughly 1 cm) of insulation stripped, hold onto the end of the stripped conductor with needle-nose pliers. Hold the wire firmly with the other hand while rotating the pliers to form a hook (Figures 19 and 20). Students might want to practise this skill with scrap material to perfect their hooks. Many electricians use their pliers to make hooks, and some use wire strippers; all will work. Students may try the different tools to find which one works best for them.
**Note:** It is important that no insulation touch the terminal screw (too little insulation stripped), as this could cause a high-resistance fault. Also, do not allow bare conductor to run past the end of a device (too much insulation stripped), as it could result in a short circuit or shock hazard (Figure 21). The hook should fit perfectly under the terminal screw (Figure 23), and the teacher should be very strict about getting students to perfect this skill. The hook should be positioned under the terminal screw so that tightening the screw clockwise will help to close the hook.

![Figure 21—Bad hooks (too little insulation stripped and too much stripped)](image1)

![Figure 22—Good hook](image2)

![Figure 23—Proper installation under terminal screw](image3)
4. Make hooks with the ground, white, and black wires. The receptacle will have two silver screw terminals (neutral wire), two brass terminal screws (hot wire), and one green (ground wire) terminal screw. When looking at the receptacle from the front view:
   - The green terminal screw should be positioned at the bottom left.
   - The silver (neutral) terminal screws should be positioned to the left (longer knife blade shape).
   - The brass (hot) terminal screw should be positioned to the right with a smaller knife blade shape.

   The receptacle should always be aligned this way when installed.

5. Attach the ground wire to the green screw with the hook in proper arrangement and tighten.
6. Attach the neutral wire to the proper terminal screw (silver) and tighten.
7. Attach the hot wire to the terminal screw (brass) and tighten. The two terminal screws that are not being used may be tightened so they do not protrude.

![Complete wired receptacle](image-url)
Switch Box

1. Cut, strip, and make a hook on the two black wires in the switch box (constant power coming from the receptacle) and switch leg (going to the light).

2. There are only two terminals on a single-pole switch. Most switches will have TOP written on the front and On and Off on the toggle, or a small raised dot on the toggle switch which indicates the On (up) position. Another way to configure a single-pole switch is to have the terminal screws to the right when looking at the switch from the front view when installing. The switch will work regardless of which terminal screws the two wires are connected to.

3. Attach the wires to the switch and tighten the terminal screws.

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Octagon (Light) Box

The last device to be wired is the light.
1. Strip the ends of the black and white wires and put a hook on each.

2. Connect the white wire to the silver (neutral) terminal screw, and the black wire to the brass (hot) terminal screw.

Since there are only two wires to be connected, no pigtail is needed. If there were two lights, a pigtail would be used at the first box. The two terminal screws not being used should be tightened.

![Figure 27—Properly wired lamp holder](image)

Note the importance of properly wiring a lamp or light to the proper terminals (polarity). See Figure 28.
3. The demonstration is now complete. The teacher should question the students to check their understanding. It is advised that the teacher go over the wiring demonstration beforehand, to practise the skills and plan appropriate questions to ask the students during the demonstration.

4. Have the students work in pairs to wire the same circuit as in the demonstration.

When complete the teacher should assess the students’ ability and have them redo poor work. DO NOT ENERGIZE THE CIRCUIT. THIS ACTIVITY IS TO PRACTISE WIRING DEVICES.
Evaluation Guidelines

The student will:

• Display knowledge of wiring diagrams
• Display competence with hand tools
• Work safely and responsibly with hand tools
• Understand the terminology in the activity
• Wire devices correctly
• Produce good quality workmanship
• Understand the safety implications of proper wiring methods

Extension Activity

• Have students practise wiring another circuit individually and perfect their technique. Use the same devices but install the feed into the switch.

• Add another light or receptacle to the circuit by adding another box.

• Have students produce a wiring diagram for another configuration of the circuit they propose to wire.

Note: It is not advised to energize any circuits at this time.