Electric Wiring

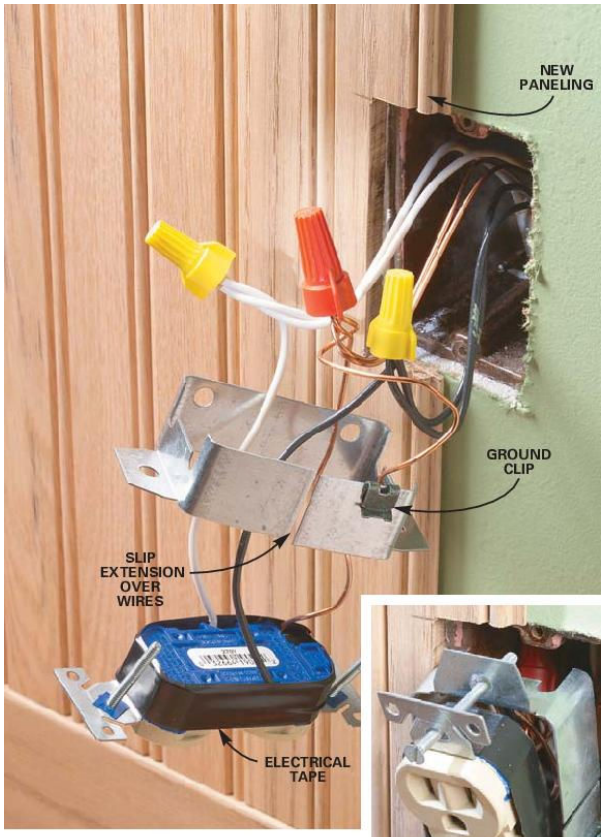
FOR

DUMMIES®

Watts=Volts x Amps!!!

Created especially for Engineers and Scientists who copied old lab reports instead of running the experiments themselves!!!

Electrical Wiring Informatiom

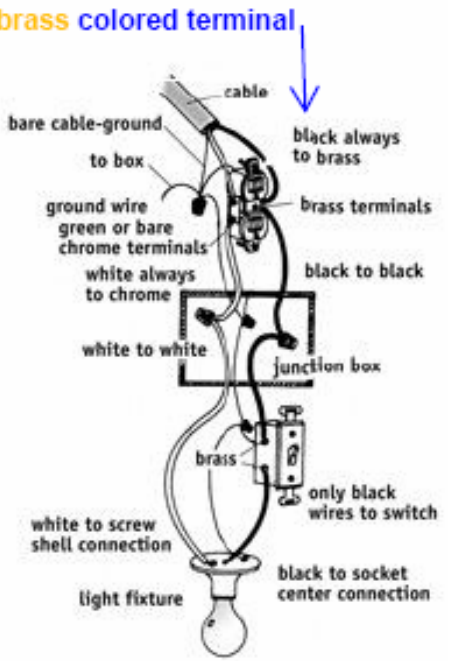


Key points to remember:

- **4 wires at the breaker box …**
  - Black … hot … 110-120 volts
  - Red … hot ….. 110-120 volts
  - White … neutral … just grounds
  - Green or bare … protection from “shorts” ground
  - Red and Black at an outlet …. 220 volts
- **3 wires at a wall outlet**
  - Black … hot … 110-120 volts
  - White … neutral … just grounds
  - Green or bare … protection from “shorts” ground
- **Wire sizes determine the safe amount of current….**

  example… #14 wire carries 15 Amps
- **Ground Fault outlets ... GFCIs .... keep you from getting killed when things get wet!!!!!!**
- **Call 911 when you set your house on fire!**

Basic Principles of Good Electrical Wiring



- Before beginning any electrical repair, shut off the power. Remove the fuse or trip the breaker for the circuit you will be working on in your service panel. Use a neon tester to be sure the power is off. If there is any doubt, you can remove the main fuse or trip the main breaker. Remember: Removing the main fuse or tripping the main breaker will usually shut off the power to the entire house.
- Electrical wires are color coded to prevent wiring errors.
- White wires almost always connect to other white wires or to chrome terminal screws on switches and receptacles.
- Some wiring devices–such as receptacles–are back-wired by pushing the bare wire end into spring grip holes. These wiring devices are plainly labeled to show which color goes into each spring grip hole.
- Switches are nearly always connected into black wires in cables. The only exception is where a cable is extended, making it necessary for the white wire to play the role of the black wire. When this is necessary, the white wires should be painted black to prevent future wiring errors.
- Study the wiring diagram. This will help you understand the basic principles of good wiring. Also, find a good electrical how-to book. It's one book every homeowner should keep on hand for ready reference.
- Most home wiring is complete with either No. 14 gauge or No. 12 gauge wiring. No. 14 is the smallest wiring permitted under most codes.
- Always use the same size cable for a continuation of any extended wiring circuit.

Useful Terms

- **Ampere**. Measures the number of electrically charged particles that flow past a given point on a circuit (per second).
- **Breaker box (breaker panel).** Houses the circuit breakers or fuses, distributes power to various parts of your house.
- **Circuit.** All wiring controlled by one fuse or circuit breaker.
- **Circuit breaker.** Protective device for each circuit, which automatically cuts off power from the main breaker in the event of an overload or short. Only a regulated amount of current can pass through the breaker before it will "trip."
- **Main breaker.** Turns the power entering your home through the breaker box on or off. This is sometimes found in the breaker box, or it may be in a separate box and at another location.
- **Neutral bus bar.** The bar to which the neutral wire is connected in the breaker box.
- **Roughing-in.** Placement of outlets, switches and lights prior to actual electrical hook-up.
- **Volt.** Measures the current pressure at receptacles and lights. Average household voltage is 120.
- **Watt.** The rate at which an electrical device (light bulb, appliance, etc.) consumes energy. Watts=volts x amps.

A 1200 watt appliance plugged into a 120 volt outlet pulls about 10 amps!!!

Cable ….. Wire

- Refers to a collection of two or more strands of wire or conductors. Basically, cable has a "hot" line to carry the current and a "neutral" line to complete the loop. They often have a third wire as that acts as a grounding wire.
- Classified according to the number of wires it contains and their size or gauge.
- All cables are marked with a series of letters followed by a number, a dash and another number. The letters indicate the type of insulation (cord, wire and insulation). The first number indicates the resistance of the wires in the cable, and the number following the dash indicates the number of individual conductors in the cable.
- If the designator "G" follows the series it means that the cable is also equipped with a non-current-carrying ground wire. Hence, the designator USE 12-3/G indicates an underground cable containing three separately insulated wires capable of carrying 20 amps of current plus a grounding wire.
- The most common jackets are NM-B (Non-Metallic Building Indoor), UF-B (Underground Feed) and BX, which is flexible metallic cable.

Wire Gage	Amp Capacity
10	30
12	20
14	15
16	10
18	5
20	3.3

- **Two-conductor cable** contains one black wire and one white wire. The black wire is always the "hot" wire and must be fused. The white is always neutral and must never be fused. When current bridges the gap from the 110V hot wire to the neutral, it results in a 110V input to the appliance.
- **Three-conductor cable** contains a red wire in addition to black and white. The black and red wires are "hot," carrying 110V each, and both must be fused. The white remains neutral. This three-wire circuit is increasingly common in home wiring; it accommodates major 220V appliances, such as ranges and air conditioners.
- **BX cable** is armored metallic cable. It consists of two or three insulated wires individually wrapped in spiral layers of paper. The steel casing acts as a ground wire. There is also a bond wire included in the casing that acts as a ground if the casing breaks.
- **Romex™ cable** is a flat, beige thermoplastic jacket surrounding two or three wires. Each wire is wrapped in insulation and a spiral paper tape. Type NM means it can be used indoors. Type NMC means it can be used indoors or outdoors. Type UF means it is suitable for use underground outdoors.

Copper wire resistance table

AWG	Ampacity	Feet/Ohm	Ohms/100ft
10	30	490.2	.204
12	20	308.7	.324
14	15	193.8	.516
16	10	122.3	.818
18	5	76.8	1.30
20	3.3	48.1	2.08
22	2.1	30.3	3.30
24	1.3	19.1	5.24
26	0.8	12.0	8.32
28	0.5	7.55	13.2

Cable ….. Wire

Wire sizes ---- USA --- inside wall

- For a 20 amp circuit, use 12 gauge wire.
- For a 15 amp circuit, use 14 gauge wire (in most locales).
- For a long run, though, you should use the next larger size wire, to avoid voltage drops. Go up a size for more than 100 foot runs, when the cable is in conduit, or ganged with other wires in a place where they can't dissipate heat easily:

Wire Gage	Amp Capacity
10	30
12	20
14	15
16	10
18	5
20	3.3

Here's a quick table for normal situations.

Gauge	Amps
14	15
12	20
10	30
8	40
6	65

Copper wire resistance table

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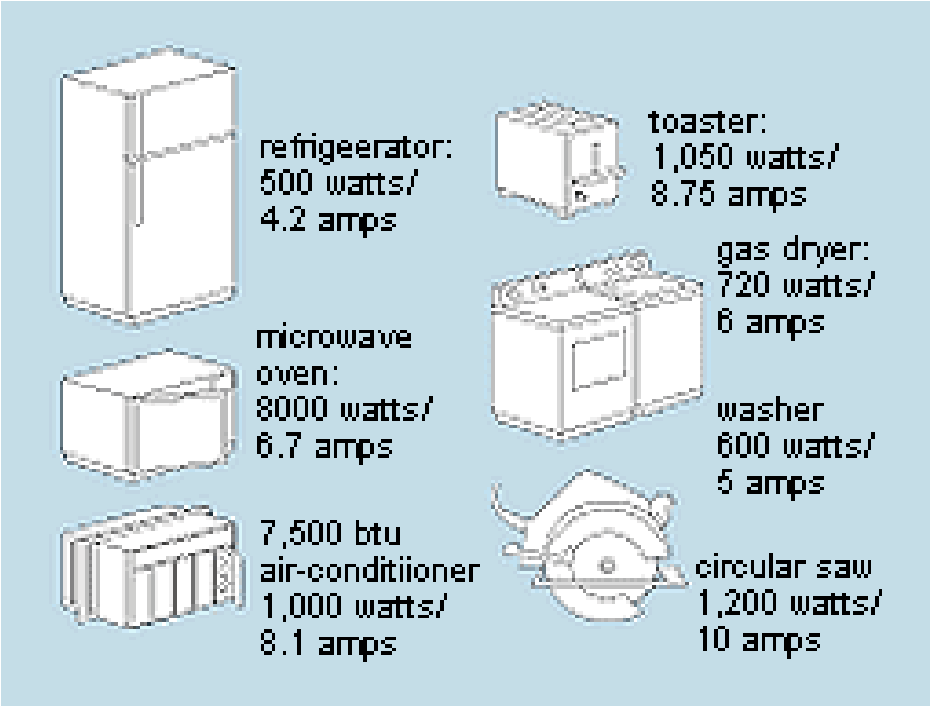
Amps drawn by certain appliances & amp capacities by wire gages



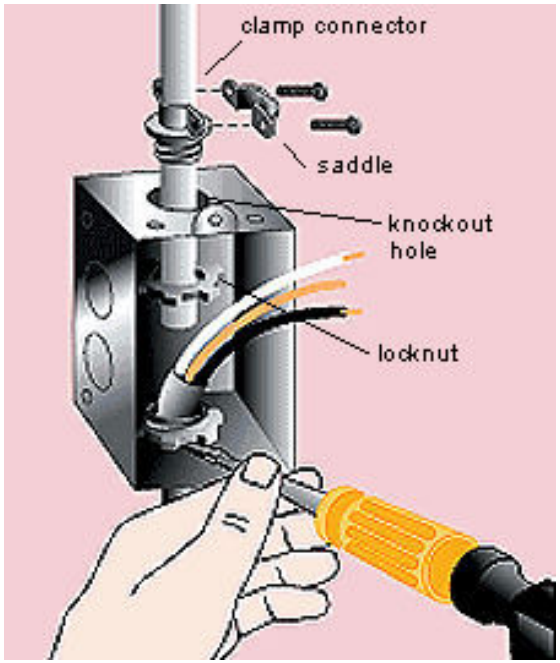
Wire gage	Amps
14	15
12	20
10	30
8	40
6	65

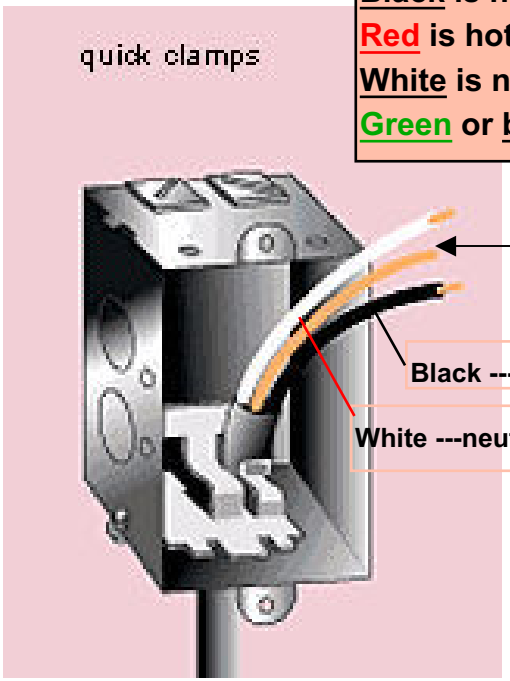
Wiring inside walls

- For a 20 amp circuit, use 12 gauge wire.
- For a 15 amp circuit, use 14 gauge wire (in most locales).
- For a long run, use next larger size wire, to avoid voltage drops. (Go up a size for more than 100 foot runs, when the cable is in conduit, or grouped with other wires in a place where they can't dissipate heat easily.)

Wiring colors:

Black is hot ---110 volts
Red is hot --- 110 volts ... 180 degrees out of phase with black
White is neutral
Green or **bare** .... ground

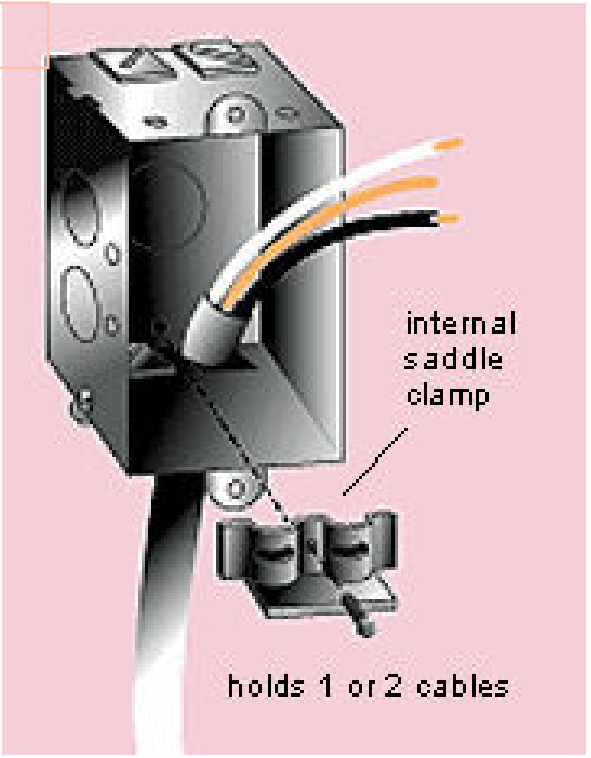


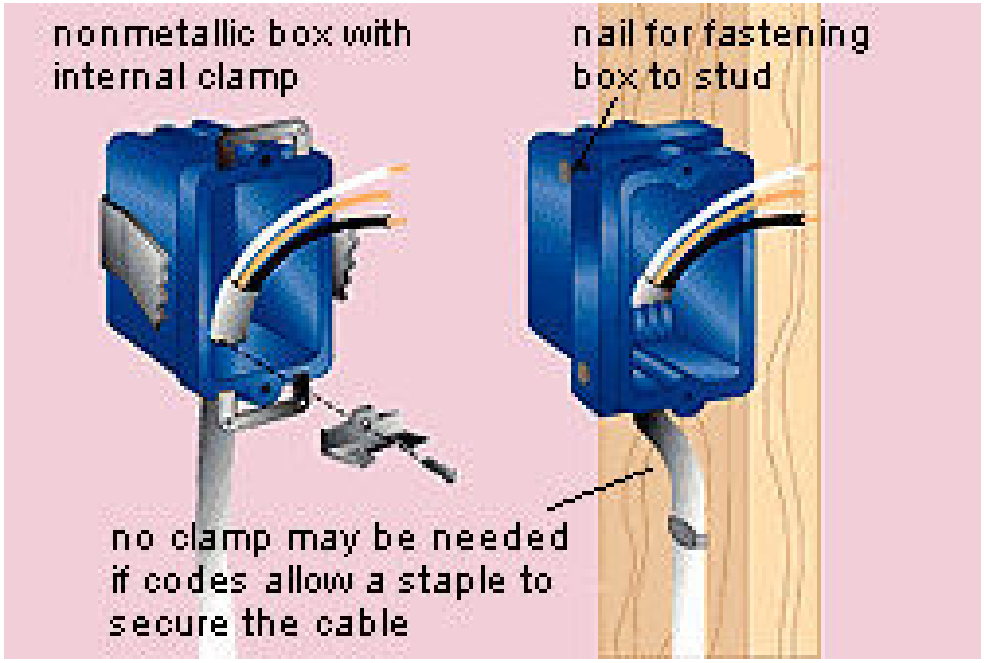


Copper wire is a ground; same as green

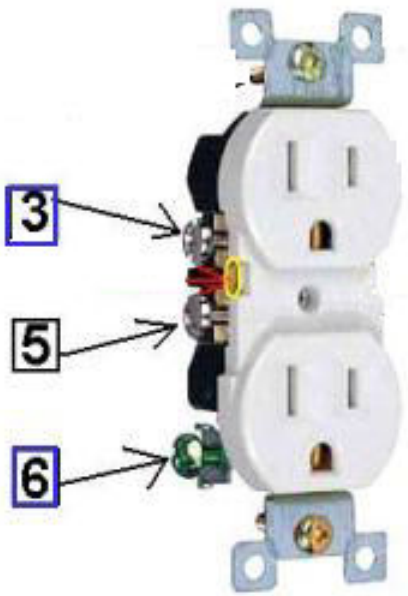
Black ---110 volts

White ---neutral





White wire to silver screw … "neutral" … not hot

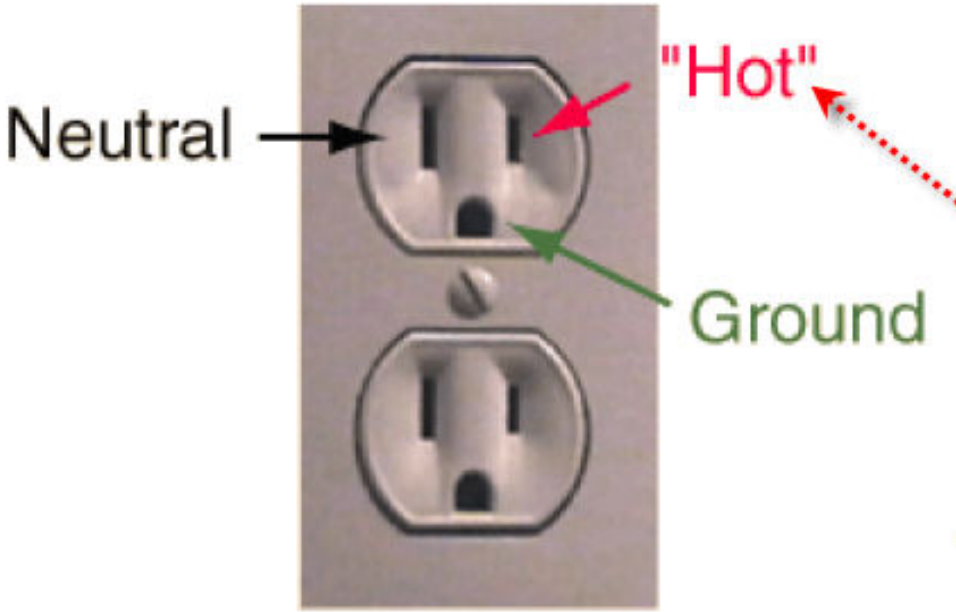


Black wire to copper screw … "hot"

Green wire or bare copper wire … "ground"

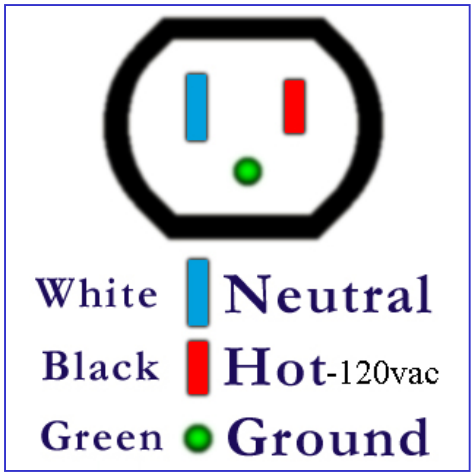
3 & 5 … Silver color screws, this is where your grounded leg {aka neutral} wire goes, this by North America standards should be a white wire, however it can be white or gray.

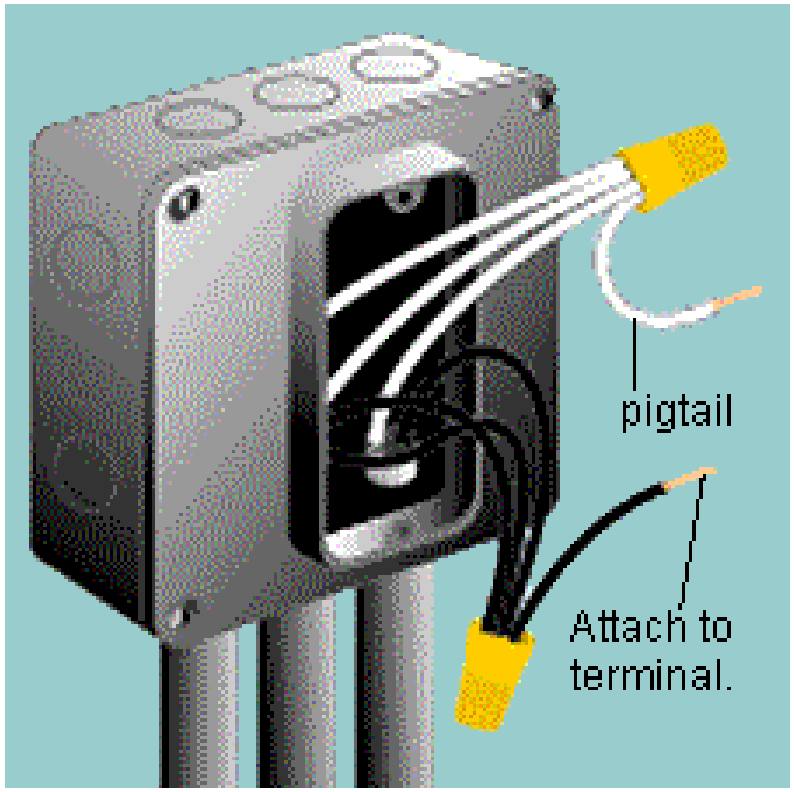
10 & 12 … Brass color screws, this is where the ungrounded leg [aka hot conductor] wire is attached, the most frequently used wire colors are black & red but can be {any color in rainbow but white, gray, bare or green]

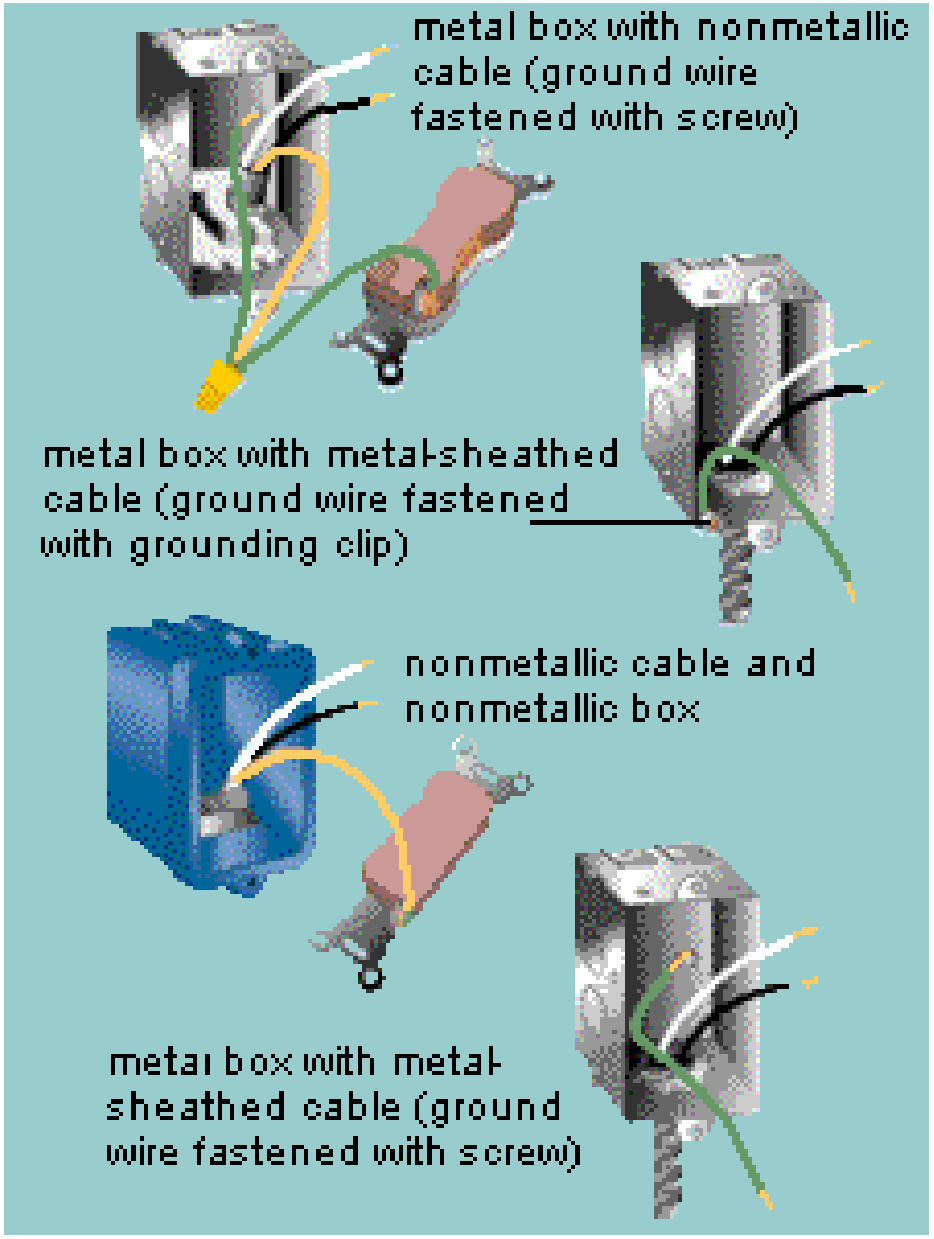


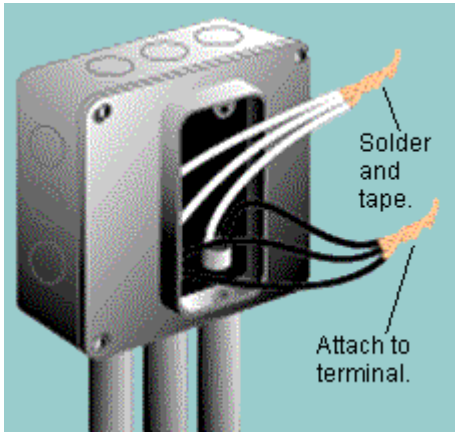
The high voltage (about 120 volts effective, 60 Hz AC) is supplied to the smaller prong of the standard polarized U.S. receptacle. It is commonly called the "hot wire". If an appliance is plugged into the receptacle, then electric current will flow through the appliance and then back to the wider prong, the neutral.

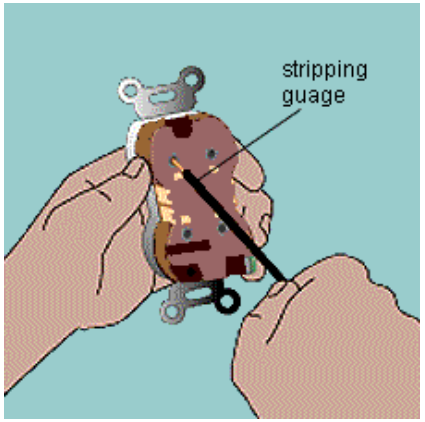
The neutral wire carries the current back to the electrical panel and from there to the earth (ground). The ground wire is not a part of the electrical circuit, but is desirable for prevention of electric shock.



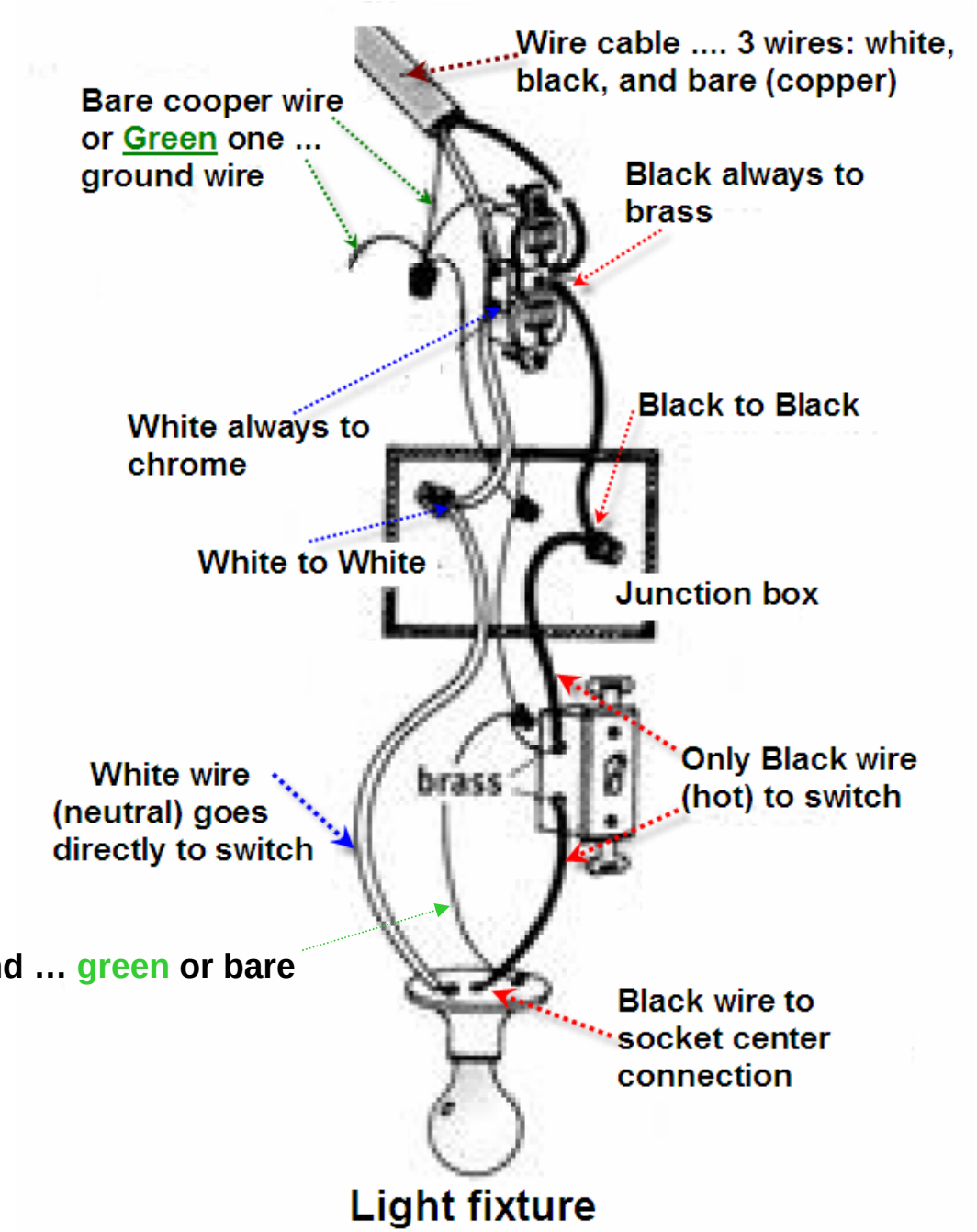

pigtail
Attach to terminal.


metal box with nonmetallic cable (ground wire fastened with screw)
metal box with metal-sheathed cable (ground wire fastened with grounding clip)
nonmetallic cable and nonmetallic box
metal box with metal-sheathed cable (ground wire fastened with screw)

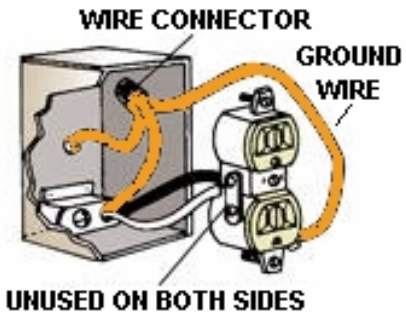

Solder and tape.
Attach to terminal.


stripping guage

A closer look ….
Wiring up a light



CONNECT NEW WIRING TO LAST OUTLET IN CABLE

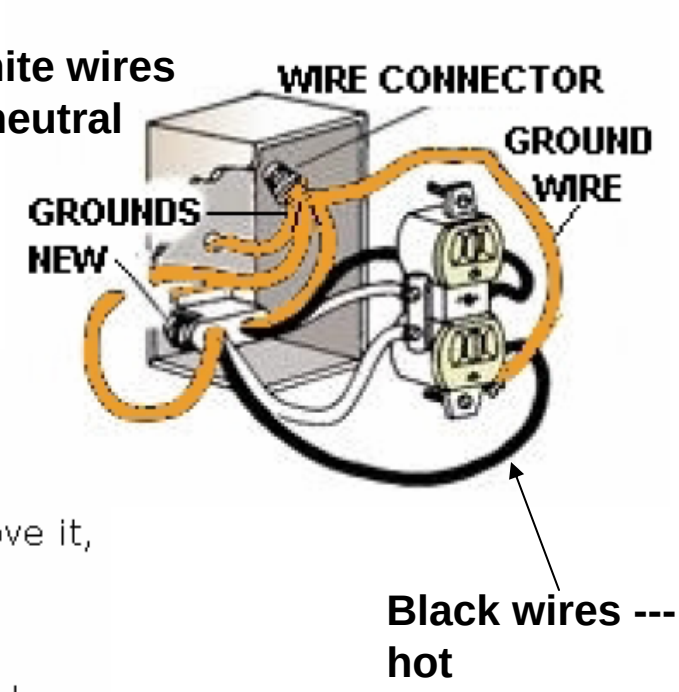


- New wiring should be connected to the last outlet in a run of cable. To locate the last outlet in the run, shut off the current. Remove the cover plates from each outlet on the circuit. The last outlet in the run has wires connected to only two of the four terminal screws.

- The two unused terminal screws on the last receptacle serve as a starting point for wiring to a new outlet.

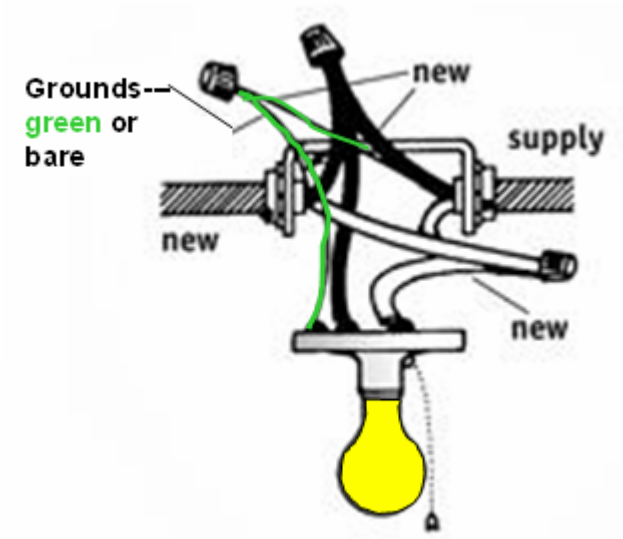
See next page …

ATTACHING CABLE FOR NEW WIRING



- Shut off the power to the circuit you will be working on at the service panel.
- Loosen the screws holding the receptacle in the box and remove it, as shown.
- Attach the the earth wire (the bare or green) to the chrome terminal. The yellow (or green in some instances) wire should be connected to the receptacle and the box maintaining the equipotential bonding on the earth system. The earth wires should only be connected to the correct screw terminals on the recepticle to the brass terminal on the receptacle and to the box, if the box is metal.
- Use care to match the size of the original cable. If No. 12 wire is used, continue with No. 12. If No. 14 wire is used, use No. 14 for continuing the cable. The size of the cable is usually stamped on the side of the cable.
- New wiring can be connected to continue the run beyond the last receptacle. Note that the new wires are pulled through knockout plugs in the back of the outlet box.

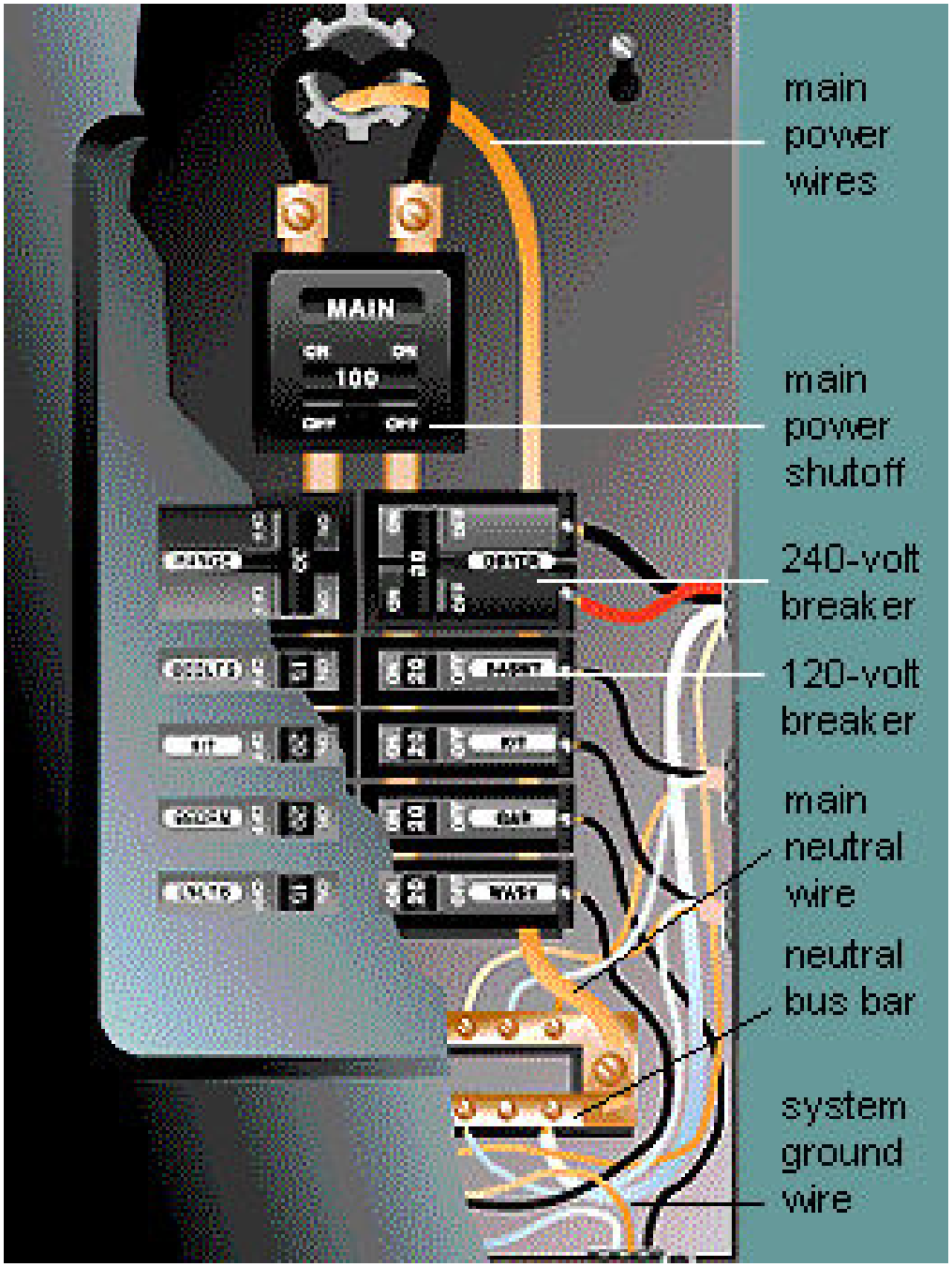
TYING IN NEW WIRING AT A CEILING LIGHT



- You can tie in new wiring at a ceiling light if the light is not controlled by a switch.
- Shut off the current at the service panel.
- Tie white wires to white wires and black wires to black wires, as illustrated.
- Connect the ground wires as illustrated. If you are using a metal box, attach them to the box as well as the light fixture.
- Knock out an opening in the outlet box, and continue the new wiring as illustrated.

Distributing current throughout the house:

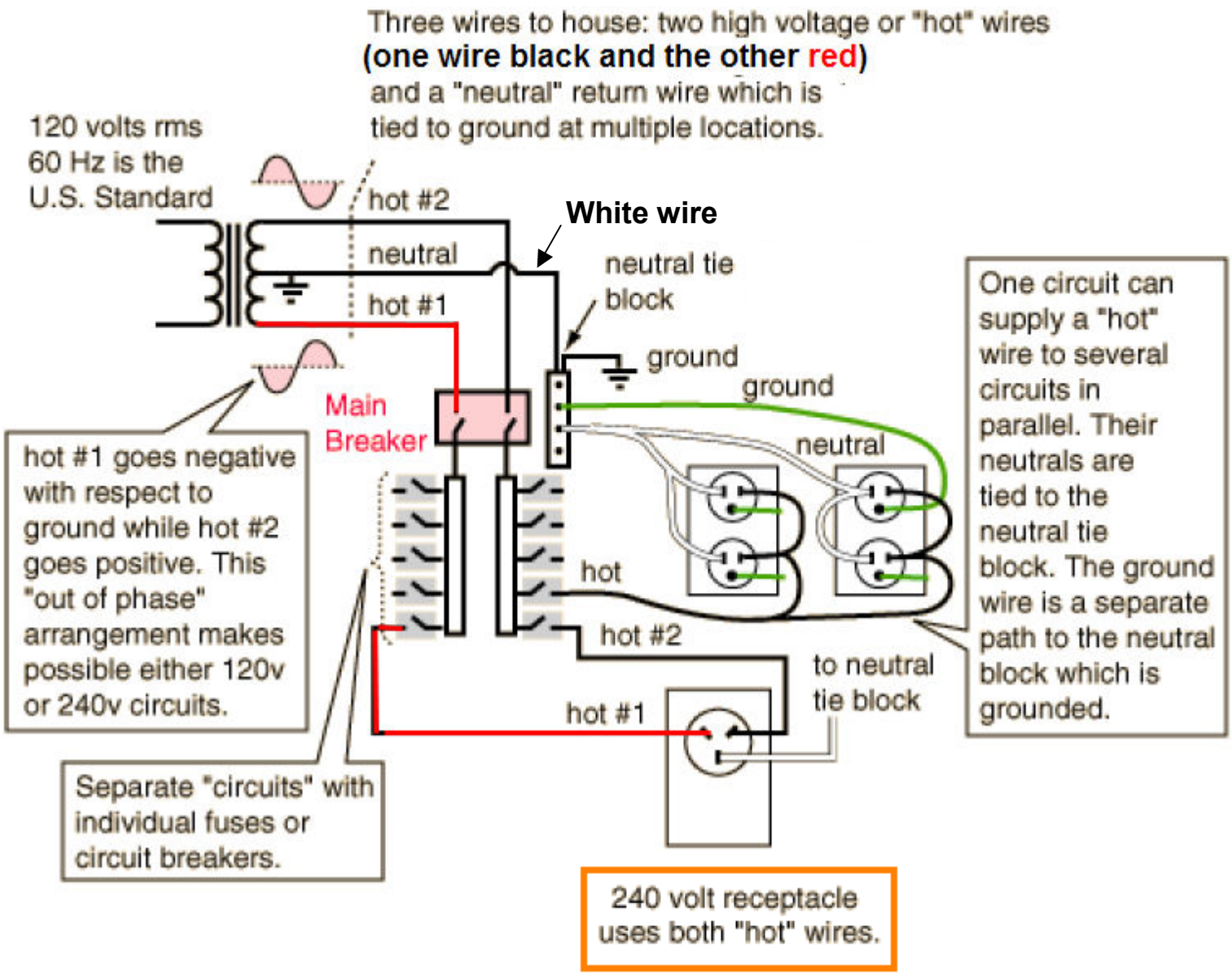
A look at the mysterious "breaker box" ...



Home Service "Breaker Box"

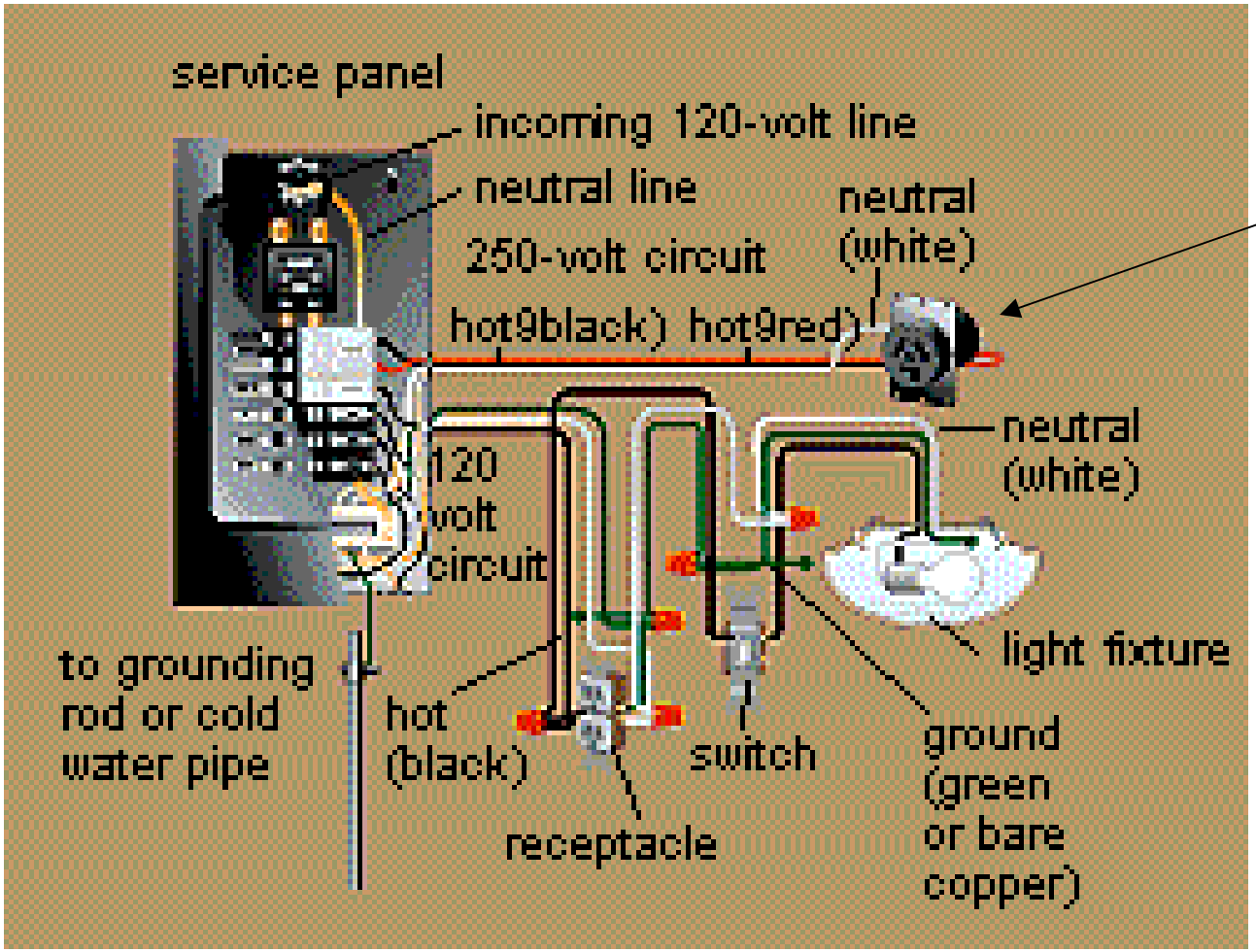
Usually 200 Amp service

Power pathway ... from the service to the outlet



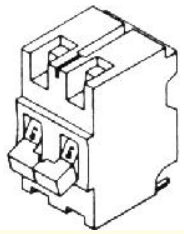
Wiring from the service panel

- Red and black wires are hot … and probably 180 degrees out of phase
- White wires are neutral … not hot
- Green is a ground … it grounds "shorts" in appliances, etc

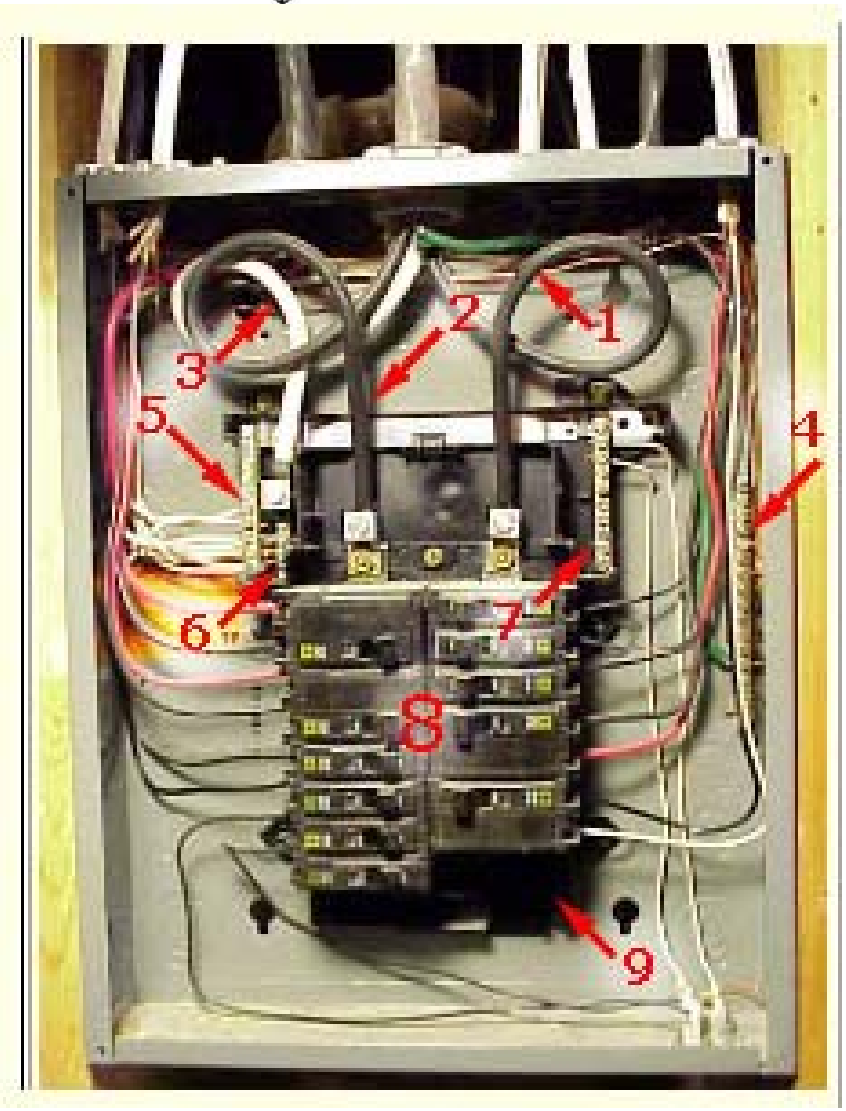


- Red and black wires in an outlet =220 volts

Grab the red and black wires together and you become a "french fry!"



Breakers and Breaker Boxes



A Bit Of Anatomy:

1, 2. Incoming Hot wires. There is 240 volts between these wires, or 120 volts between either wire and the neutral line.

3. Neutral wire. This is at the same electrical potential as the ground. At the main breaker only, the neutral is connected to ground.

4. Ground Bus Bar. This strip of metal has a row of screws for connecting the ground wires of the various circuits.

5, 6, 7. Neutral Bus Bars. This panel has 3 short bus bars for neutral wire connections. Some panels have only one long bar.

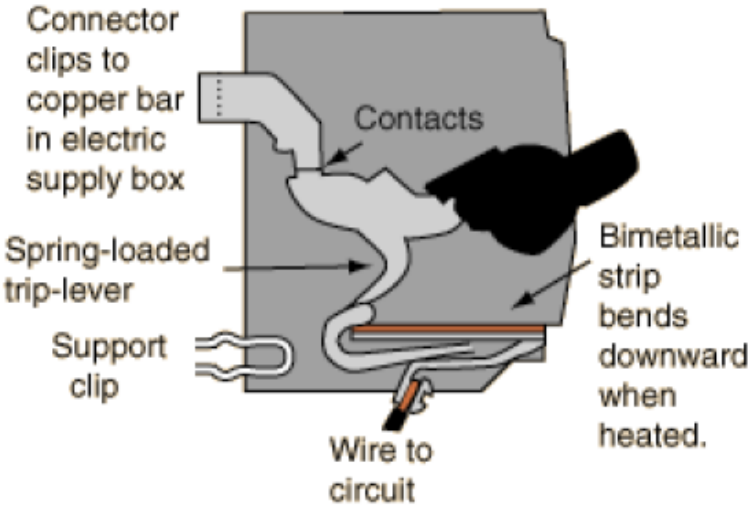
8. Circuit Breakers. Each single-pole breaker connects to one of the two hot bus bars. Each double-pole breaker connects to both of the bus bars (thus providing 240 volts between hot wires).

9. The last available space in this panel. Our new breaker will go here.

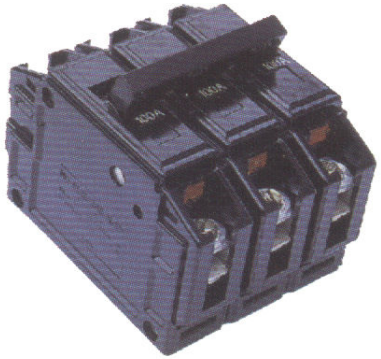
The Circuit-Breaker

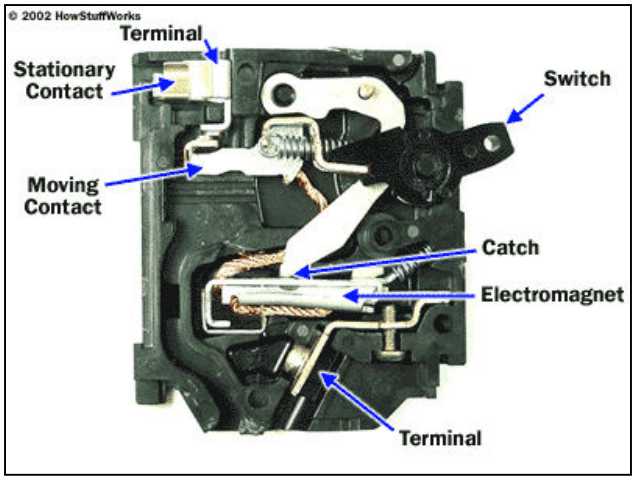
For when you plug a toaster and an iron in the same outlet!!! .....

Circuit breakers act to limit the current in a single circuit in most household applications. Typically a single circuit is limited to 20 amperes, although breakers come in many sizes. This means that 20 amps of current will heat the bimetallic strip to bend it downward and release the spring-loaded trip-lever. Since the heating is fairly slow, another mechanism is employed to handle large surges from a short circuit. A small electromagnet consisting of wire loops around a piece of iron will pull the bimetallic strip down

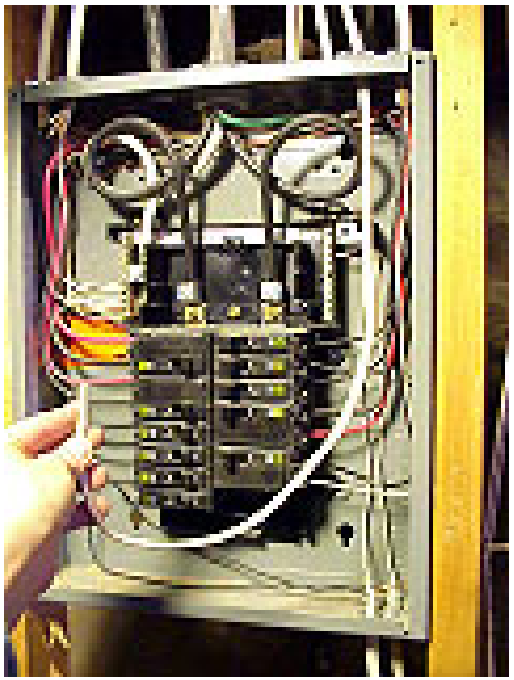


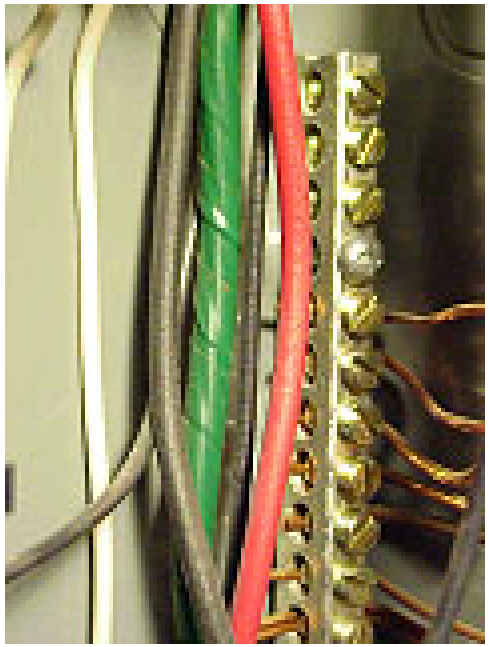
This is a simplified mechanism. the standard breaker has several springs and levers.

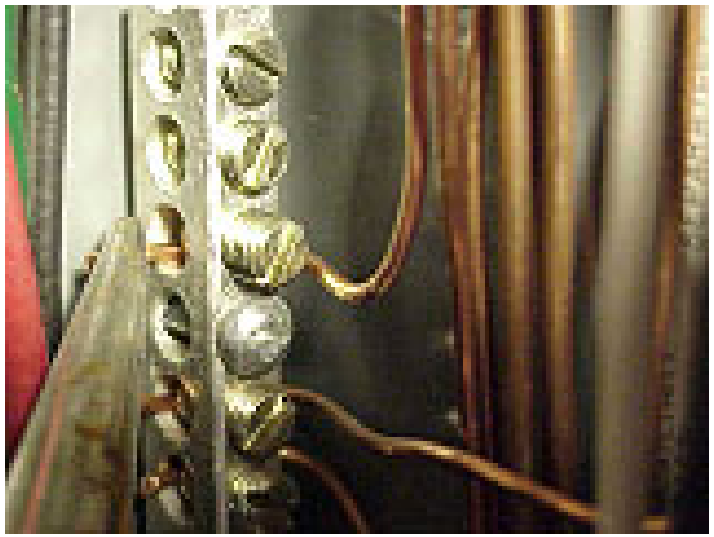


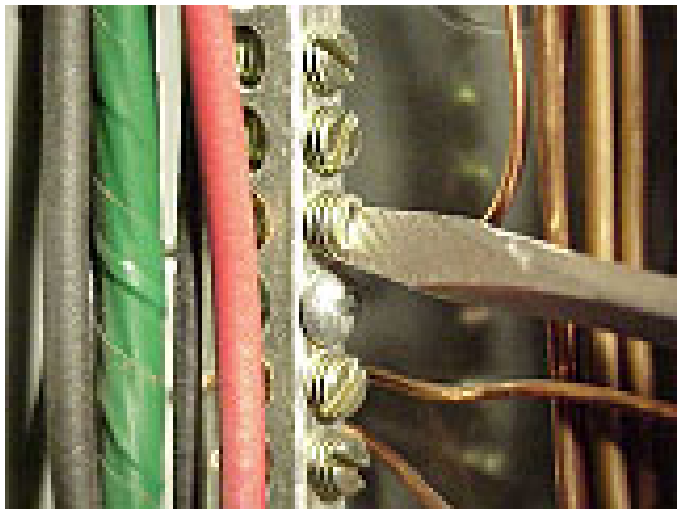


Connecting the Ground Wires

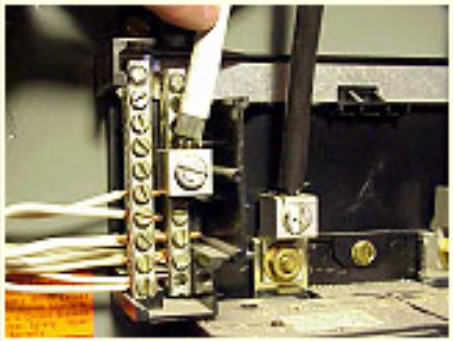






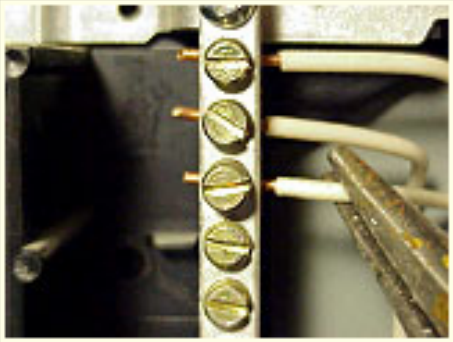


Connecting The Neutral Wire



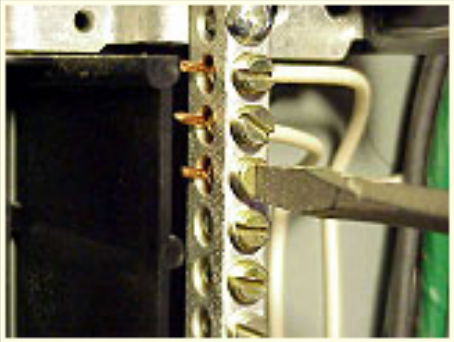
The neutral line feeding the panel is supposed to be marked white (this one was covered with white electrical tape, which is OK).

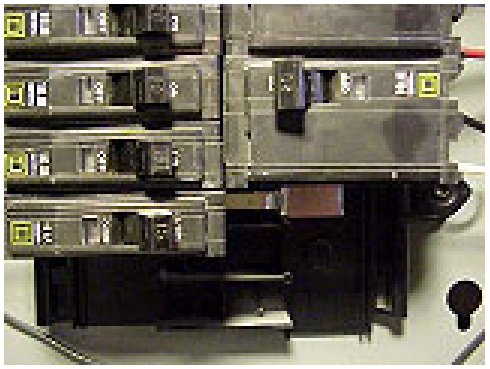
I routed the wire neatly and made some bends.

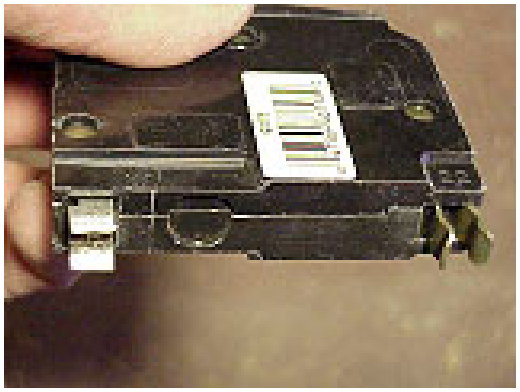


I stripped the insulation from the end of the wire and inserted the bare end into a connection terminal.

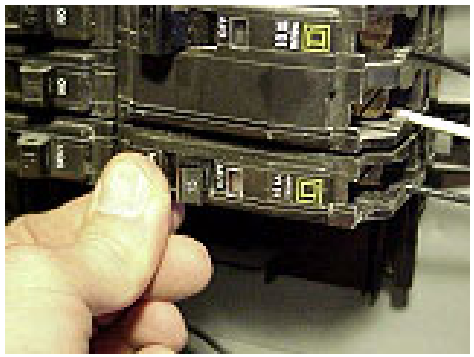
The screw was tightened.

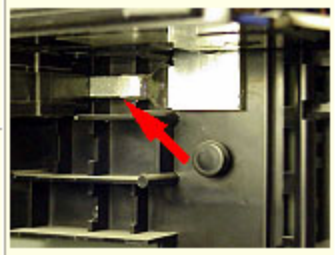
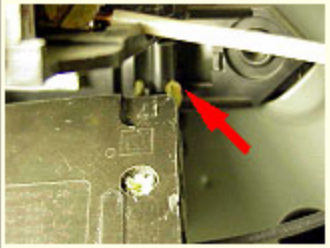
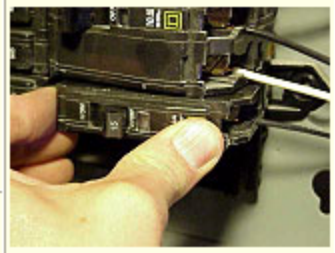




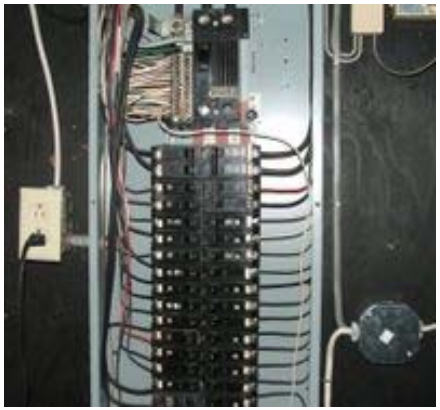


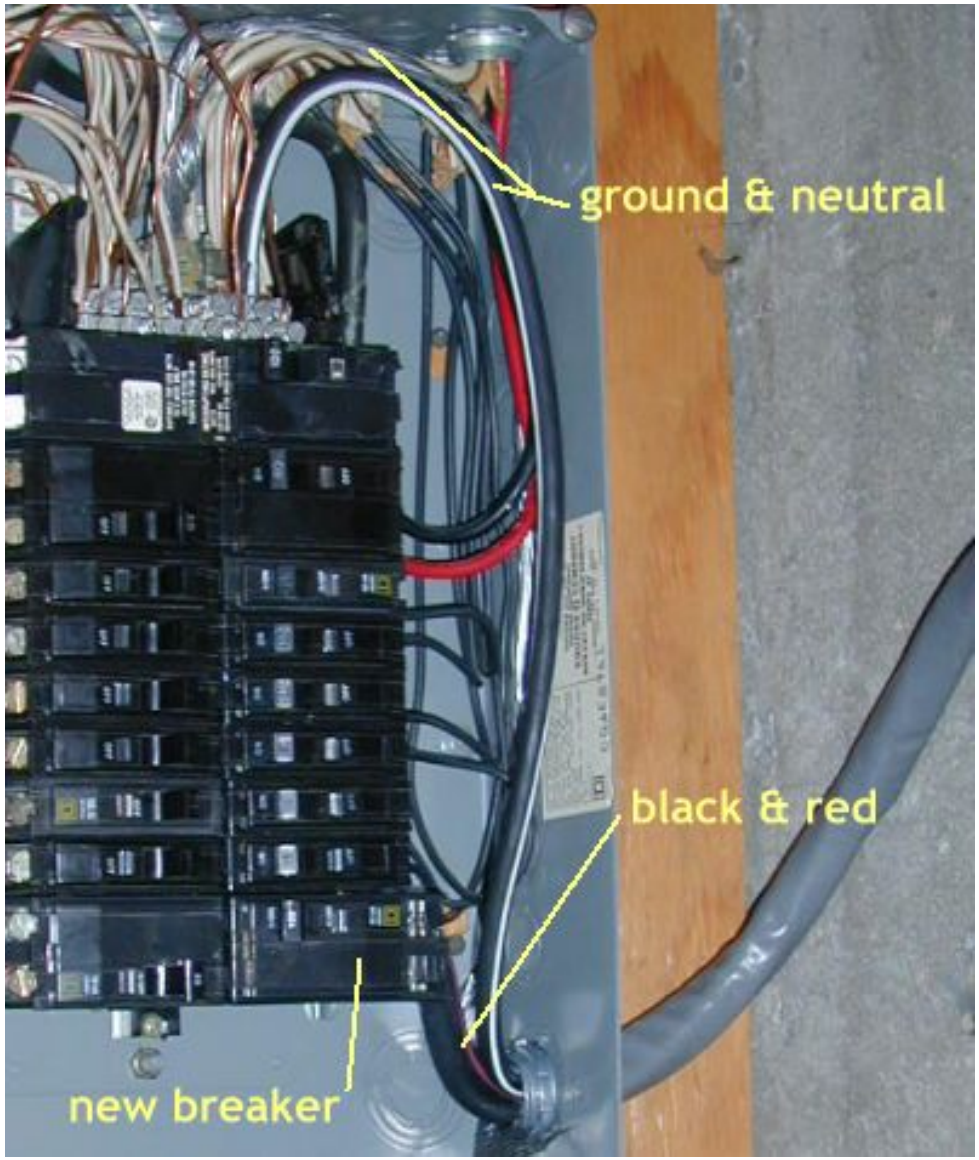
Wiring in a breaker on the "hot line"



	The hot wire was stripped and secured under the screw.	
	Note the metal bus bar. The circuit breaker grabs on here.	
	The installation sequence. First the hold-on clip is pushed onto the plastic bar. (I angled the breaker so a photo could be taken. In practice the breaker is parallel to its neighbor.)	
	With my thumb I pushed firmly until the breaker was seated. The left end was still not connected.	

Another view ....





"Stuff" you might need when doing your own electric wiring .....

Wall Box

- Used for housing switches and receptacles.
- Made of metal or plastic and have the capability to be mounted to a wall or stud.
- The holes in the side of the box where the conduit enters the box are called knockouts. In metal boxes, conduit can also be secured to the holes.
- One type is a Four-Inch Square box that is only 1-1/2" or 2"deep for places too shallow to mount a standard box.
- A *Handy box* is surface mounted and has rounded corners for safety.
- A *Drywall box* has expandable arms and can be mounted on drywall.
- A *Plastic box* is best for new installation and often has a nail built-in for quick attachment to the stud.
- A *Gem box* is a commonly made box, usually 2" wide, 3"high and 2-1/2" deep and made of metal. Deeper boxes are available.

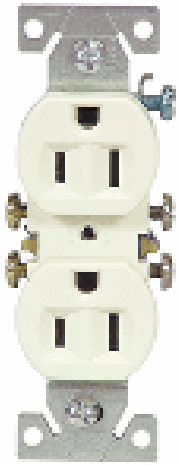
"Stuff" you might need when doing your own electric wiring .....

Ceiling Box

- Also known as a junction box or splice box.
- Used to anchor ceiling fixtures and serves as a junction box where wires can meet and run to other areas of the room.
- They are either 4" octagonal or round shaped, and either 1-1/2" or 2-1/8" deep.
- They also may include adjustable mounting hangers that attach to rafters in the ceiling and allow the box to be placed anywhere between.
- Hangers also provide the short nipple or threaded rod that secures lighting fixtures.

"Stuff" you might need when doing your own electric wiring .....

Receptacle



- Taps the electrical circuit to provide power at a given location.
- Available in flush- or surface-mounted designs.
- A single- or double-wipe contact refers to the area of the inserted prong where the contact is made.

GFCI Receptacle

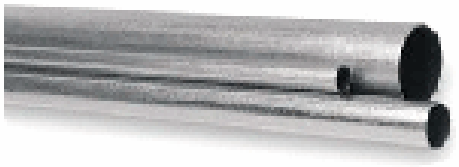
- Stands for Ground Fault Circuit Interrupter.
- Also known as a GFI or ground fault interrupter
- Used to protect against ground faults, which occur when a person comes into contact with a live electrical wire. This may be caused by worn insulation on a wire or by operating a faulty appliance or power tool.
- The GFCI interrupts power quickly enough to help prevent a lethal dose of electricity.
- To turn the GFCI back on after it trips, push the reset button located in the middle of the switch.
- They can be installed as a receptacle or at the main power panel.

"Stuff" you might need when doing your own electric wiring .....

Wire Channels

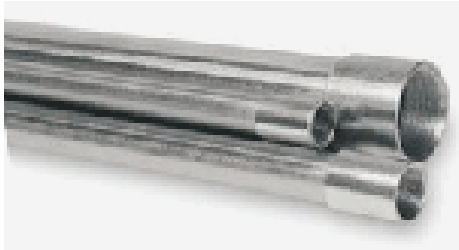
- Also known as raceway.
- Metal or plastic channels used to house wiring installed on the surface, instead of behind walls.

Thin-Wall Conduit



- Also known as EMT (electric metallic tubing).
- Steel pipe used to carry house wiring in places where it is exposed.
- Comes in inside diameters of 1/2" to 4". 1/2" is most common.
- Do not use underground.

Heavy-Wall Conduit



- Also known as rigid conduit.
- Comes in the same sizes as EMT but has thicker walls.
- Has threaded ends for connections.
- Use for carrying wire outdoors and underground.

"Stuff" you might need when doing your own electric wiring .....

Plastic Conduit

- Easy to use.
- Use inside and outside.
- Best for burying underground as it will not corrode with water.

Greenfield Conduit

- Also known as flex conduit.
- A hollow spiral metal jacket that resembles BX cable.
- Use for installing wiring in the home

Conduit Connectors

- Used to connect lengths of conduit.
- Can make straight or bent connections.
- Conduit can also be bent to a 90º curve using a conduit bender

LB Fitting

- Connects at a 90º angle.
- Has thick gaskets to make it impervious to moisture.
- Generally, an LB fitting is placed outside at the point where the conduit leaves the house.
- This fitting should not be used to make wire connections

Conduit Fasteners

- Use to fasten conduit to a wall or other framing member.
- Staples can be used to fasten conduit or bare cable.
- Straps are another type. They can be either one-hole or two-hole.
- Generally, staples are best used inside the house, straps are best used outside.

Pig-tailing

Pig-tailing connects two or more wires together with another 6" pigtail wire that has been stripped 3/4" on each end. The pigtail wire will be the wire you connect to the outlet or switch. This reduces the number of wires to be connected at the receptacle. Below are some of the common uses of pig-tailing.

Note: Most manufactures recommend cutting the wires so that they are even on the end, then applying the nut. When the nut is tightened, it will twist the wires and make a secure connection.

Connecting wires at a duplex receptacle. Strip all wires 3/4" and then hold all of the wires of like color together with another 6" wire of the same color. Twist the ends of the wires being connected with the pigtail wire tightly together. Then screw on a wire nut of the appropriate size. You can check the security of your connection by holding the wire nut and giving a good tug to each wire.

Now it is a simple matter to connect the pigtail portion of the connection to the terminal black to brass, white to silver, and the bare grounding wire to the grounding screw. Once pigtailed, it is easier to bundle all of the wires together to fit them into the box. Then you can simply screw the duplex receptacle (outlet) onto the electrical box with the screws provided.

Watch out for water!!!!!! .....

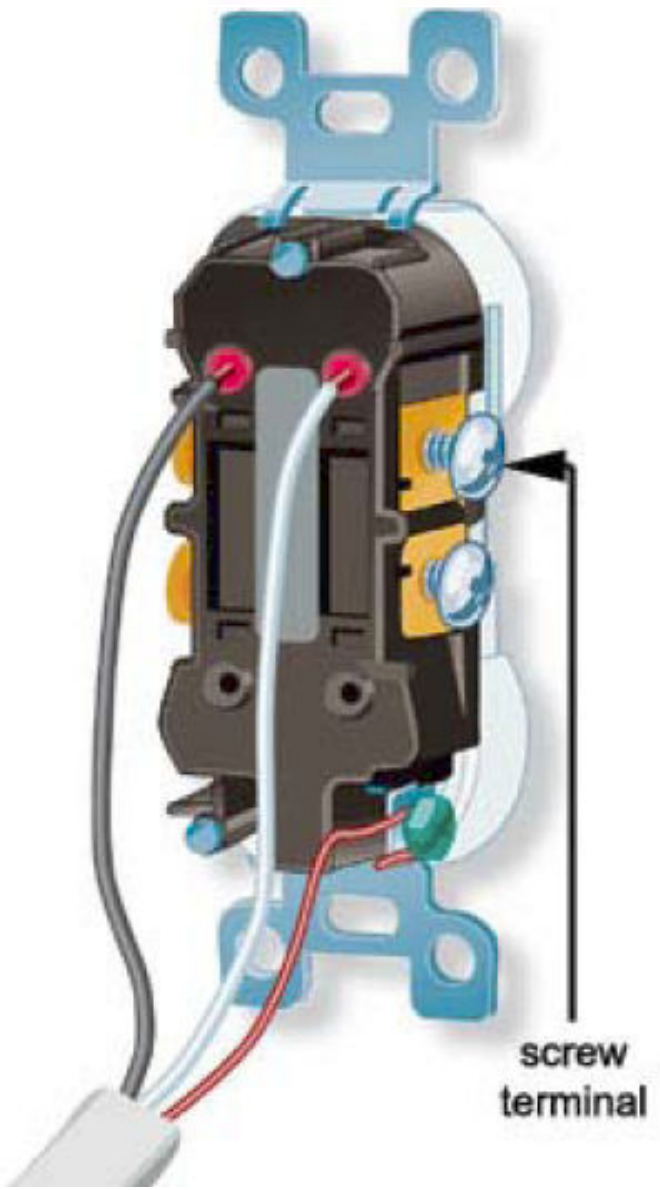
Outdoor Wiring

Basically, wiring fixtures suited for exterior use is the same as wiring indoor fixtures. However, exterior moisture-proof coated wires and boxes must be used. If possible, choose an outdoor outlet location that is convenient to get to, as well as close to an indoor receptacle. This will simplify the installation.

Outside outlets (or those in the bathroom, or garage) must also include ground fault interrupters. GFIs measure the amount of power the hot wire brings in and the neutral wire returns. If there is a 5 milliamp difference or more, due to excessive moisture, the outlet automatically shuts off. This reduces your chances of shock in wet or high-moisture areas. A GFI is usually a type of circuit breaker that is installed in the breaker box, whereupon you then use a normal outlet or an exterior light, the circuit of which is attached into a GFI breaker. However, GFIs also come built directly into the receptacle. The circuit of that receptacle can then be attached to a standard breaker or fuse.

Ground Fault ... GFCI .... keeps you from getting killed when things get wet!!!!!!

.... more than you ever wanted to know.....



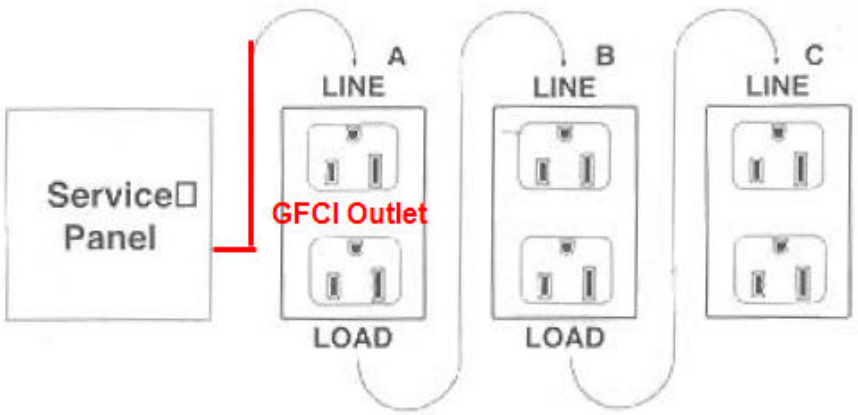
Ground Fault Interrupter

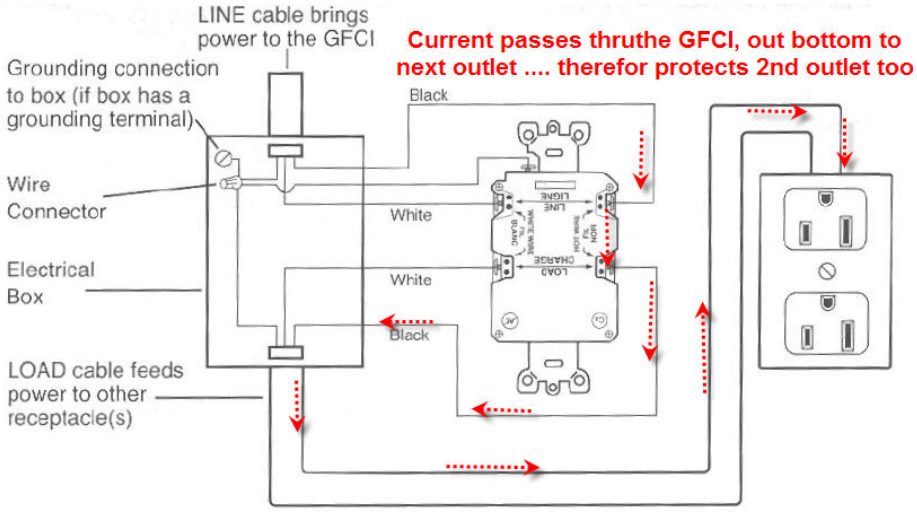
Ground fault interrupters are designed to protect from electrical shock by interrupting a household circuit when there is a difference in the currents in the "hot" and neutral wires. Such a difference indicates that an abnormal diversion of current from the "hot" wire is occuring. Such a current might be flowing in the ground wire, such as a leakage current from a motor or from capacitors. More importantly, that current diversion may be occuring because a person has come into contact with the "hot" wire and is being shocked. When a circuit is functioning normally, all the return current from an appliance flows through the neutral wire, so the presence of a difference between "hot" and neutral currents represents a malfunction which in some circumstances could produce a dangerous or even lethal shock hazard.

The GFI is designed to detect currents of a few milliamperes and trip a breaker at the receptacle or at the breaker panel to remove the shock hazard.

The GFI has a "Test" button which causes a small difference between "hot" and neutral currents to test the device. In an example given by John de Armond, the test button put the 120 volt supply across a 14.75 K resistor, producing a current of 8.2 mA. The UL requirement for a GFI is that it trip when there is 5 mA of leakage current. There is also a reset button to use after it has been tripped.

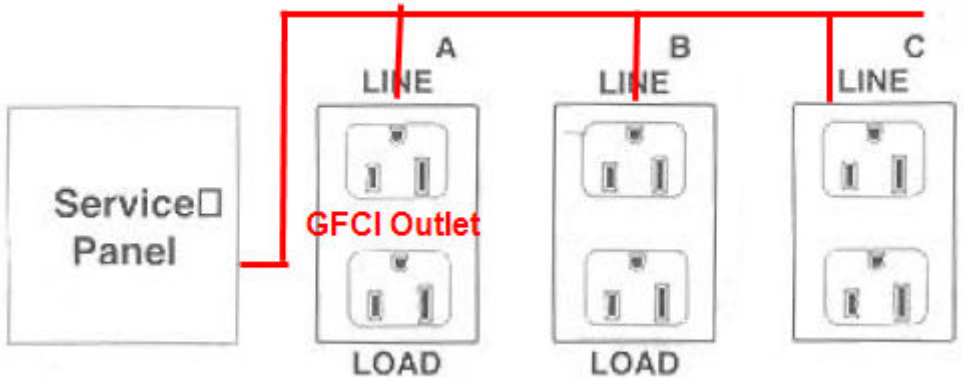
Wiring thru one GFCI to protect 3 outlets

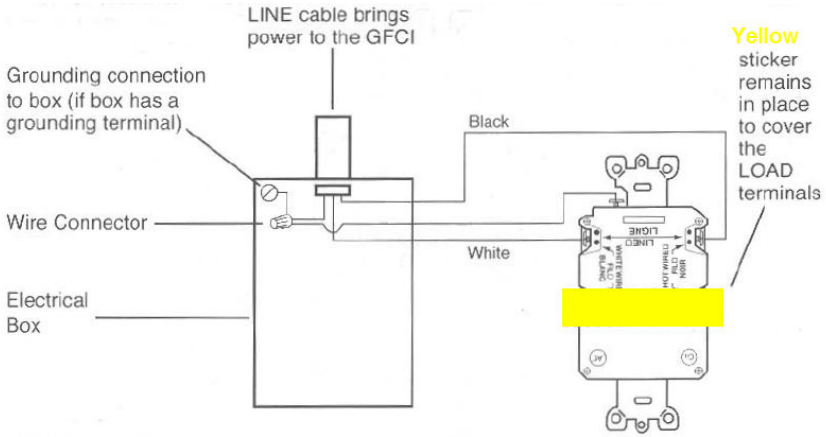




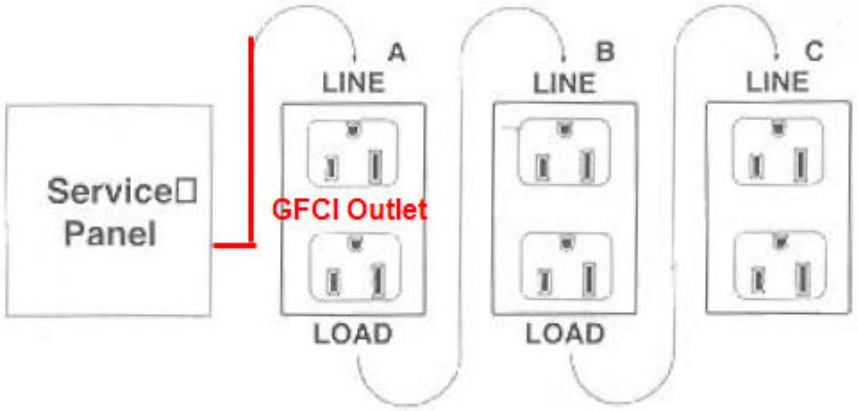
Placing the GFCI in position A will provide protection to "load side" receptacles B and C.

Wiring to one GFCI ... no protection to other 2 outlets

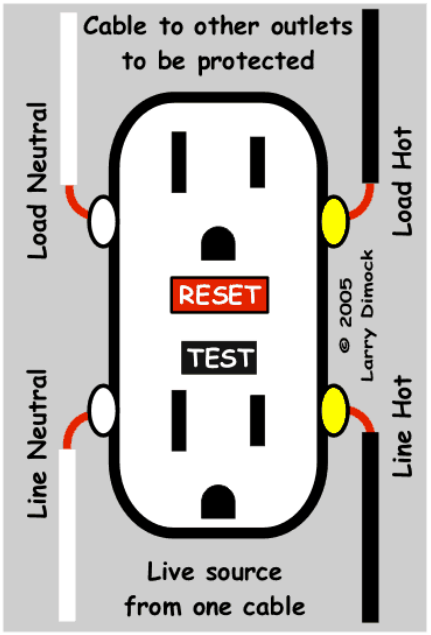




Wiring thru one GFCI to protect 3 outlets

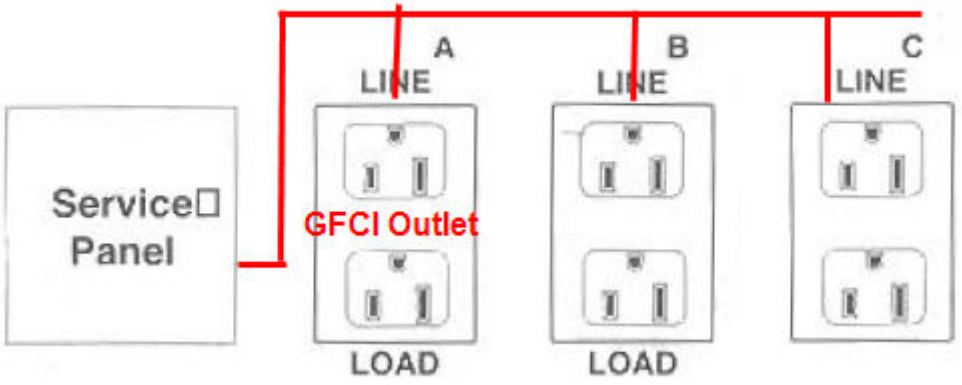


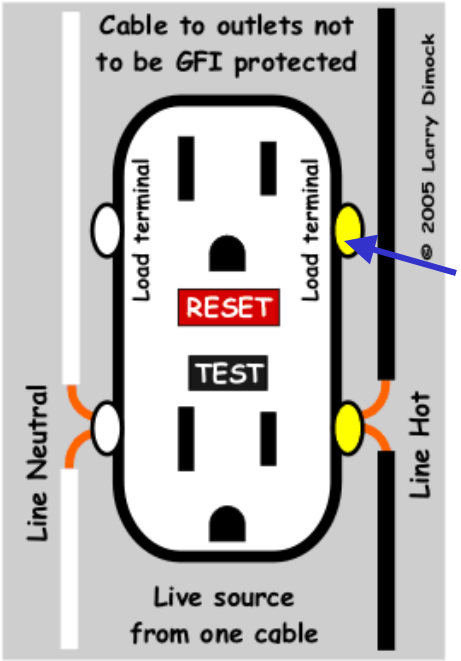
Placing the GFCI in position A will provide protection to "load side" receptacles B and C.



Load passes thru the sensor

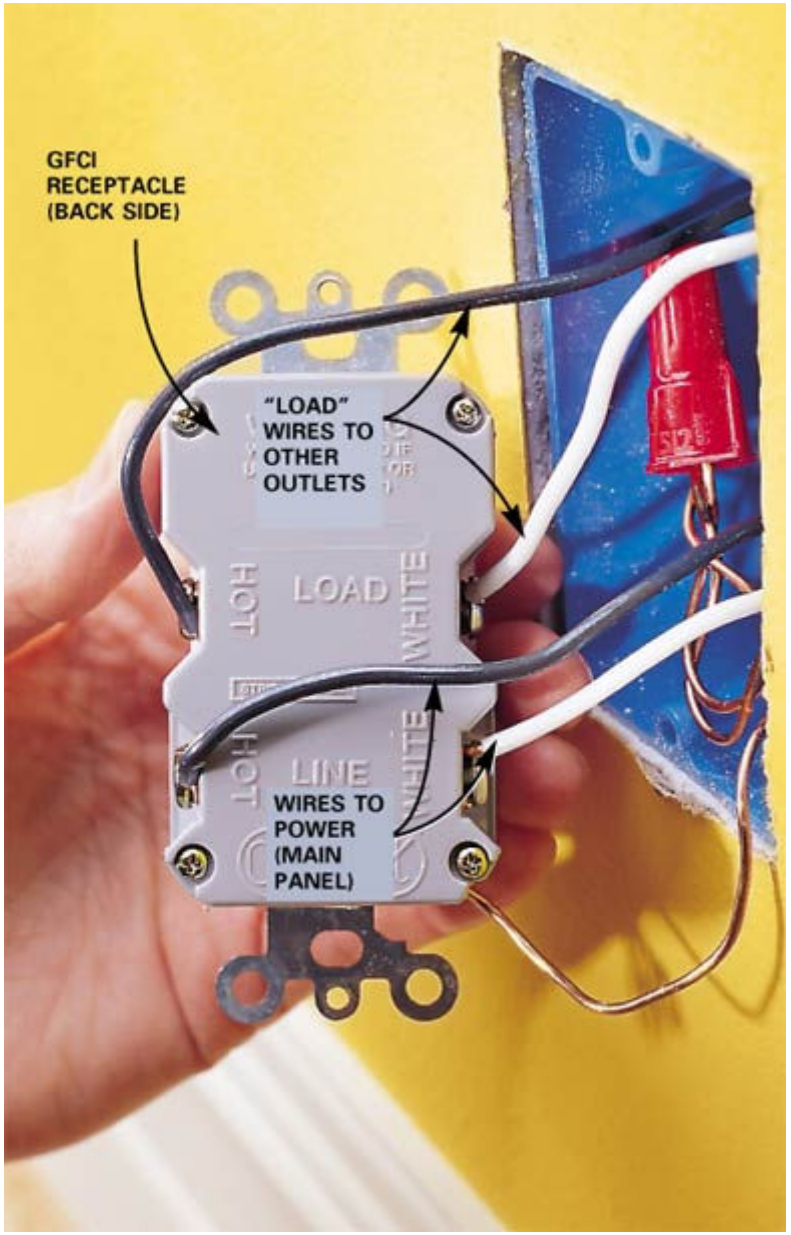
Wiring to one GFCI ... no protection to other 2 outlets

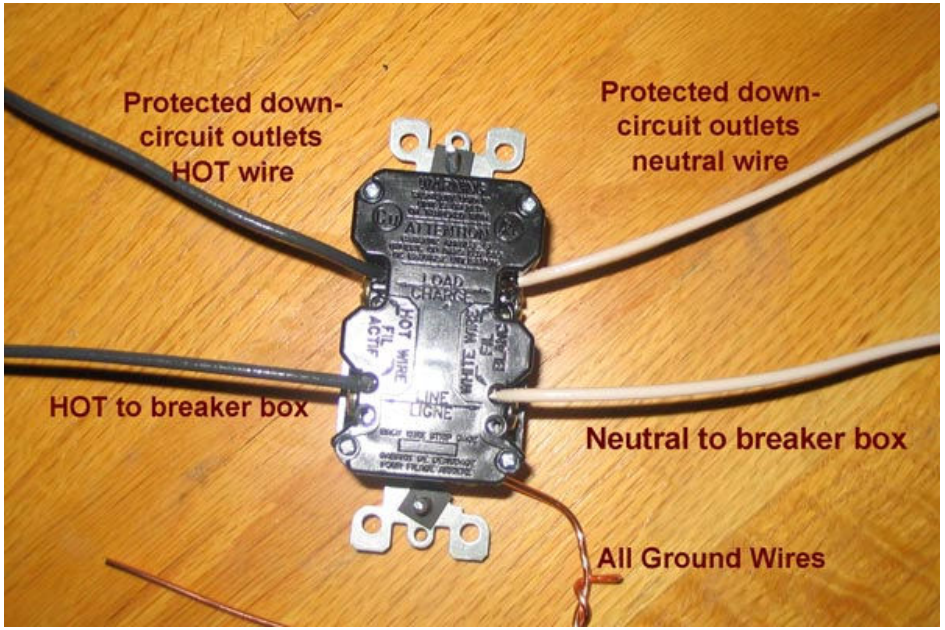




Bypass the sensor

GFCI receptacles
(more)





Remember…call 911
when you set your house on fire!!!