HANDS-ON ELECTRICAL WIRING FOR FACILITY MAINTENANCE TECHNICIANS WORKSHOP WORKBOOK

Written and Developed By Jim Johnson

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REVIEW OF ELECTRICAL TERMS

VOLTS: Electrical _____

AMPERES: _____ flow.

WATTS: _____ in a circuit.

OHMS: _____ in a circuit.

Represented by this symbol: _____

HERTZ: _____ per _____.

In the United States, electricity is generated at _____ Hertz.

SWITCH: _____ a circuit.

LOAD: _____ in a circuit.

NOTES:

_____

_____

_____

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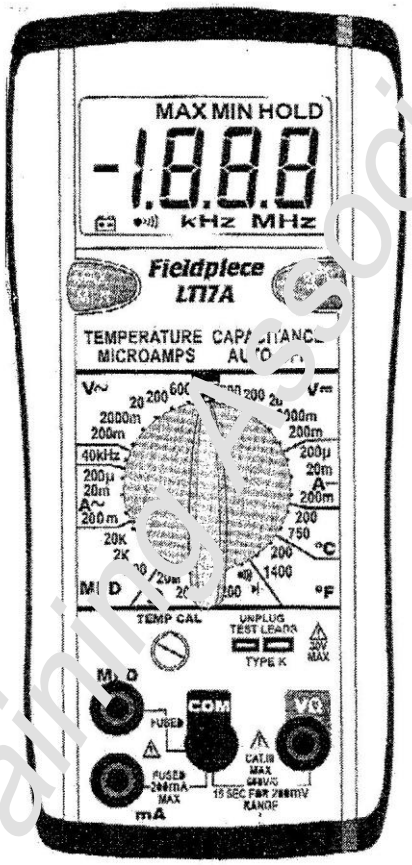
ELECTRICAL SAFETY AND PROPER USE OF METERS

The digital meter in the following example is capable of measuring AC volts, DC volts, AC current, DC current, Resistance, Capacitance, Diodes, and Temperature. The input jacks are: COM, V-OHMS, MFD, and mA. There is a separate connection for the temperature probe.



The COM is considered a common connection, the V-Ohms connection is for measuring AC and DC voltage, and resistance and continuity. The MFD connection is for measuring microfarads (capacitors), and the mA connection is for measuring milliamps and micro amps.

Not all digital meters have multiple lead placement to accomplish mA and MFD tests. In some cases, only two connecting ports are used, and the dial settings are changed to switch to other functions.

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TO TEST AC VOLTAGE IN A CIRCUIT:

1. Connect the meter leads to the COM and V-ohms input jacks
2. Set the dial to the appropriate scale 0n the VAC section
3. Proceed with the test on the component or circuit.

TO TEST DC VOLTAGE IN A CIRCUIT:

1. Connect the meter leads to the COM and V-ohms input jacks.
2. Set the dial to the appropriate scale on the VDC section.
3. Proceed with the test on the component or circuit.

TO TEST RESISTANCE:

1. Connect the meter leads to the COM and V-ohms input jacks.
2. Set the dial the appropriate scale on the Ohms section.
3. Disconnect the power from the circuit.
4. Disconnect the wiring to the component under test.
5. Test the component for resistance.

TO TEST CONTINUITY:

1. Connect the leads to the COM and V-ohms input jacks.
2. Set the dial to the continuity test setting.
3. Disconnect the power in the circuit.
4. Disconnect the wiring to the switch under test.
5. Test the contact points for continuity.

TO TEST A CAPACITOR:

1. Connect the meter leads to the COM and MFD input jacks.
2. Disconnect power in the circuit.
3. Disconnect the wires from the capacitor.
4. Test across the capacitor terminals.

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TO TEST AC CURRENT DRAW IN A CIRCUIT:

1. Remove the ends from the meter leads and insert them into the ACH Clamp Head.
2. Connect the meter leads to the COM and V-ohms input jacks.
3. Set the dial to the correct setting on the VAC scale.
4. Operate the equipment or component under test.
5. Clamp the jaw around one conductor leading to the equipment or the component under test.

TO TEST TEMPERATURE:

1. Disconnect all meter leads from the input jacks.
2. Connect the thermocouple to the Type K connections.
3. Set the dial to the appropriate temperature setting.
4. If necessary, calibrate the meter.
5. Attach the thermocouple lead to the surface being tested, or allow it to test air temperature.

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FUNDAMENTAL SAFETY PRACTICES RELATED TO ELECTRICAL WORK

1. When doing any electrical work in a damp area, always stand on a dry mat or board.

2. Always double-check for voltage before working with wires. Never trust your meter without testing it.

3. Always use tools with insulated handles.

4. Always follow lockout procedures when working on circuits away from the breaker panel or disconnect switch.

5. Pull on the plug, not the cord.

6. Never run extension cords under rugs.

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EFFECTS OF ELECTRICAL SHOCK

	Current in milliamperes @ 60 hertz	
	Men	**Women**
• cannot be felt	0.4	0.3
• a little tingling — mild sensation	1.1	0.7
• shock — not painful — can still let go	1.8	1.2
• shock — painful — can still let go	9.0	6.0
• shock — painful — just about to point where you can't let go — called "threshold" — you may be thrown clear	16.0	10.5
• shock — painful — severe — can't let go — muscles immobilize — breathing stops	23.0	15.0
• ventricular fibrillation (usually fatal) length of time . . 0.03 sec.	1000	1000
length of time . . 3.0 sec.	100	100
• heart stops for the time current is flowing — Heart may start again if time of current flow is short	4 amperes	4 amperes
• burning of skin — generally not fatal unless heart or other vital organs burned	5 or more amperes	5 or more amperes

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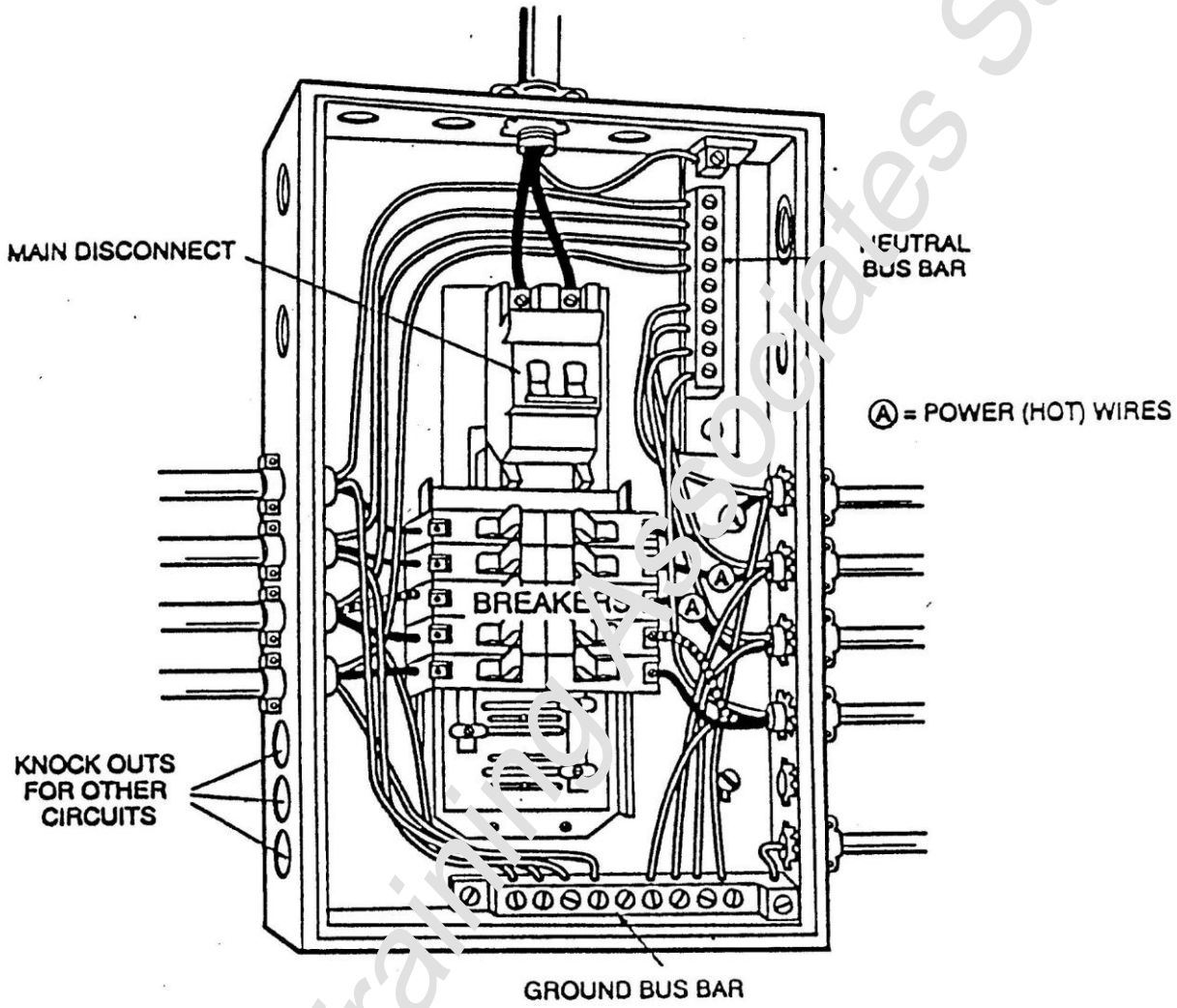
CIRCUIT BREAKERS ONLY KILL THE POWER “DOWNSTREAM”!



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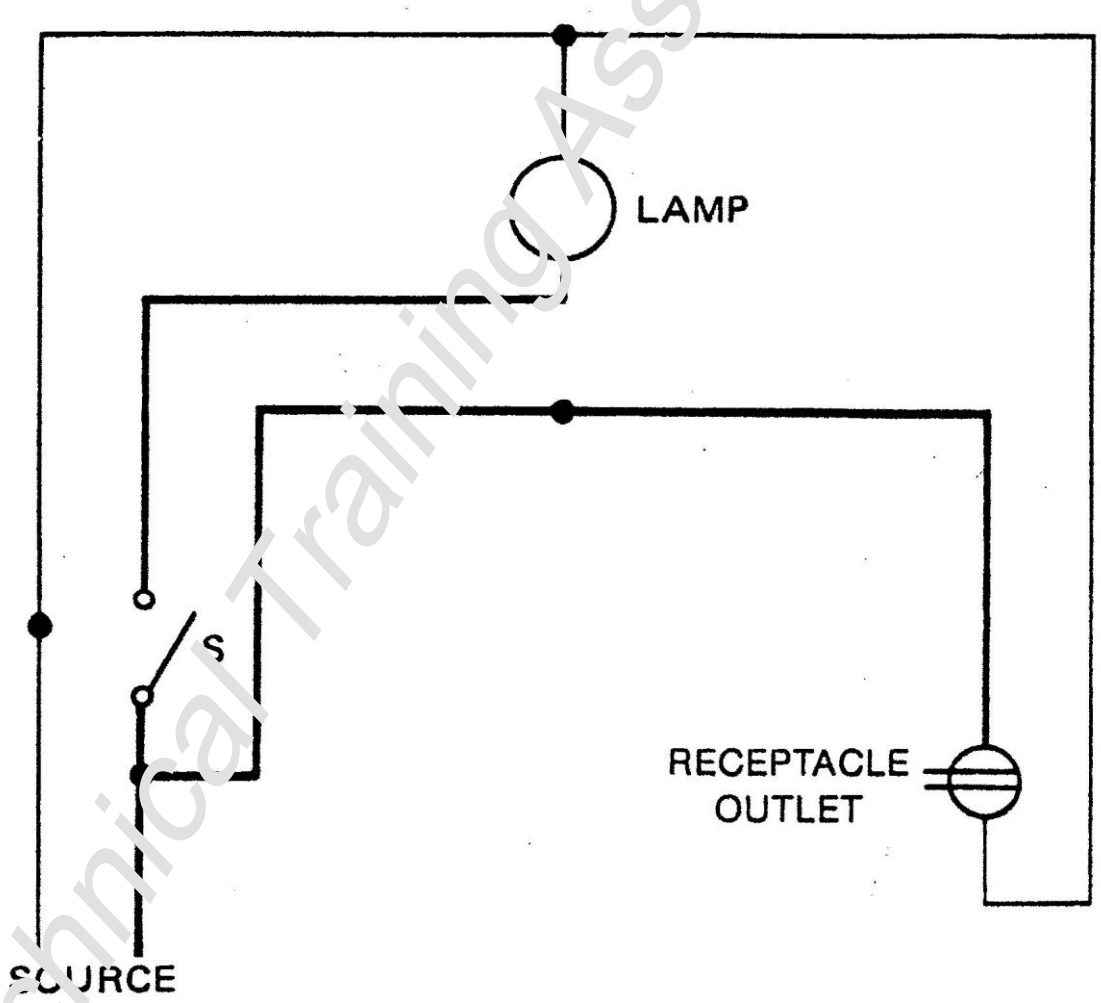
WIRING A SINGLE-POLE SWITCH AND LIGHT FIXTURE WITH A DUPLEX RECEPTACLE

There are two types of diagrams to understand when wiring circuits and doing electrical troubleshooting and repair work.

1. _____

2. _____

This schematic shows the wiring you will be installing and it shows the power coming into this circuit from the switch location.



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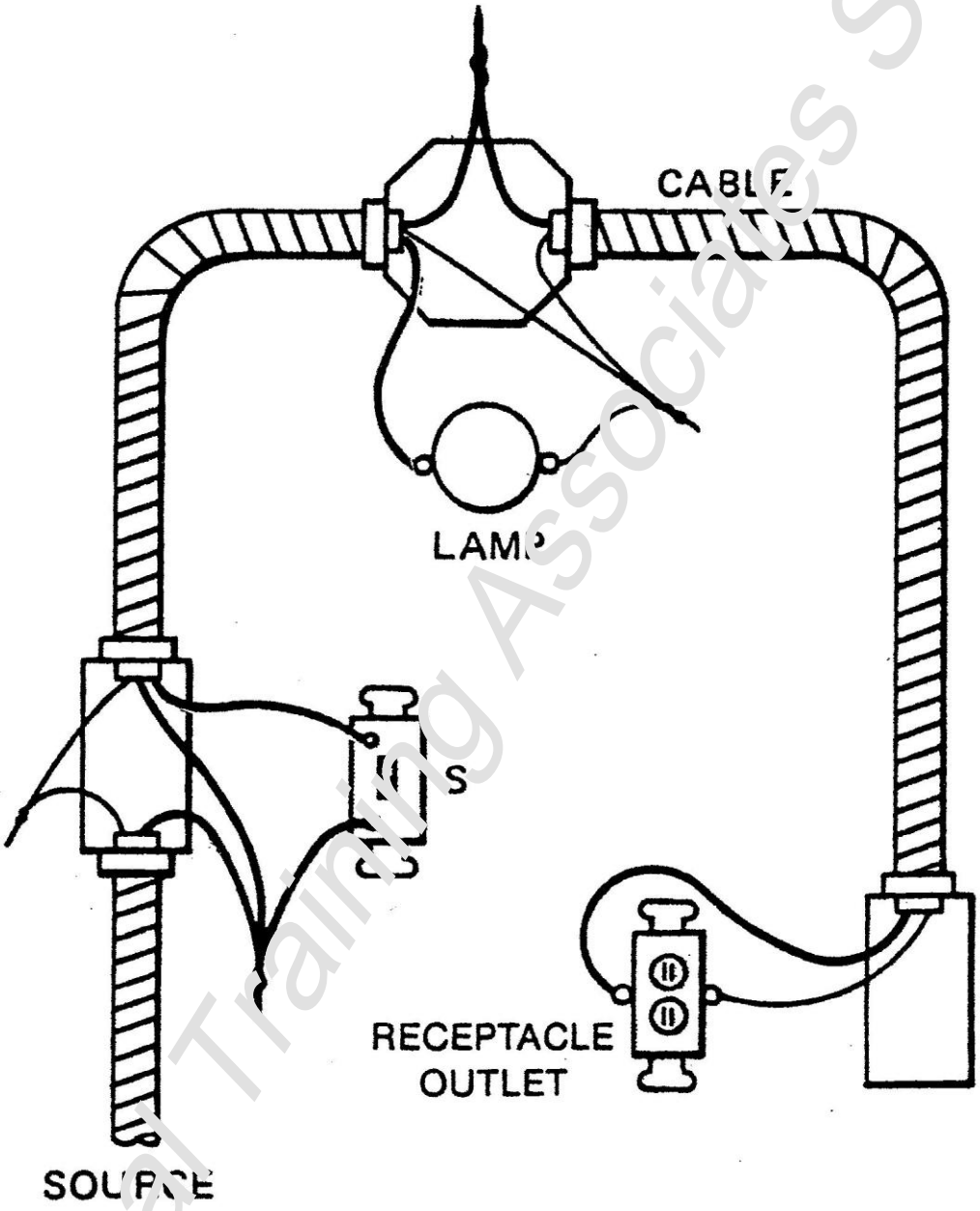
This illustration shows the exact same circuit in a pictorial format.



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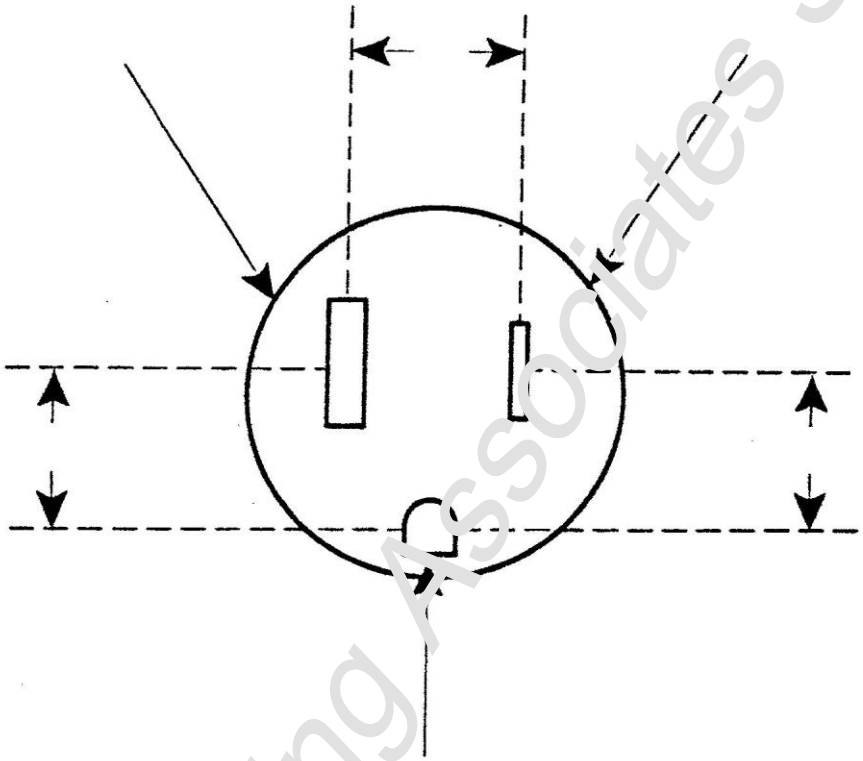
UNDERSTANDING A 120-VOLT RECEPTACLE THAT IS WIRED FOR PROPER POLARITY AND GROUNDING



A = B = C =	PROPERLY POLARIZED AND PROPERLY GROUNDED
A = B = C =	NOT GROUNDED
A = B = C =	PROPERLY GROUNDED BUT THE POLARITY IS REVERSED

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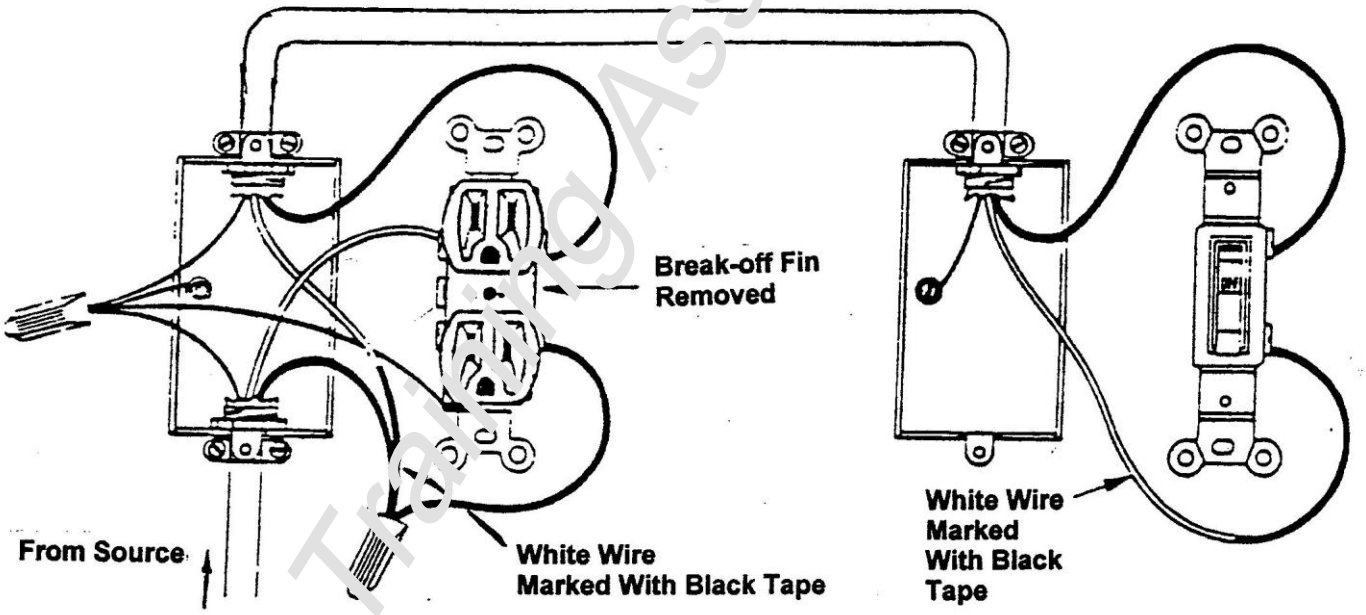
WIRING A SPLIT RECEPTACLE CIRCUIT

A split receptacle is used in certain specific applications:

….For a garbage disposal that is connected to a dishwasher circuit.

….In an office where lighting is plugged into a receptacle along with a computer.

….In residences where a table lamp is plugged into ½ of a receptacle that is controlled by a switch.



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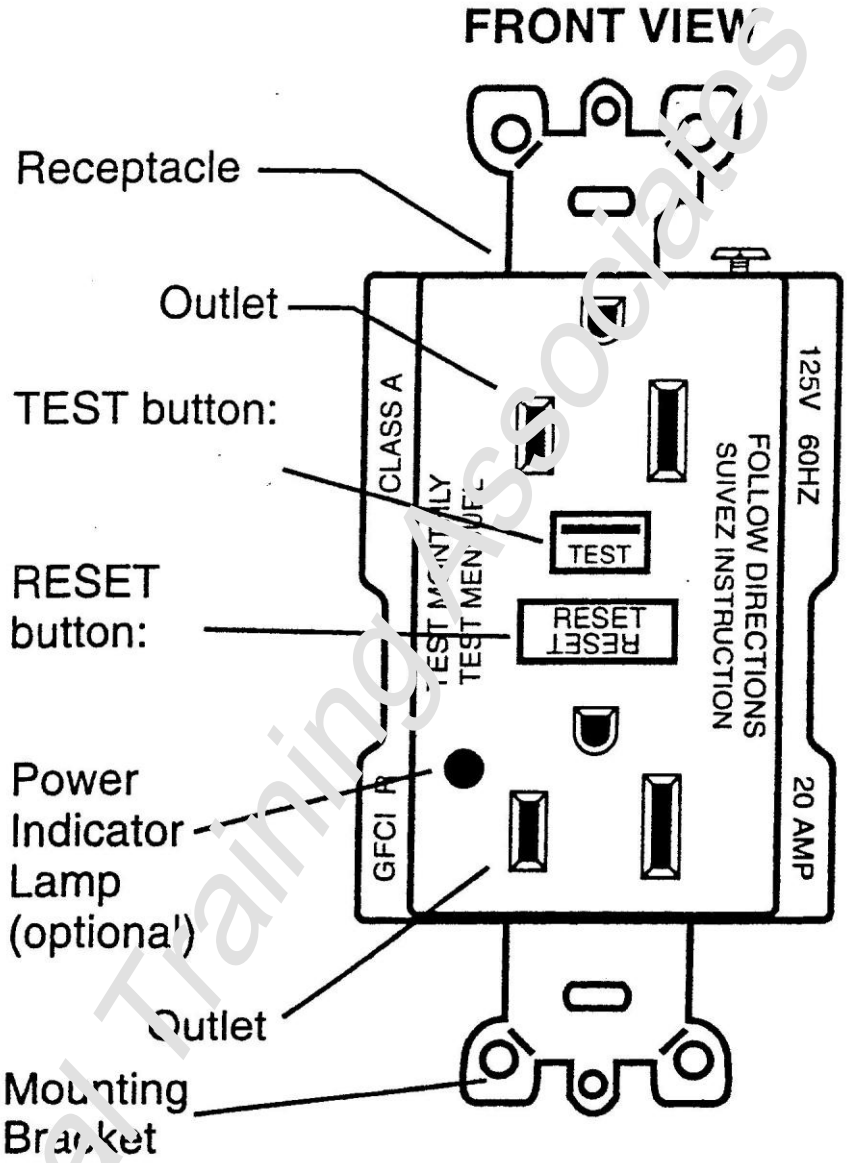
WIRING A GFCI RECEPTACLE

The first step in wiring a GFCI receptacle is to understand its features.



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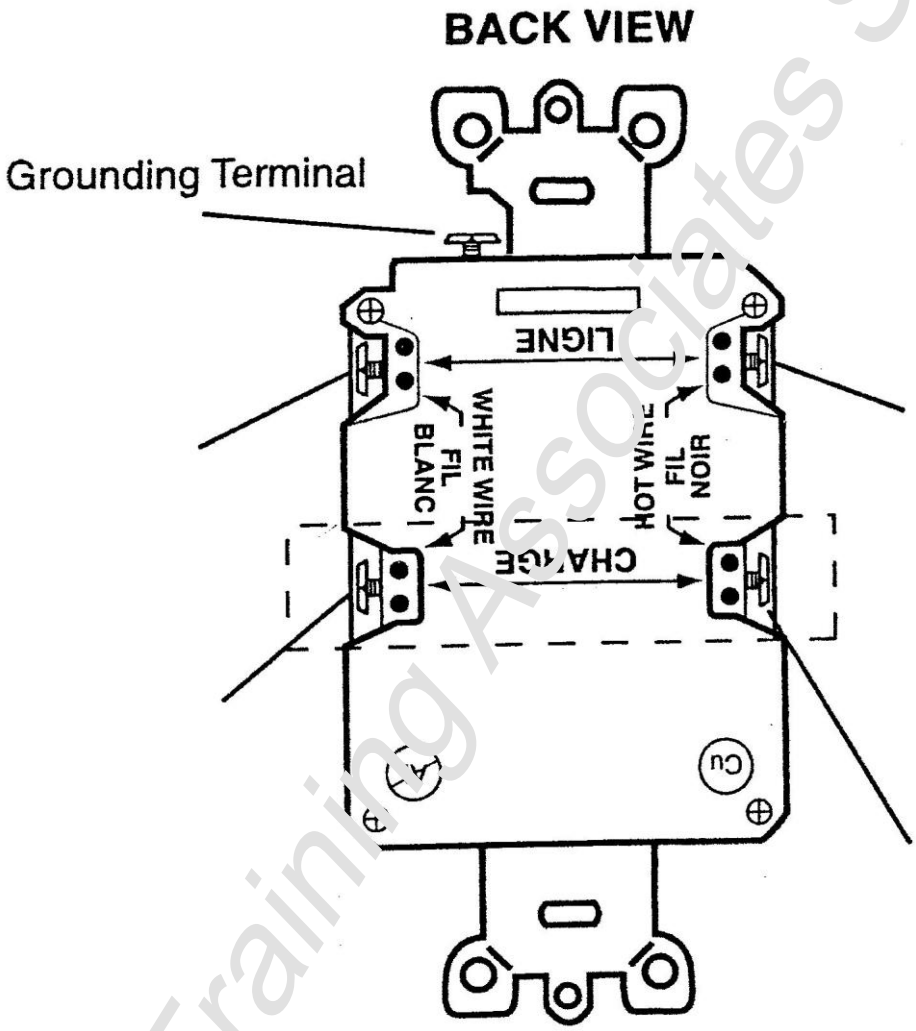
It is also necessary to understand the Line and Load connections, and how connecting the wiring to a GFCI is done differently than with a standard receptacle.



Your instructions for this wiring project are:

1. Wire a power supply to the line connections.
2. Wire one receptacle so it is not protected by the GFCI.
3. Wire a second receptacle that is protected by the GFCI.

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WHERE GFCI BREAKERS AND RECEPTACLES ARE USED

….125-Volt, single-phase, 15 and 20 amp receptacles in bathrooms, and outdoor where there is a direct grade level access to the building.

….125-Volt single-phase 15 and 20 amp receptacles in garages, attached or detached, where there is ready access to the receptacle.

….In unfinished basements, storage areas and crawlspaces that are below grade level.

….In kitchens where a 15 or 20 amp receptacle serves countertops and are located within 6 feet of a kitchen sink or wet bar sink.

WHERE GFCI RECEPTACLES ARE NOT REQUIRED

….A branch circuit dedicated to a refrigerator or freezers.

….A receptacle below a sink for plug-in connection of a disposal.

….A receptacle below a kitchen cabinet for a microwave oven fastened to the underside of a cabinet.

….Receptacles installed solely for clocks.

TO AVOID NUISANCE TRIPPING OF GFCI BREAKERS

….Use non-metallic staples or straps to secure wiring.

….Avoid extremely long cable runs.

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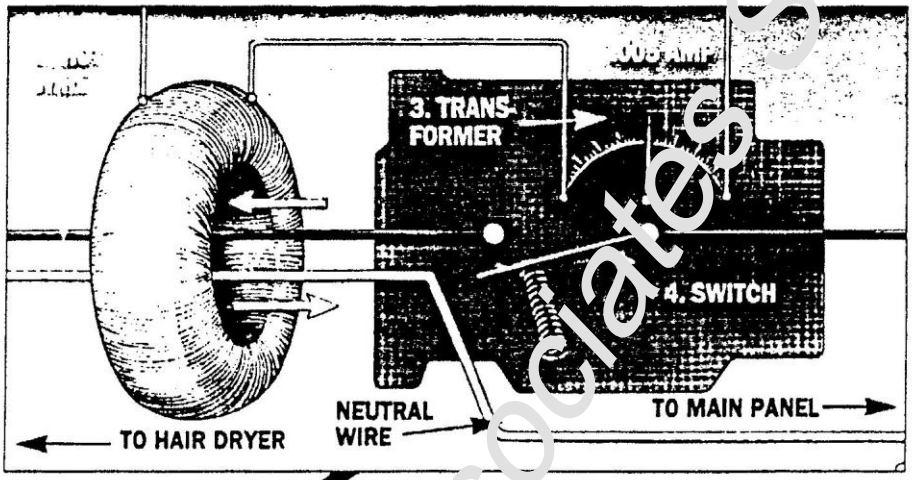
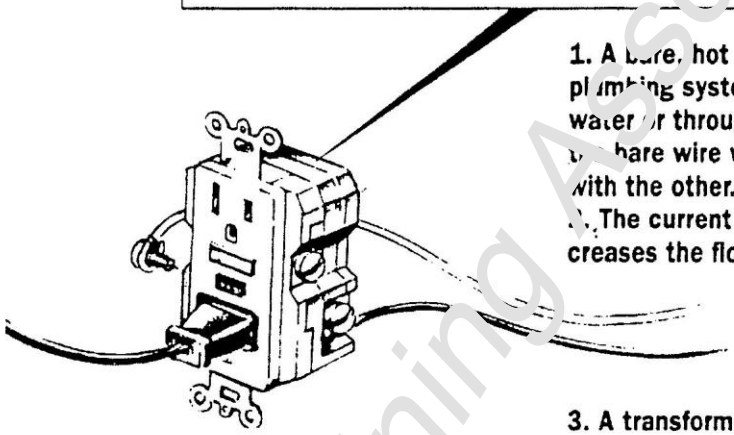
HOW A GFCI WORKS





1. A bare, hot wire "grounds" to the metal plumbing system (faucet) either through water or through your body when you touch the bare wire with one hand and the faucet with the other.
2. The current lost through this leak increases the flow of current in the hot wire.

3. A transformer senses the difference in current between the hot and neutral wires.
4. When the difference reaches .005 amp, a switch opens the circuit and stops the flow of current.

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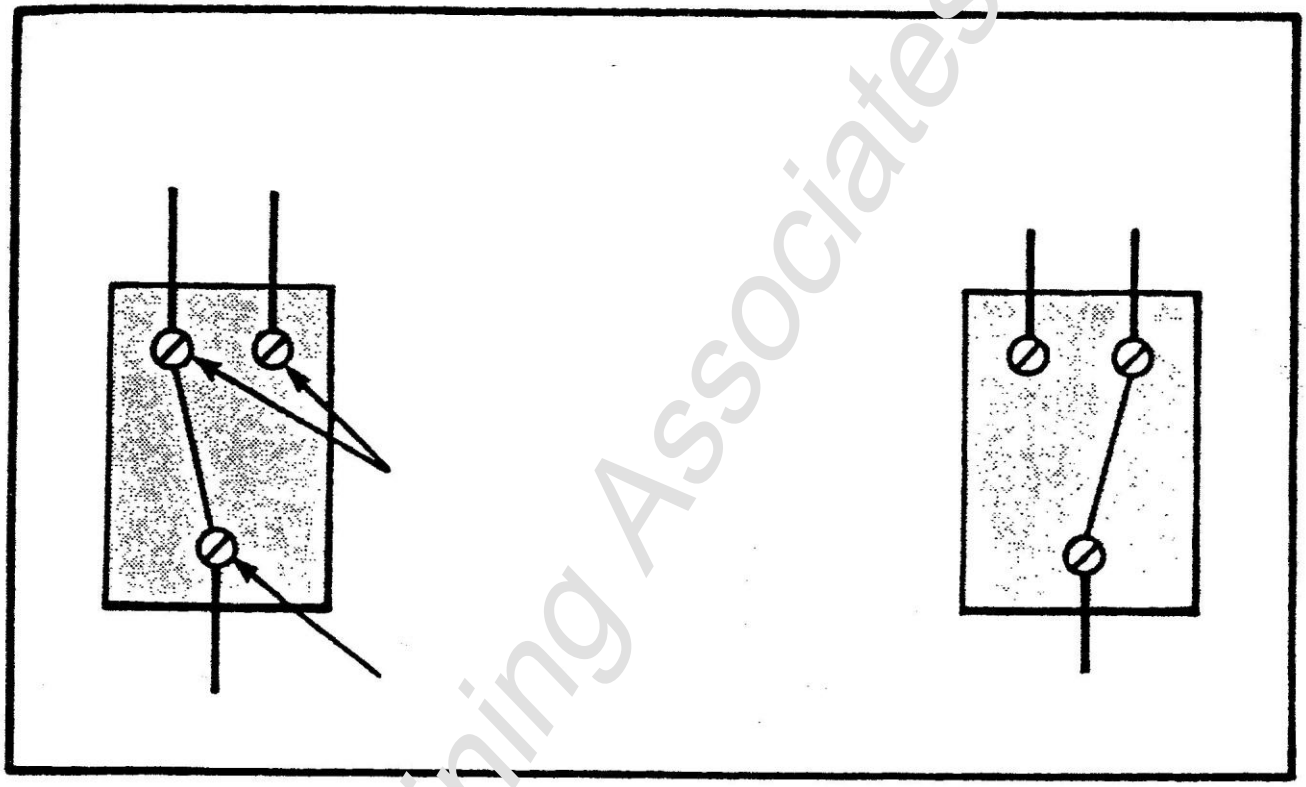
WIRING A FIXTURE THAT IS CONTROLLED BY THREE-WAY SWITCHES

To understand a 3-way switch circuit, begin by understanding the two positions of the switch and its terminal identifiers.



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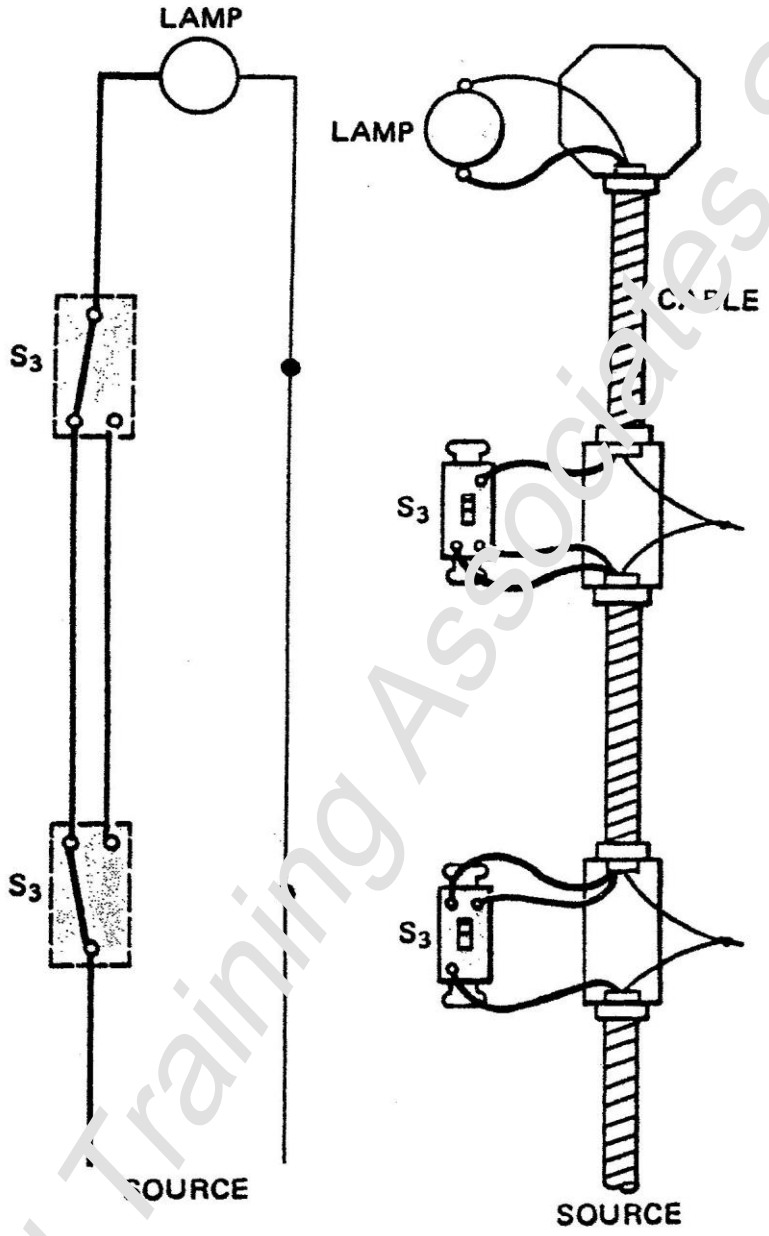
A SCHEMATIC AND PICTORIAL DIAGRAM OF A 3-WAY SWITCH CIRCUIT



In this circuit, the power source is at the first switch. The load is downstream from the second switch control point. Black and red wires are used as travelers. This is one configuration for a 3-way switch circuit. A different configuration would have the power supply starting at the load, one example of which is shown on the next page.

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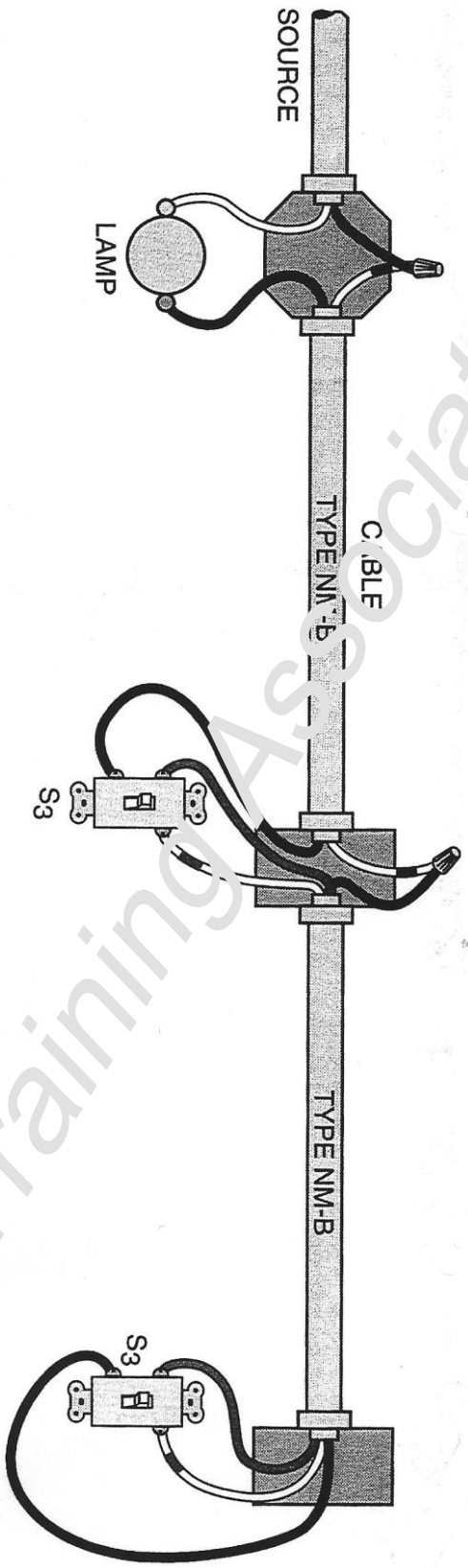

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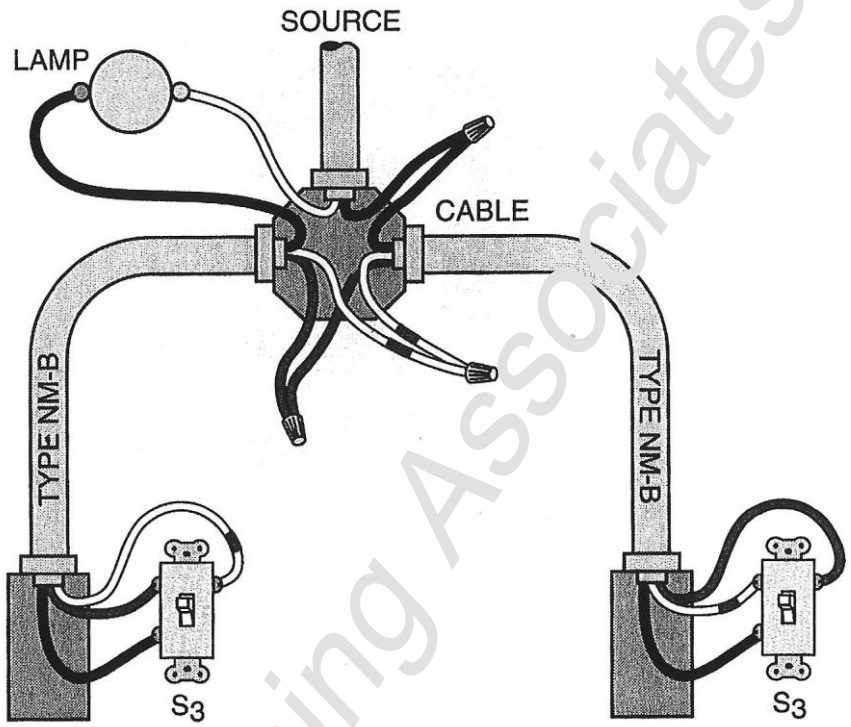
Another example of wiring a 3-way switch with the power supply at the load is a more complex set-up, as shown below.



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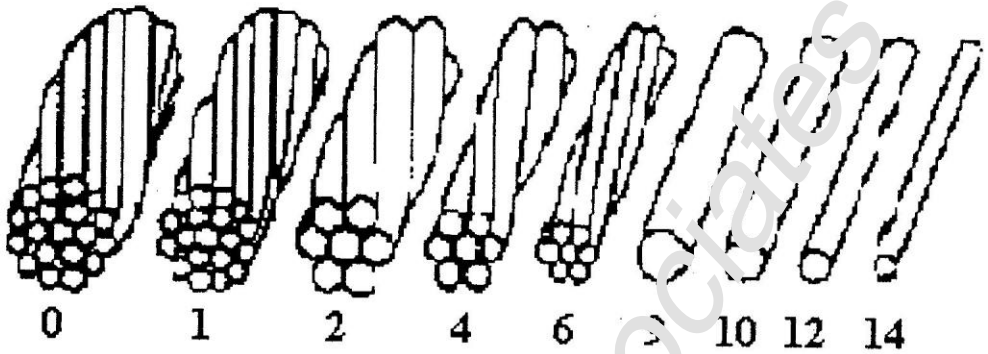
WIRE SIZE AND ELECTRICAL CIRCUITS

The first fact to understand about wiring and circuits is that when it comes to wire, the smaller the number, the larger the wire.



Gauge No. (AWG)	OHMS per 1000 FEET	Ampacity Copper	Ampacity Aluminum
0000	0.050	230	180
000	0.062	200	155
00	0.080	175	135
0	0.100	150	120
1	0.127	130	100
2	0.159	115	90
3	0.202	100	75
4	0.254	85	65
6	0.400	65	50
8	0.645	50	40
10	1.020	30*	25
12	1.620	20*	18
14	2.570	15*	
16	4.100	10*	
18	6.510	5*	

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THREE TERMS TO UNDERSTAND ABOUT WIRING CIRCUITS:

1. _____

This term refers to the current carrying capacity of a wire.

2. _____ _____

Examples of this type of circuit are wall outlets

3. _____ _____

An example of this type of circuit would be a line between a main panel and a sub-panel or junction point.

BASIC WIRE SIZE REQUIREMENTS FOR ELECTRICAL CIRCUIT WIRING

1. Lighting circuits in residences are generally _____ amp.
2. A gas furnace requires a single, dedicated _____ amp circuit.
3. A refrigerator should be connected to its own _____ amp circuit.
4. Electric clothes dryers require a _____ amp circuit.
5. A washing machine circuit should be a _____ amp circuit.
6. Receptacles in kitchens for small appliances are _____ amp.

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7. An electric range is usually _____ amp.

8. A dishwasher should be connected to its own _____ amp circuit.

9. # _____ gauge wire is commonly used in residential lighting circuits

10 # _____ gauge wire is commonly found in residential 20-amp circuits.

11 Electric dryers typically require # _____ solid wire or # _____ stranded wire.

12 Electric ranges are typically wired with # _____ stranded wire.

Regardless of the wire size, two fundamental rules to remember are:

1. Never load a circuit conductor or overcurrent protective device to more than _____ of its rating.

2. The current carrying capacity of wiring is de-rated by:

_____ and high _____

temperatures.

Also, remember to use the right wire for the right purpose:

THHN= **T**hermoplastic insulation, **H**eat resistance, **H**igh heat resistance up to 194-degrees F, **N,** impervious to damage from oil or gas.

THWN= **T**hermoplastic insulation, **H**eat resistance, **W**et locations, **N**, impervious to damage from oil or gas.

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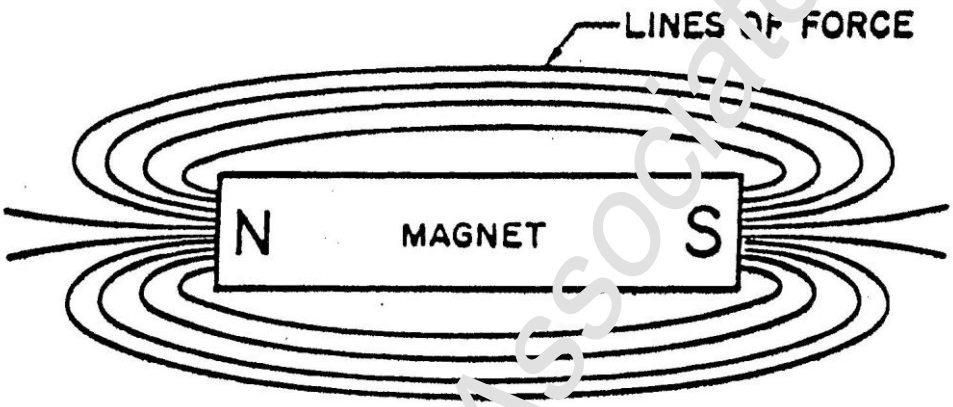
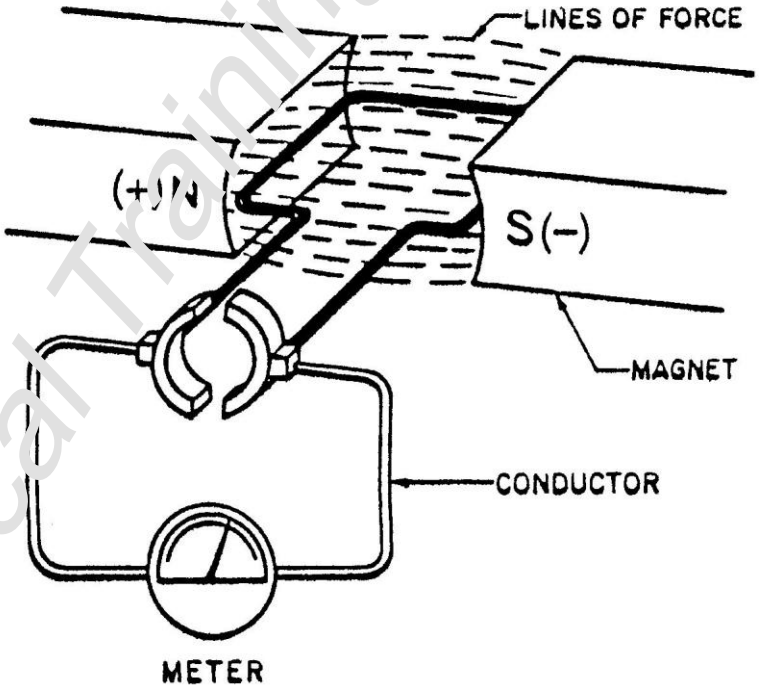
ELECTRICAL CIRCUIT TROUBLESHOOTING FUNDAMENTALS

Learning how to troubleshoot and evaluate electrical circuits starts with eliminating the mysteries of generating electricity, which begins with:

_____



The basic idea behind the process is known as cutting lines of force of a magnet with a conductor.



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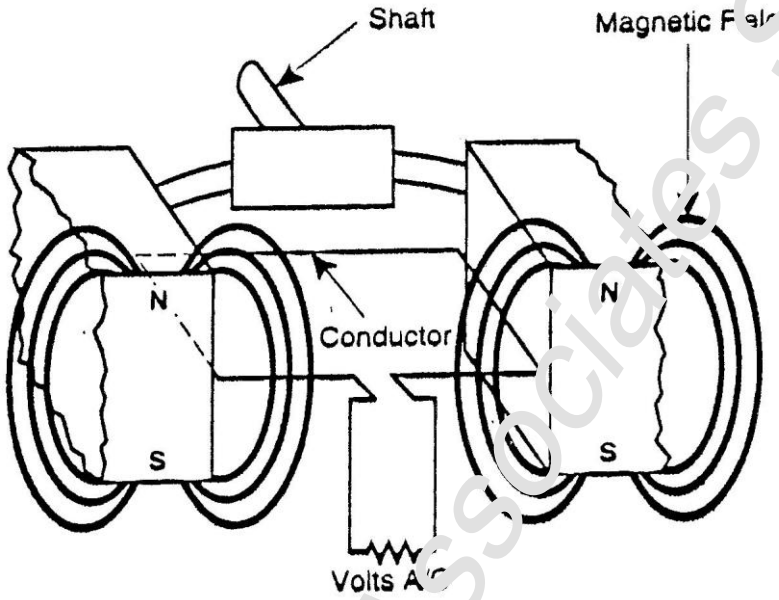
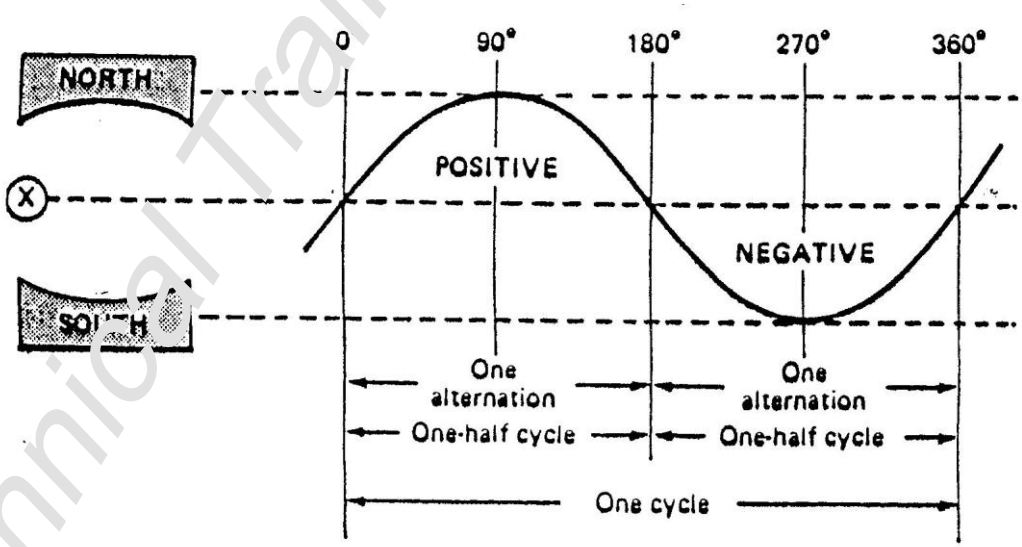
It doesn't matter whether you rotate conductor or the magnet, it doesn't matter. The conductor still cuts the lines of force of the magnet, and electricity is generated.



This is how we generate:

_____ _____.



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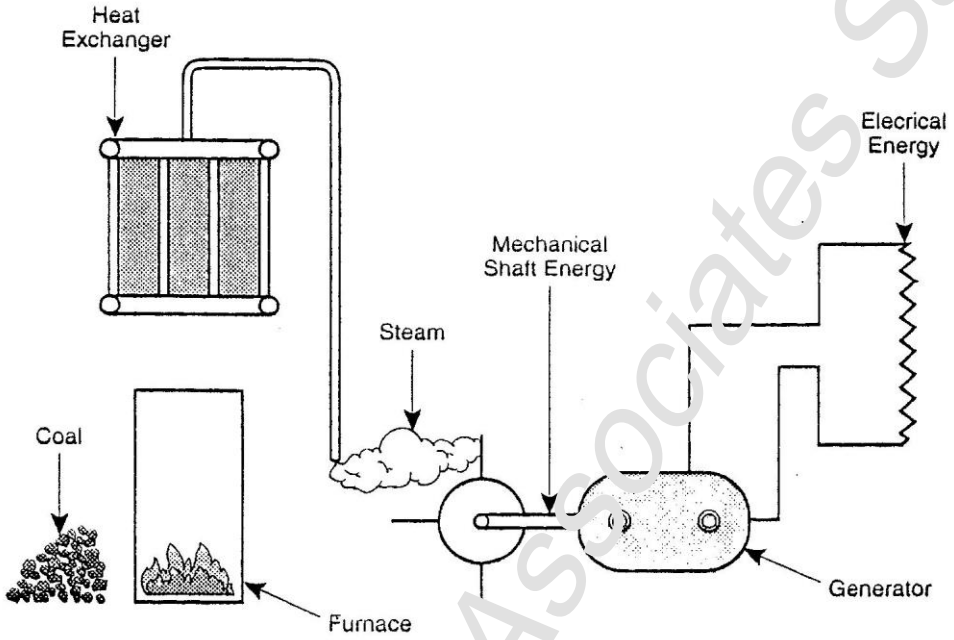
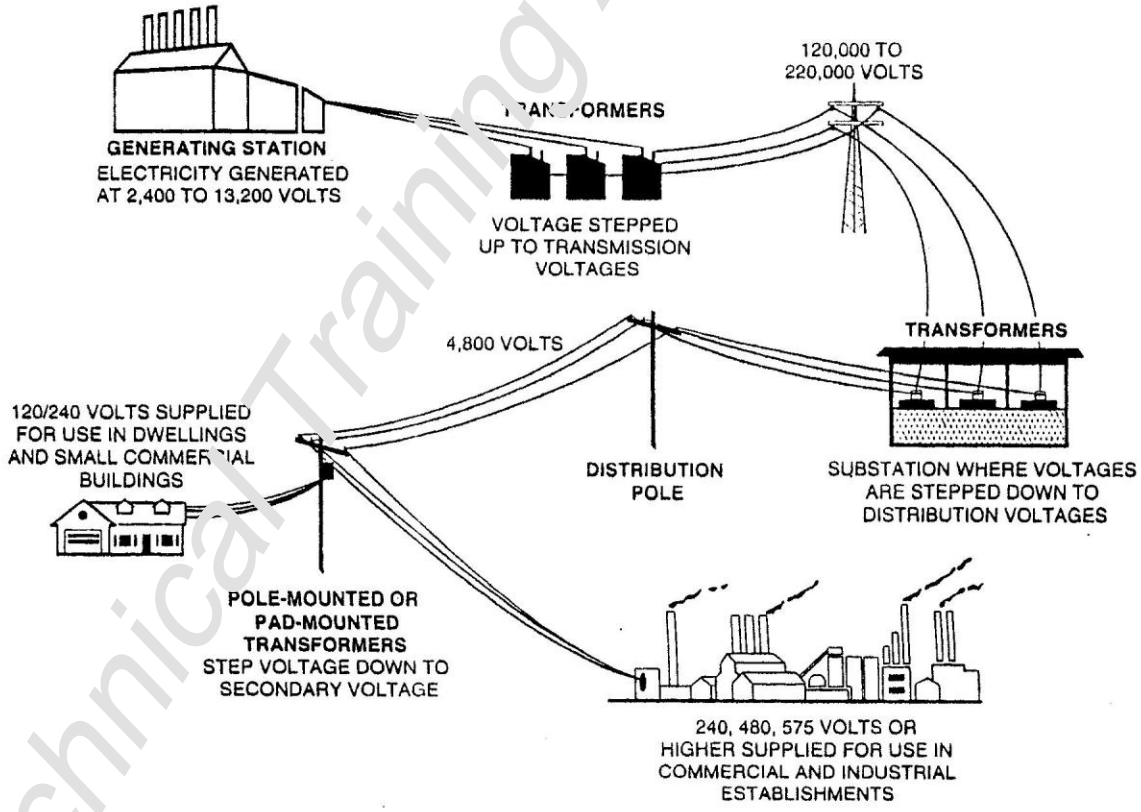
To simplify the idea of understanding electricity, look at the generating station is nothing more than a factory that takes a raw material and turns it into electrical energy, and then a distribution system delivers the product to the end user.





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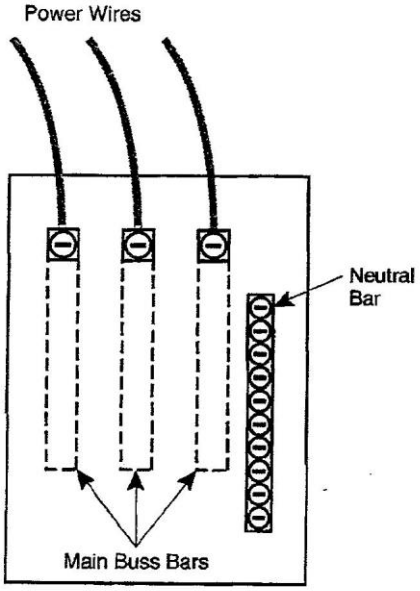
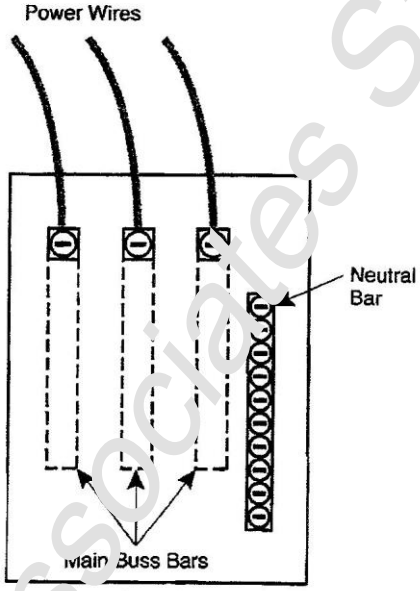
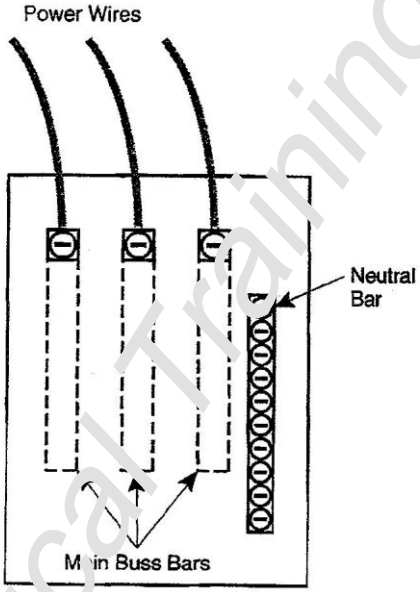
Electricity is then delivered to buildings in a variety of voltages that are either single-phase or three-phase systems. The circuit breakers in the distribution panels are wired to the circuits throughout the building.



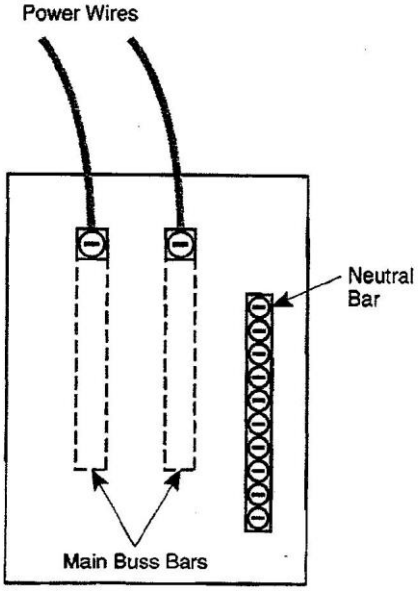
Panel A
In a 230V three phase system, the applied voltage will be measured between any two hot legs.



Panel B
In a 460V three phase system, the applied voltage will be measured between any two hot legs.



Panel C
In a 208V three phase system, the applied voltage will be measured between any two hot legs.



Panel D
In a 230V single phase system typically found in a residence, the applied voltage will be read at the two hot legs and 115 VAC will be read from a neutral bar to either hot leg.

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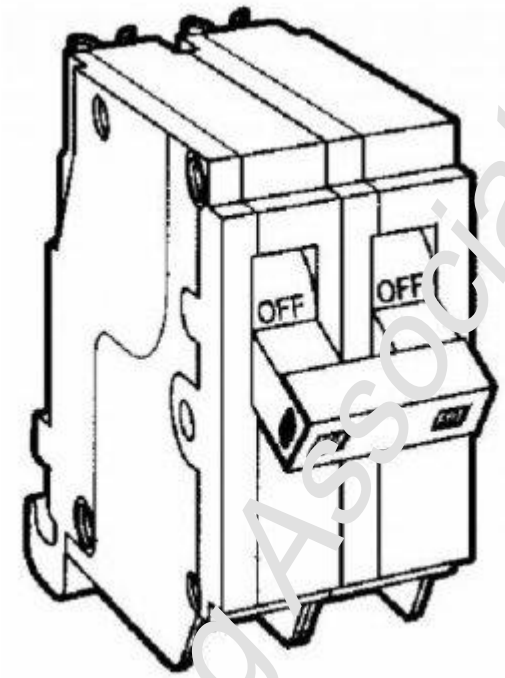
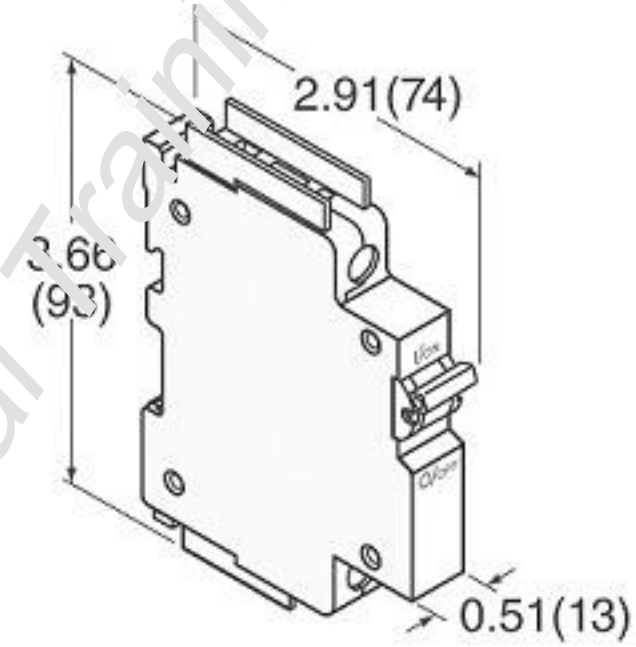
CIRCUIT BREAKERS

In residential wiring systems, it's common to find breakers that are:

_____ or _____ pole.





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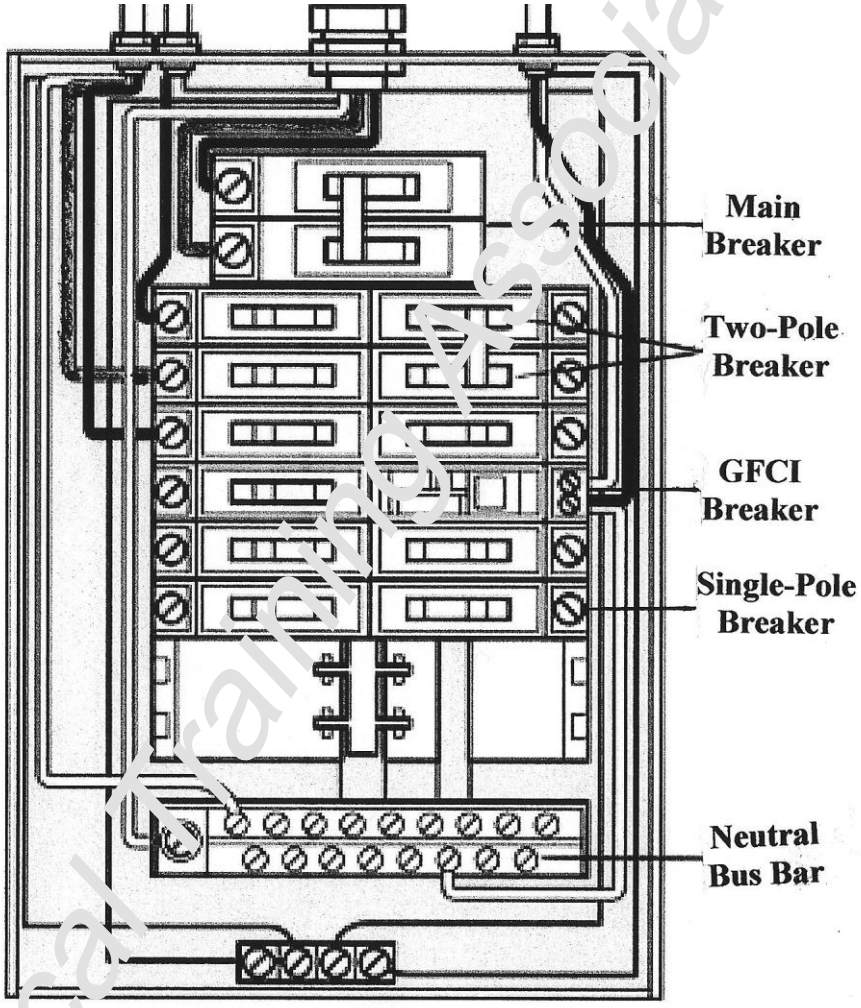
Evaluating an electrical circuit begins with checking the circuit breaker in the distribution panel, checking for loose connections and voltage drop.



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UNDERSTANDING VOLTAGE DROP

Lower than normal voltage can have the following effects:

1. _____ lights.
2. Motors will run _____ _____.
3. _____ output of electric heaters.
4. _____ operation of appliances.

Low voltage is caused by:

1. Wire that is _____ _____ for the load being served.
2. A circuit that is too _____.
3. Poor _____.
4. Conductors operating _____ temperatures causing _____ resistance than when operating at normal temperatures.

The NEC requires that voltage drop in a branch circuit should not exceed:

_____ %

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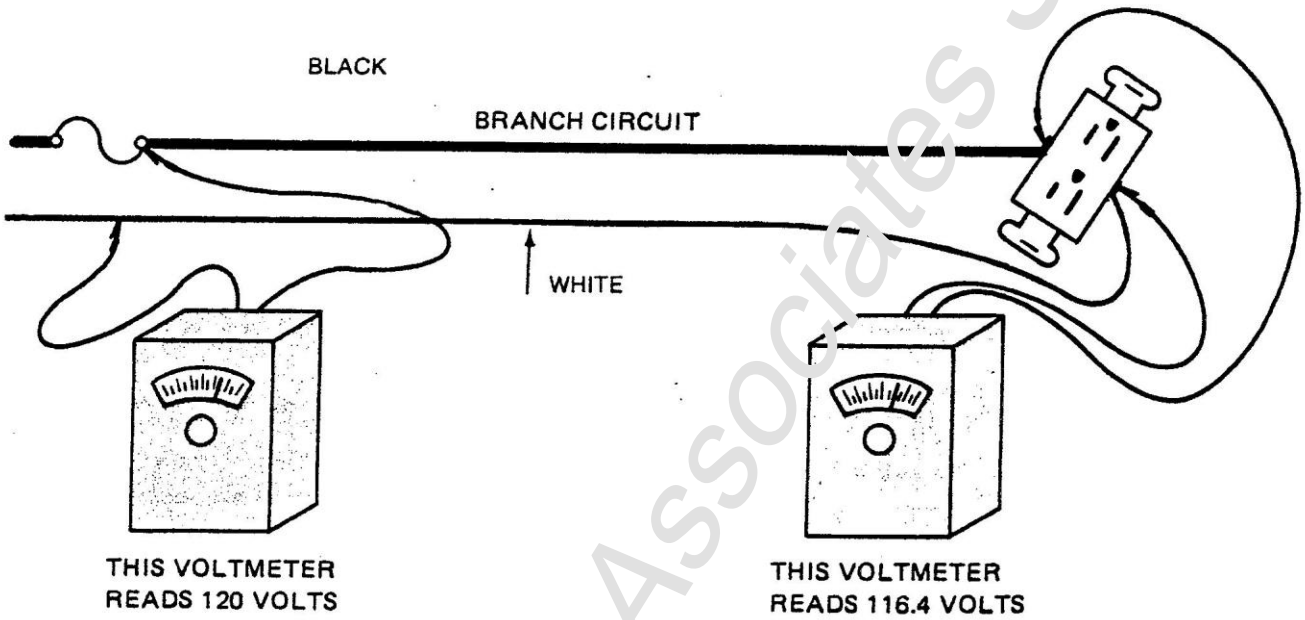
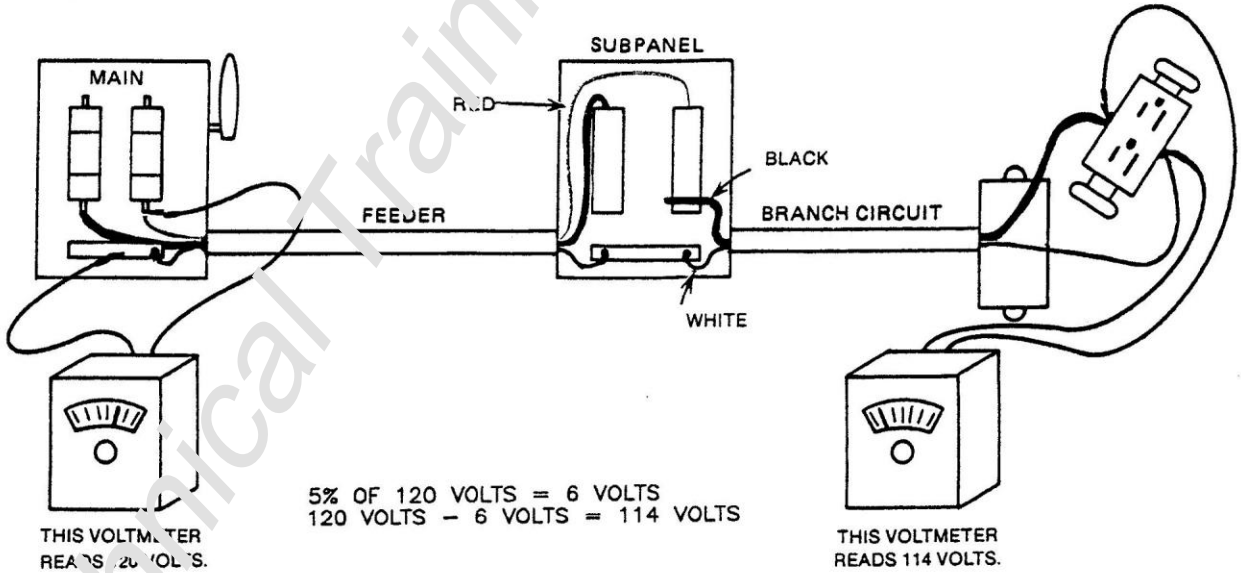
MEASURING VOLTAGE DROP IN AN ELECTRICAL CIRCUIT

Due to resistance there will always be some voltage drop in a circuit. The example below shows a circuit that has an allowable level of voltage drop.



3% OF 120 VOLTS = 3.6 VOLTS
120 VOLTS – 3.6 VOLTS = 116.4 VOLTS

This circuit has voltage drop that exceeds NEC recommendations.



5% OF 120 VOLTS = 6 VOLTS
120 VOLTS – 6 VOLTS = 114 VOLTS

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FUSES

Fuses used as overcurrent protection in electrical circuits are in one of three categories:

Edison-Base Plug Fuses

Type S Fuses (used with an adapter)

Cartridge Type Fuses

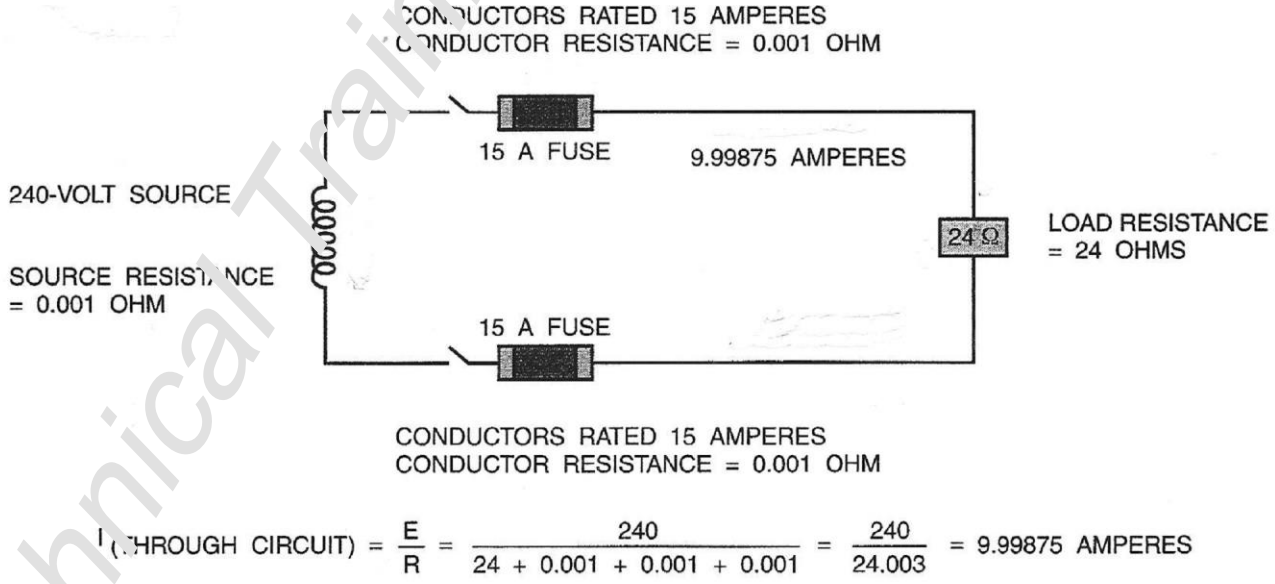
Two other characteristics of a fuse are either:

Nontime-Delay

Time-Delay

When troubleshooting electrical circuits and fuse protection, consider that there are five circuit conditions that can exist.

1. Normal Circuit: In this situation, the conductors can safely carry the current and the fuses do not open.



$$I_{(THROUGH\ CIRCUIT)} = \frac{E}{R} = \frac{240}{24 + 0.001 + 0.001 + 0.001} = \frac{240}{24.003} = 9.99875\ AMPERES$$

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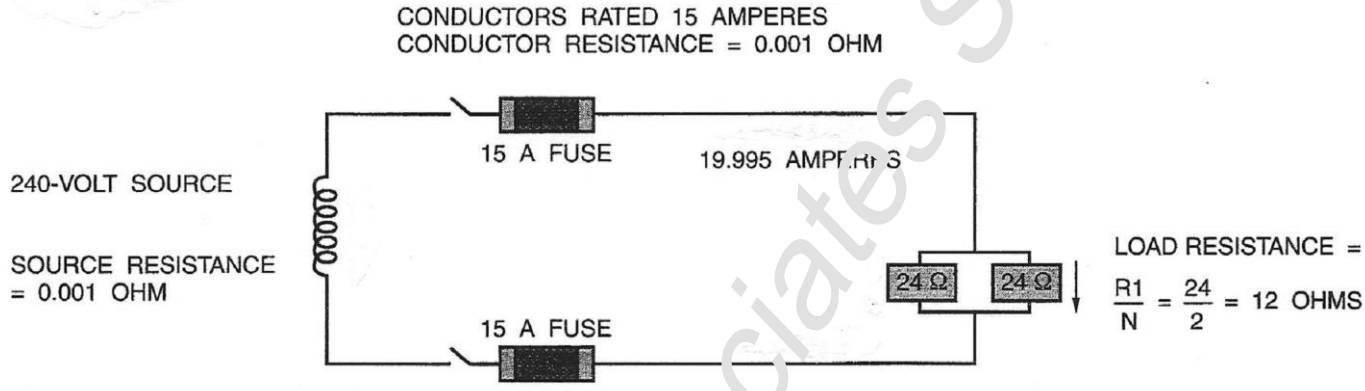
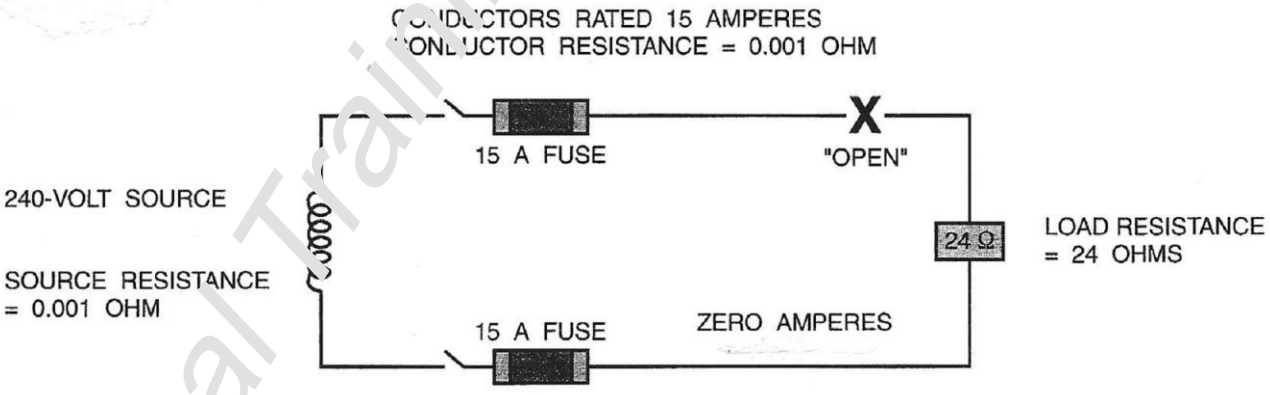
2. Overloaded Circuit: The conductors will get hot when this circuit is energized, and the fuses will open fairly quickly.



$$I_{(\text{THROUGH CIRCUIT})} = \frac{E}{R} = \frac{240}{12 + 0.001 + 0.001 + 0.001} = \frac{240}{12.003} = 19.995 \text{ AMPERES}$$

3. Open Circuit: In the case of an open anywhere in the circuit wiring, or failure of the load, there will be no current flow in the circuit.



$$I_{(\text{THROUGH CIRCUIT})} = \frac{E}{R} = \frac{240}{\infty} = \text{ZERO AMPERES*}$$

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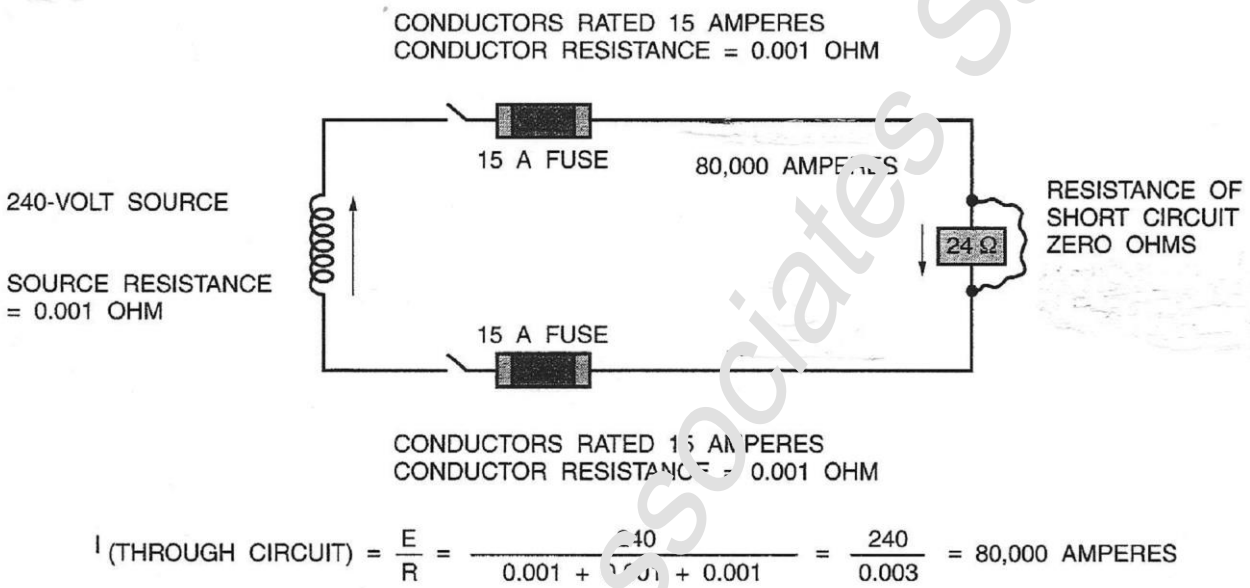
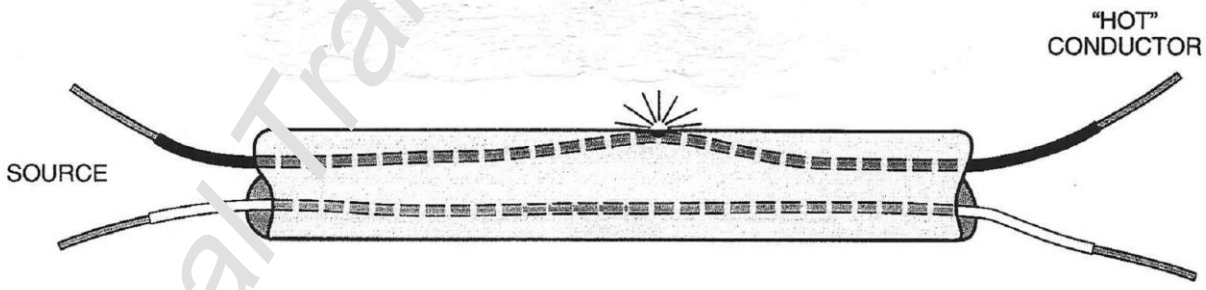
4. Short Circuit: There is no load resistance in the circuit, and the fuses will blow immediately.



$$I_{(\text{THROUGH CIRCUIT})} = \frac{E}{R} = \frac{240}{0.001 + 0.001 + 0.001} = \frac{240}{0.003} = 80{,}000 \text{ AMPERES}$$

5. Ground Fault: A hot wire in the circuit has come in contact with conduit or ground wire, creating a dead short to ground.



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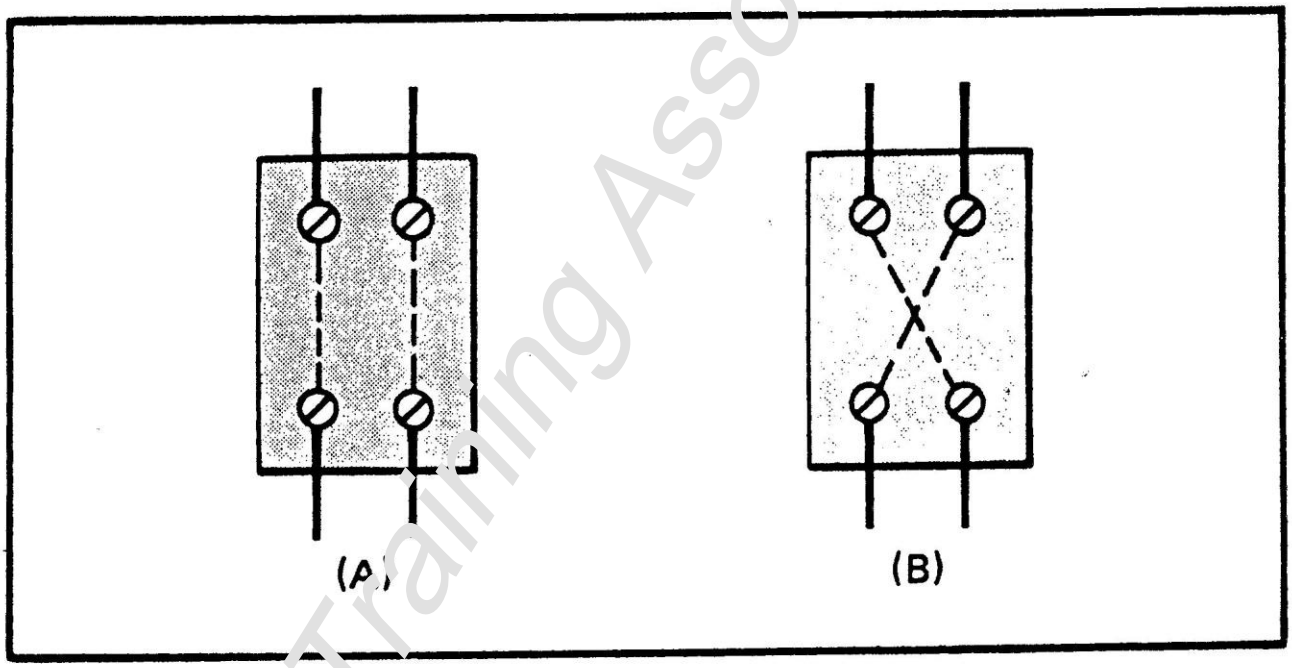
WIRING A CIRCUIT WITH A 4-WAY SWITCH

When a light is controlled from three different locations, two 3-way switches and a 4-way switch are wired into the circuit.

A 4-way switch is constructed so that the switching contacts can alternate their positions.

Neither position is ON or OFF.



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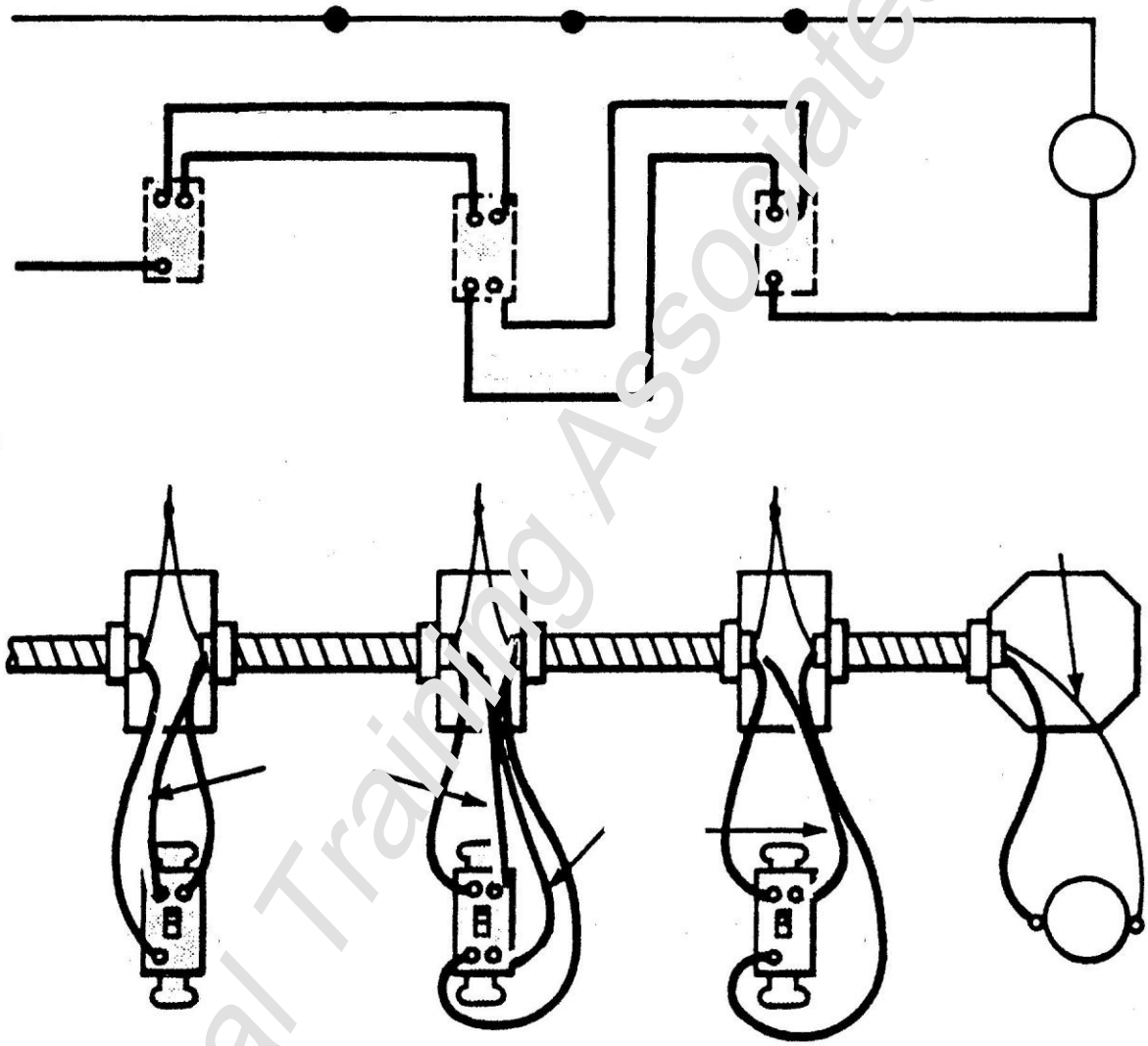
A schematic and pictorial diagram of a light controlled from three different locations.



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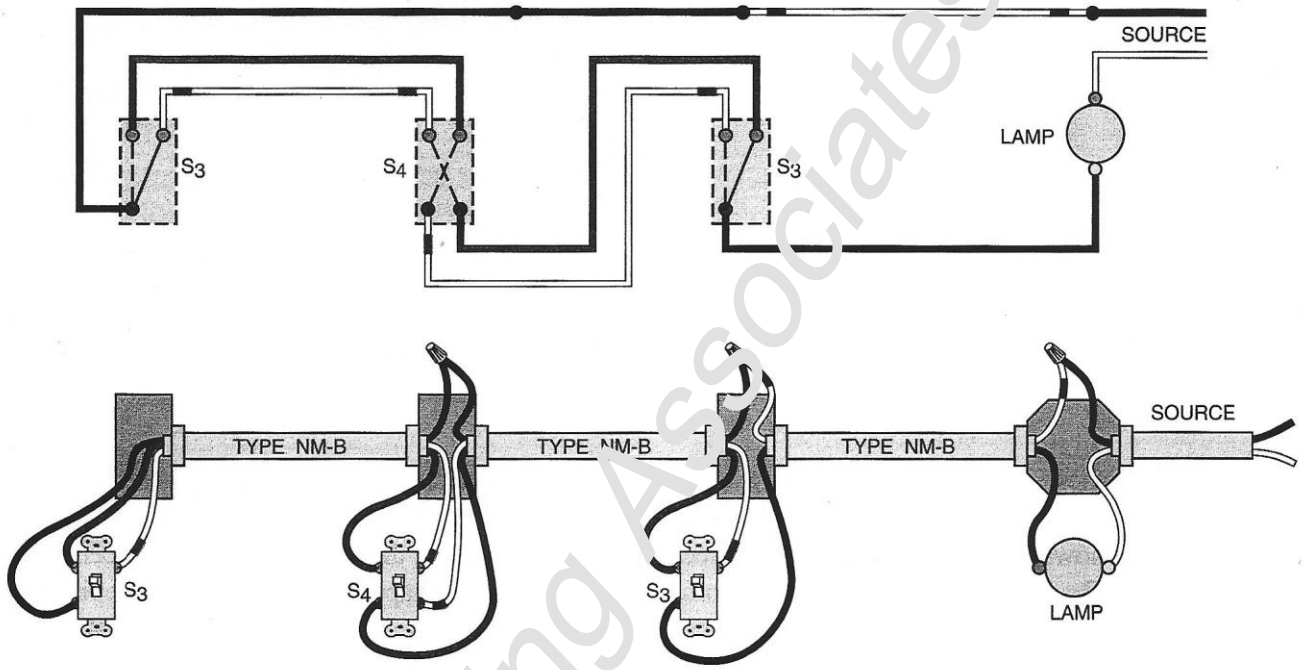
Another method of wiring a circuit that controls a light from three locations is to bring the power supply in at the light rather than at a switch.



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