Maintenance and Light Repair: Electrical

TABLE OF CONTENTS

Unit 1: Introduction To Electricity 4
Overview 4
Safety 4
Electricity 5
Electrical Circuits 9
Protection Devices 10
Control Devices 14
Symbols 16
Electrical Properties 18
Voltage 18
Current 20
Resistance 21
General Rules 22
Voltage Drop 23
Digital Multimeters 24
Introduction 24
Digital Multimeters 25
Scaling 26
Measurements 30
Converting Values 33
Unit 2: Electrical Circuits And Devices 37
Series Circuits 37
Introduction 37
Circuit Elements 37
Voltage Drop 39
Series Circuits 42

Unit 3: Electrical Relationships And Equations....................................44
Ohm's Law.. 44
Ohm's Law 44
Relationships and Formulas.. 45
Calculations for Circuits 47
Unit 4: ADVANCED ELECTRICAL CIRCUITS 49
Parallel Circuits.. 49
Parallel Circuits 49
Ohm's Law for Parallel Circuits 55
Series-Parallel Circuits 56
Unit 5: Electrical Diagnosis And Wire Repair.......................................58
Electrical Diagnosis.. 58
Circuit Faults 58
Test Lights 63
Headlight Circuits 65
Wiring Diagrams 67
Wire and Wire Repair... 70
Wire Applications 70
Stripping 70
Splicing 71
Terminals 74

UNIT 1: INTRODUCTION TO ELECTRICITY

The following topics are addressed in this unit:

Overview

- Safety
- What is Electricity?
- Electrical Circuits
- Protection Devices
- Control Devices
- Symbols

Electrical Properties

- Voltage
- Current
- Resistance
- General Rules of Electricity
- Voltage Drop
- Digital Multimeters
- Introduction

Digital Multimeters

- Introduction
- Digital Multimeters
- Scaling
- Measurements
- Converting Values

Overview

In this unit, we take a look at the fundamentals of electricity.

Safety

Safety Warnings and Cautions

Safety in the workplace is of great concern to all of us. Especially since the concepts learned in each module of this training program will be applied using real test equipment, on live electrical circuits.

It is, therefore, imperative that students understand how extremely important electrical safety is. The words "**caution**", "**warning**", and "**danger**" will appear throughout this material and must always be heeded. If you do not heed the safety message, you can not only damage components and equipment, you can injure or kill yourself or someone else.

Every year, people are injured or killed and property is damaged as a result of not following electrical safety rules and common sense. Pay attention and use safe practices.

WARNING! To avoid possible personal injury:

- Always follow all general safety guidelines for servicing motor vehicles with regard to electrical connections, flammable or corrosive materials, adequate ventilation, jacking and supporting, working around hot or moving parts, proper use of parking brakes, gear selectors, wheel blocks, and disabling fuel or ignition systems. **Refer to the equipment user's manual and vehicle service manual for the operation you are performing.**
- When making electrical measurements, never exceed the voltage or current limits for the equipment.
- Use extreme caution when working with circuits that have greater than 60 volts DC or 24 volts AC.
- Do not operate damaged equipment.
- **Automotive batteries can explode, and have enough power to arc weld.** Always respect the power of a battery, even a dead battery. Always wear approved **safety glasses** when working around batteries. The use of **rubber gloves** is recommended when working with electrolytes.
- The ground terminal of a battery should always be disconnected **first** and reconnected **last**.
- Connect battery chargers to a battery **before** plugging in the charger.
- When jump-starting a vehicle, always follow the proper procedure. **Do not** connect the jumper cable to the negative battery terminal of the vehicle you are jump-starting.
- **Accidentally shorting the positive battery terminal, or system voltage, to ground with a tool or metal object can cause severe burns**. Jewelry should be removed before working with electrical systems.

Know the locations of fire extinguishers, eyewash stations, and first aid kits. First aid kits should always contain a bottle of sterile, acid-neutralizing eyewash. This is especially important near the battery storage and service area.

Electricity

What is Electricity?

In order to properly diagnose and repair automotive electrical systems, a technician must first have an understanding of how those systems operate. In this section, we will look at electrical fundamentals and how they determine the construction and application of automotive circuits.

What is electricity?

Electricity can be described in a number of ways, but for our purposes it is defined as **the movement of electrons through a conductor**, **in a closed circuit**, **having the ability to do work**.

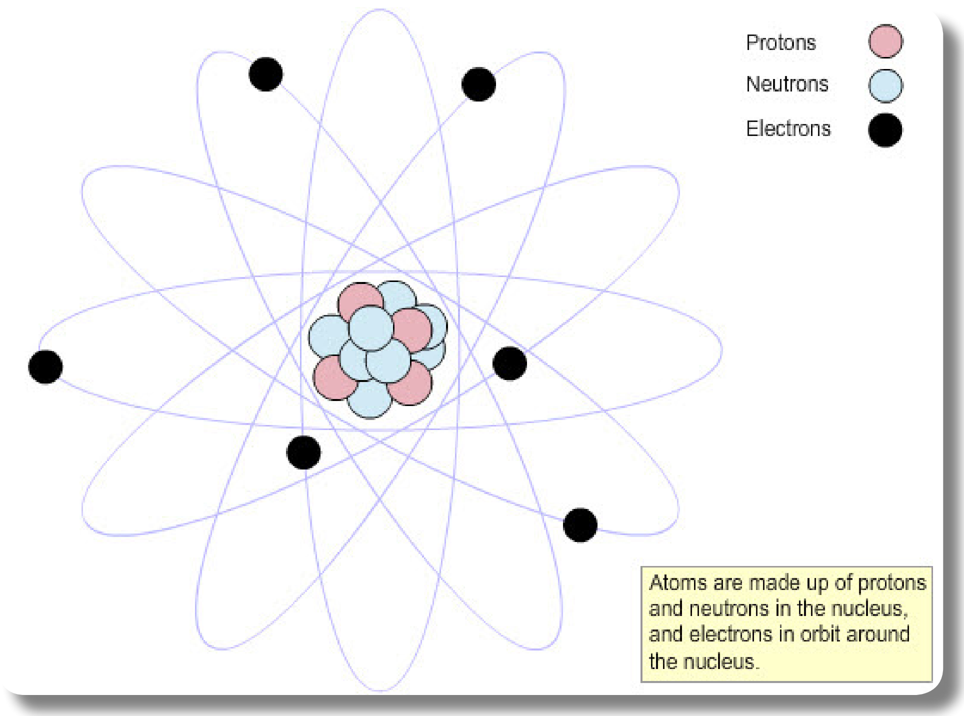
Definition of Electricity:

The movement of electrons through a conductor, in a closed circuit, having the ability to do work.

Atoms

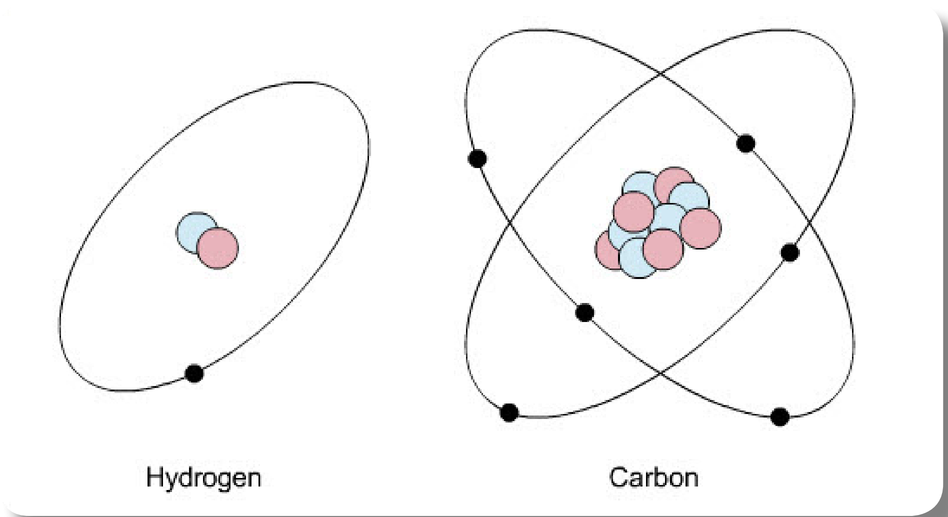
Remember from science class that atoms are composed of a nucleus, containing protons (which have a positive charge) and neutrons (which have no charge), with electrons revolving around it (which have a negative charge).

Atom



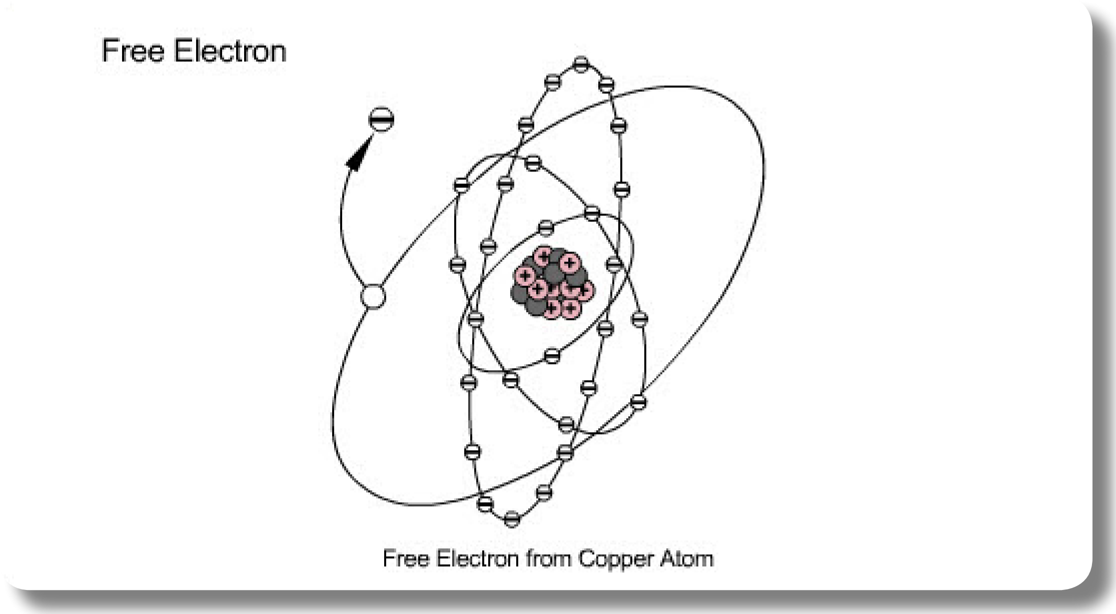
Recall also that each type of atom has a different number of protons and neutrons in the nucleus, as well as electrons around its perimeter, than other types of atoms. For example, hydrogen has one electron while carbon has six.

Atomic Structures of Hydrogen and Carbon



Let's look at one specific example of an atom -- copper.

Atomic Structure of Copper



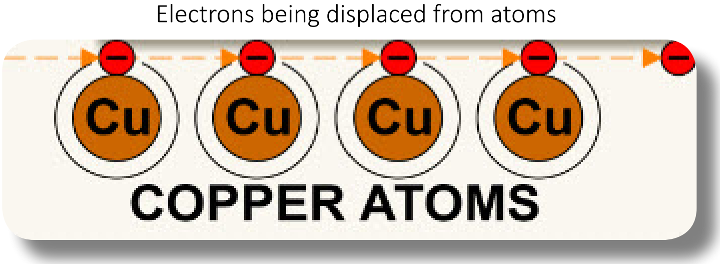
A copper atom has 29 electrons arranged in different layers, or shells, around the nucleus; two in the first shell, eight in the second shell and 18 in the third shell, for a total of 28. That leaves just one **free electron** in the outer shell, or **valence shell**, of the atom. That free electron is also referred to as a **valence electron**.

When a sufficient electrical force (voltage) is applied to an atom, the one free electron in the outer shell is pushed out of its orbit. It will then begin to carry its negative charge down a wire (conductor), much like feeding ping pong balls through a paper towel roll.

Valence electrons:

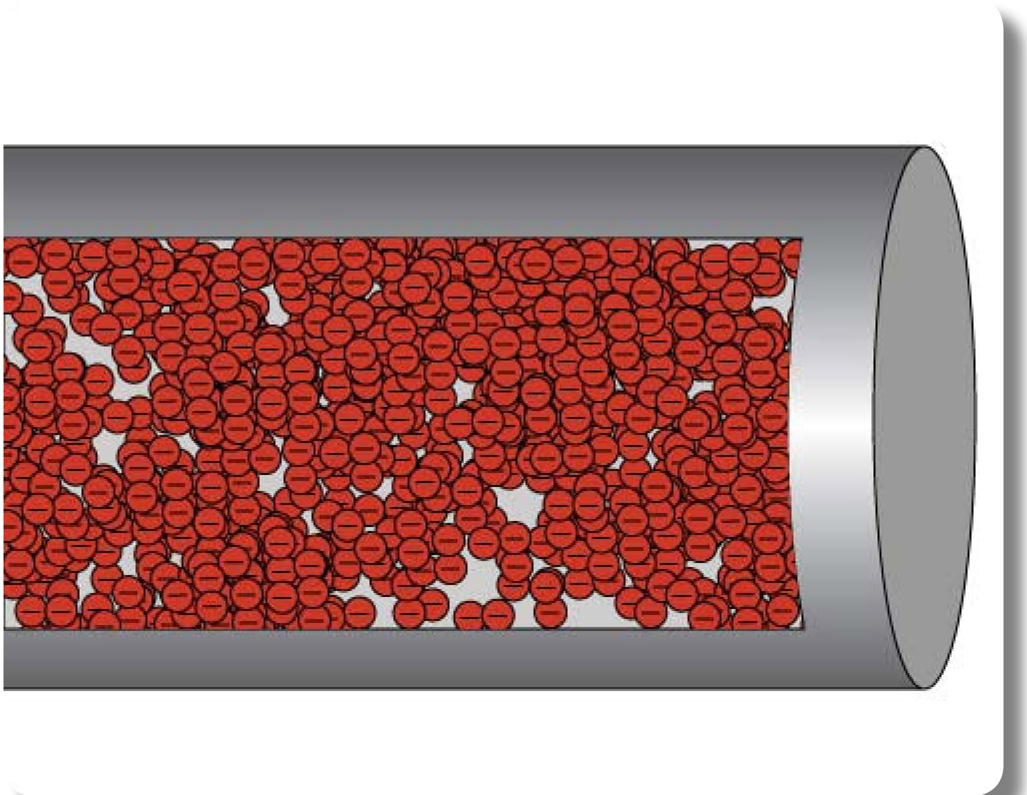
The electrons that exist in the outermost shell, or orbit, of an atom.

Electrons being displaced from atoms



The greater the applied force (voltage), the more electrons will be moved.

Electrons in a conductor



The movement of those electrons is what makes up electricity, and is what operates the lights, horns, computers, and every other electrical device on a car or truck.

Conductors, Insulators, and Semiconductors

Atoms that have one or two electrons in the valence shell are called conductors because they move electrons well. These conductors include copper, gold, silver, aluminum, nickel, zinc, and others. That is why those substances are used to make wire.

Atoms with a large number of electrons in the outer shell (six to eight) are called insulators because they don't release electrons easily. Materials that make good insulators include rubber and plastics.

The remaining atoms that have around four electrons in the valence shell (three to five) are called semiconductors because they are neither good conductors nor good insulators. Semiconductors are used, however, to make electronic components such as diodes and transistors.

Atom info:

1 or 2 valence electrons are conductors

3, 4, or 5 valence electrons are semiconductors

6, 7, or 8 valence electrons are insulators

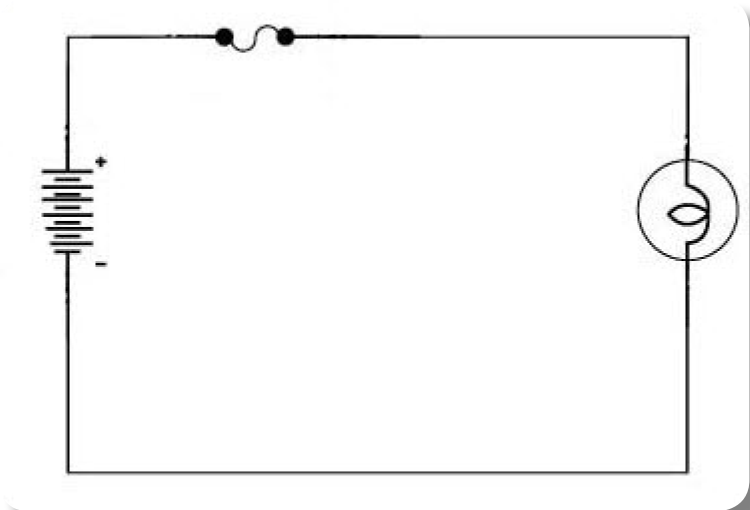
Electrical Circuits

Recall from the definition that a closed circuit is needed to turn electricity (electron flow) into work. But what, exactly, is a circuit?

Electrical circuits must make a complete 'loop'.

For electrical applications, a circuit is a complete 'loop' that carries electrons from a power or energy source -- such as a battery or generator -- through one or more conductors, such as wires, through one or more loads, to transform that electron flow into useful work.

Circuit



All circuits must start at the power source and, after moving through all of the conductors and loads, return to that same power source. In addition, most circuits also contain some form of control device, such as a switch, to turn the circuit ON or OFF, and a protection component (a fuse or circuit breaker) to protect the circuit against damage.

Circuit Components

All circuits, regardless of how complex they are, contain the same six types of components.

These components include:

1. A power source, such as a battery or generator
2. Protection devices, such as fuses or circuit breakers, to prevent damage to the circuit
3. Control devices, such as switches, to manage the electron flow
4. Loads (lights, motors, etc.) that turn the electron flow into work
5. Conductors to carry the electrons
6. Ground, such as the battery negative terminal or the '-' connection on a power supply, for completing the circuit loop

Each of these will be covered in greater detail in later sections.

Note: Going forward, we will be using electrical circuit diagrams like the one shown above. Diagrams such as this one are known as **schematics**.

Protection Devices

One of the characteristics of electrical circuits is that the more electrons that flow through a conductor, the greater the heat that will be created. As a result, protection devices are used in circuits to prevent damage from excessive electron flow.

Circuit Protectors

Circuit protectors are used to prevent wiring damage from excessive current.

Automotive circuit protectors come in three primary forms: fuses, circuit breakers (automatic and manual reset), and fusible links. While fuses and circuit breakers are still commonly used in automotive applications, fusible links are not (although we will cover them here).

All three varieties are designed to perform the same function, which is to open a circuit (like turning a switch OFF) if there is too much electron flow, before the circuit wiring can be damaged.

There are two things to keep in mind concerning fuses and circuit breakers:

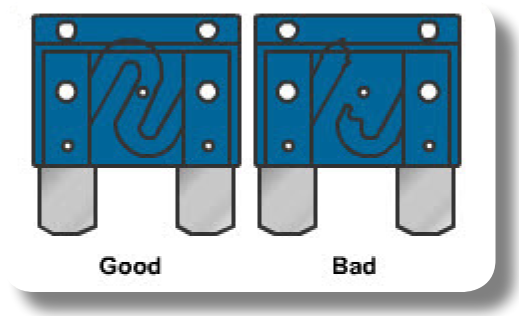
- They are designed to protect the circuit wiring, but not necessarily any other components.
- It is the HEAT from electron flow that causes these devices to open, not the electron flow itself.

Fuses

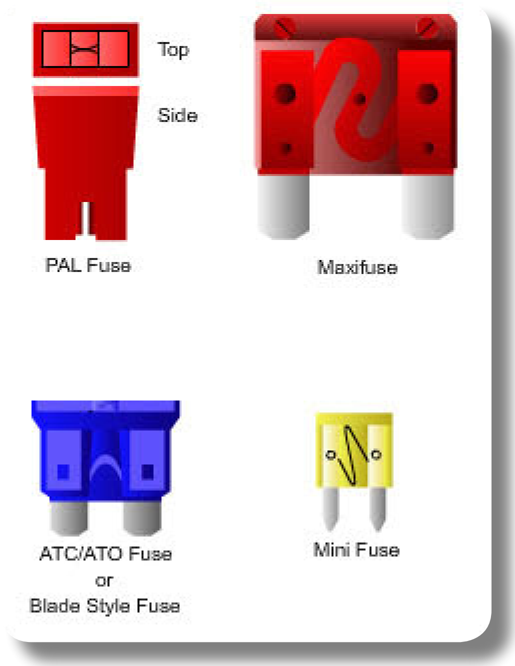
The most common type of protection device is the **fuse**. A fuse has a thin metal strip either inside a glass cylinder or in a plastic holder. The metal strip is designed to melt and open the circuit if too many electrons pass through the fuse. A fuse that has blown cannot be repaired and must be replaced.

Typical Fuses

Good/Bad Fuses



Assorted Automotive Fuses

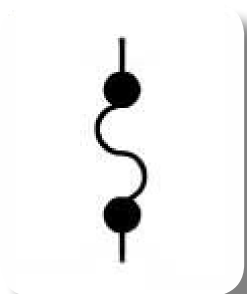


Automotive fuses typically come in three sizes -- small (minifuses), medium (autofuses), and large (maxifuses) -- and are rated in **amps** (the measurement of electron flow). They are also color-coded and labeled (see chart below) to indicate the maximum amps they are rated to handle.

Automotive Fuse Amp/Color Code Chart

Current Rating in Amperes	Fuse Color
Auto Fuse, Mini Fuse	
2	Gray
3	Violet
5	Tan
7.5	Brown
10	Red
15	Blue
20	Yellow
25	White or Natural
30	Green
Maxi Fuse	
20	Yellow
30	Light Green
40	Orange or Amber
50	Red
60	Blue

Fuse Symbol



CAUTION: Never replace a fuse with one of a higher amps rating. Serious circuit damage or electrical fire could result!

Automotive electrical fuses, regardless of their rating, will be indicated on electrical schematics with the symbol to the left.

Circuit Breakers

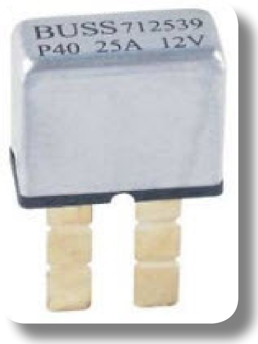
A circuit breaker, like a fuse, is a protection device designed to open when the electron flow exceeds a calibrated amperage.

Circuit breakers can be either cycling or non-cycling.

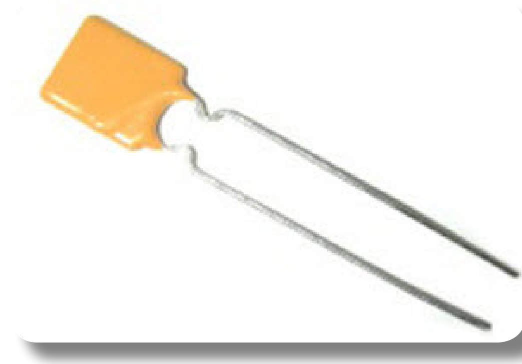
An electromechanical circuit breaker contains a bimetal strip made of two different metals bonded together. When excess heat is applied, the metal strip will separate, opening the circuit and preventing electron flow. Some circuit breakers must be reset manually while others reset automatically; these are referred to as 'cycling' circuit breakers.

An electronic circuit breaker, also called a PTC, will open automatically when the rated amperage is exceeded, and close again when the amperage is reduced. Electronic circuit breakers are typically used to protect power window circuits, and other similar circuits, if a switch becomes stuck and does not turn off.

Mechanical Circuit Breaker

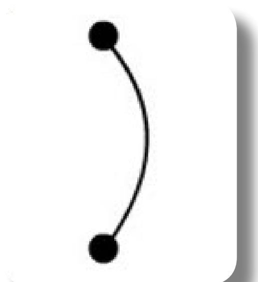


Electronic Circuit Breaker (PTC)

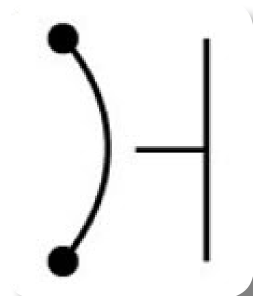


Automotive circuit breakers, regardless of their rating, will be indicated on electrical schematics with the two symbols below.

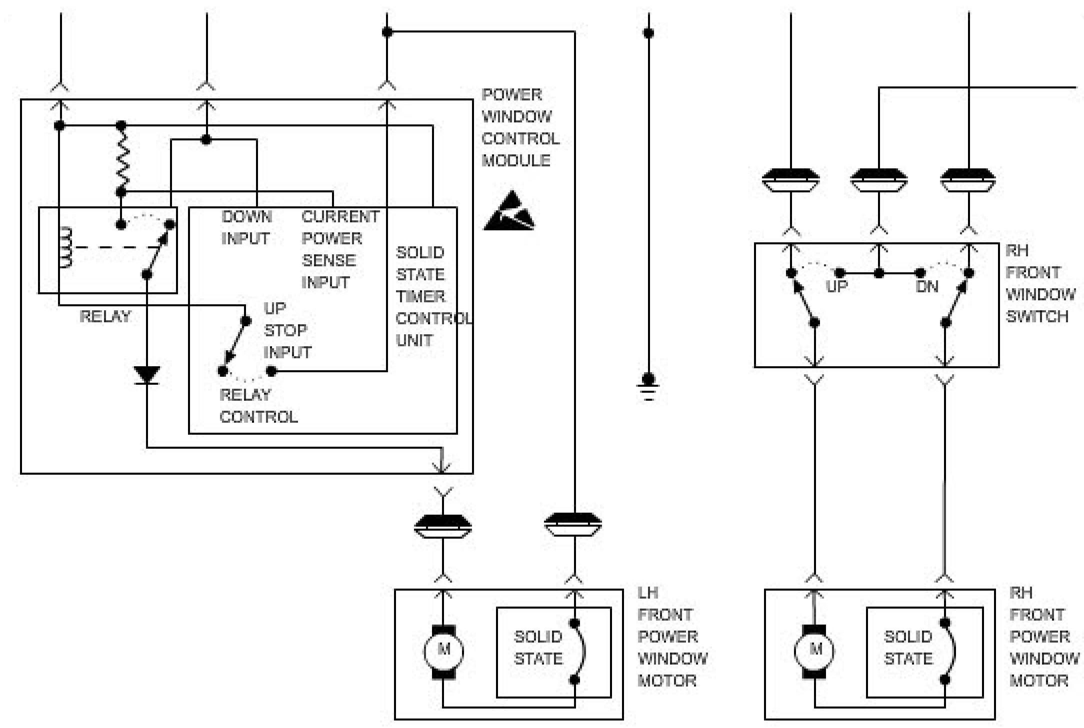
Self-Resetting Circuit Breaker Symbol



Manually-Resetting Circuit Breaker Symbol



Power Window Schematic with PTCs



Fusible Links

Another type of electrical protection device is the fusible link wire. A fusible link is a section of wire that is typically four wire-gauge sizes smaller than the conductors of the circuit it protects. Because they are smaller than the rest of the circuit wire, they will melt first, in the case of excessive electron flow, and prevent other damage to the circuit. Fusible links also have a special insulation coating that resists melting when it overheats.

> Fusible links should be four sizes smaller than the wire they protect.

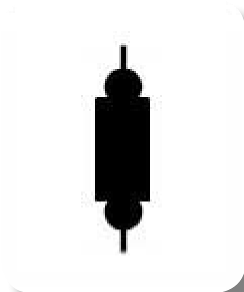
Although fusible links are no longer as common as either fuses or circuit breakers, there are still many of them currently in use, mostly in circuits rated at 30 amps or higher.

CAUTION: A blown fusible link cannot be repaired and must be replaced. Never attempt to replace fusible link wire with regular electrical wire!

Automotive fusible links, regardless of their rating, will be indicated on electrical schematics with the symbol below.

Fusible Link

Fusible Link Symbol



Control Devices

Control devices in electrical circuits are used either for the purpose of starting or stopping electron flow, or to limit the electron flow. Those that turn the electron flow ON or OFF are called **switches**, while those that limit electron flow are **variable resistors**. For now, we will limit ourselves to switches.

> Electrical control devices are either ON/OFF or variable.

Switches

Electrical switches are used to control current flow in an electrical circuit. Switches come in different shapes and sizes and can be controlled either manually or by hydraulic pressure, heat, vacuum or even light.

An electrical switch can be either normally-open or normally-closed, depending on the type of circuit it is controlling. A normally-open switch does not pass electrons when it is OFF but does pass electrons when it is ON. A normally-closed switch has contact (passes electrons) when it is OFF but not when it is ON.

When replacing an electrical switch, make sure you are using one that can handle the electrical load.

Switches are classified by the number of 'poles' and the number of 'throws' they have. For instance, a single-pole switch controls only one circuit, while a double-pole can control two circuits, and so on. Likewise, the 'throws' are the number of ON/OFF positions a switch has. As such, a single-throw switch has one ON and one OFF position, a double-throw has two (ON-OFF-ON), and so on. Common types of switches include the single-pole single-throw (SPST), the single-pole double-throw (SPDT), the double-pole double-throw (DPDT), and on to multiple poles and multiple throws.

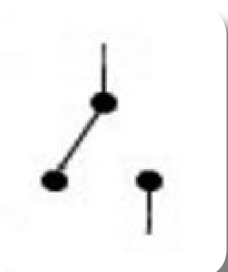
One additional type of switch is the **momentary switch**, which is spring-loaded and has contact only as long as it is held closed. Horn switches and brake light switches are examples of momentary types.

Electrical Switch Symbols

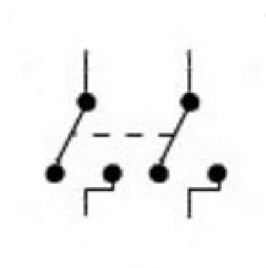
The symbols and pictures shown here are common with most manufacturers.

Switches are classified by their poles and throws.

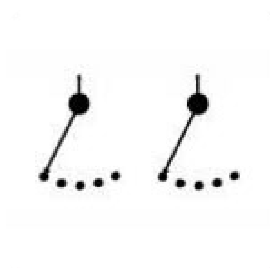
Single Pole
Single Throw



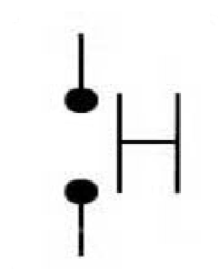
Double Pole
Single Throw



Multiple Pole
Multiple Throw



Momentary

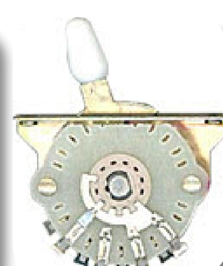


Actual Switches

Single Pole
Single Throw

Single Pole
Double Throw

Multiple Pole
Multiple Throw



Momentary

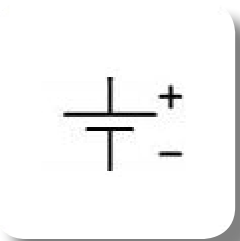
Switches can be used on either the positive side of a circuit or on the negative side of a circuit.

SYMBOLS

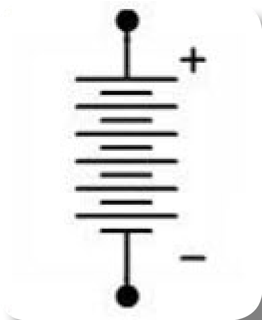
A diagram that is used to show the components and configuration of an electrical circuit is called a **schematic**. Instead of pictures showing a circuit's parts, schematics use symbols. Technicians and students must learn to read and recognize electrical symbols in order to understand and repair electrical circuits.

Listed below are a few of the most common electrical symbols. Some have appeared before and some have not, but all of them will be used during electrical training. If desired, this page can be printed out and saved for future reference.

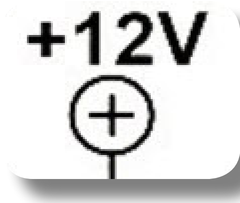
Battery Cell



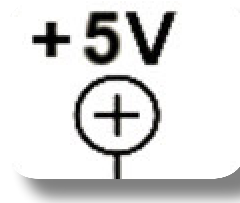
Battery



Power Supply-
12 Volts



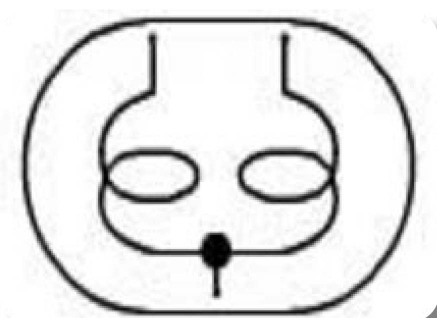
Power Supply-
5 Volts



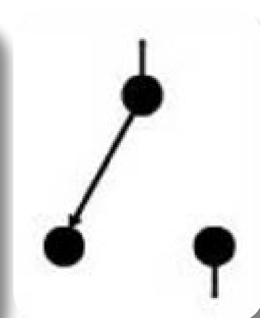
- Battery cell - This symbol indicates a two-volt battery cell. The longer line is the positive side and the shorter line is the negative side.
- Battery - Six of the two-volt cells are combined to form this automotive battery.
- Power supply - The 12-volts indicated here is from either a power supply or a charging system rather than a battery.
- Power supply - Same as above except it is 5-volts instead of 12.

Single Filament
Bulb

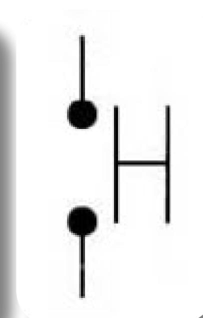
Dual Filament
Bulb



Switch

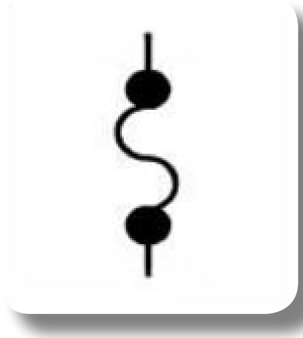


Momentary
Switch

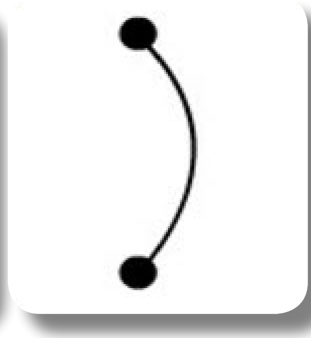


- Bulb - This could be any bulb with a single filament.
- Bulb - The bulb shown here will have two filaments.
- Switch - This is a toggle-type device with ON or OFF positions.
- Momentary switch - A switch like this closes a circuit only as long as it is pressed.

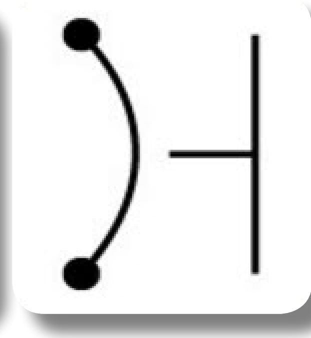
Fuse



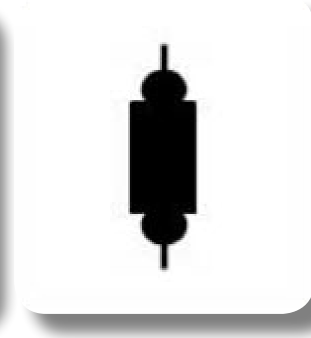
Circuit Breaker-
Automatic



Circuit Breaker-
Manual

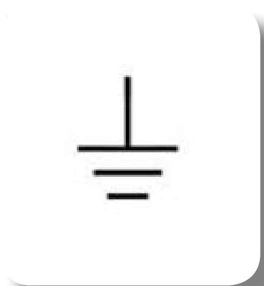


Fusible Link

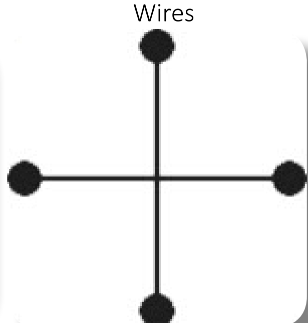


- Fuse - One-time-use protection device.
- Circuit breaker - This device will automatically reset after a circuit failure.
- Circuit breaker - Same as prior device except it must be manually reset.
- Fusible link - Wire-type protection device.

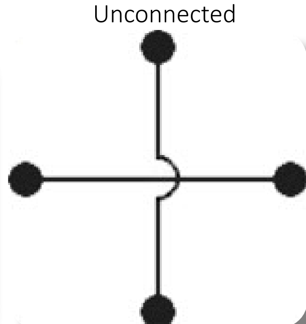
Ground



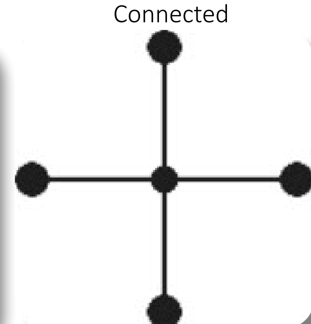
Two Circuit
Wires



Two Circuit Wires-
Unconnected

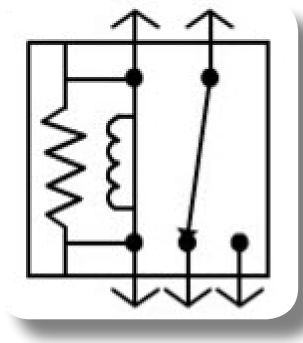


Two Circuit Wires-
Connected

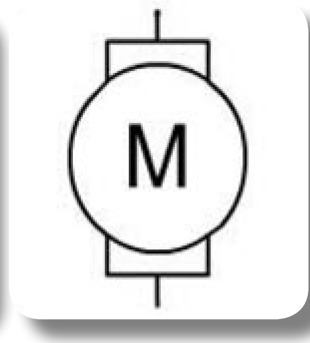


- Ground - This symbol shows a connection back to the negative side of a circuit.
- Two circuit wires - This symbol may or may not show connected wires. If it used to indicate connected wires, then the next symbol indicates non-connected wires. If it is used to show non-connected then the last symbol, with the dot in the middle, will show connected wires.
- Two circuit wires (unconnected) - These wires are not connected.
- Two circuit wires (connected) - These wires are connected to each other.

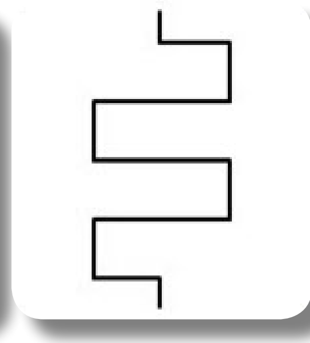
Relay



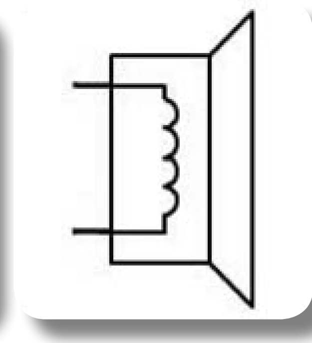
Electric Motor



Electric Heating Element



Horn or Speaker



- Relay - This is an electromagnetic switch.
- Electric motor - Only one symbol is used for motors, regardless of their size or use.
- Electric heating element - This item is the same for rear window defoggers, seat heaters, cigarette lighters, etc.
- Horns or speakers - Any device whose purpose is to project sound.

Electrical Properties

In this section, we will cover the four basic electrical entities: voltage, current, resistance, and power.

Voltage

Voltage is the component of electricity that is best described as the pushing force or **electrical pressure** which causes electrons to move through a conductor.

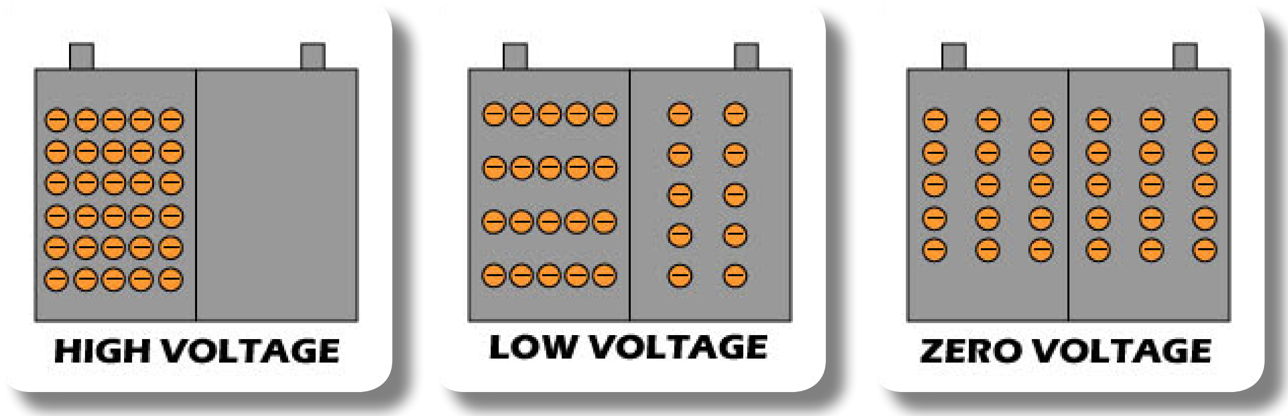
> Voltage is defined as electrical pressure.

Voltage is often compared to the water pressure in a garden hose that pushes water out of a nozzle. Even if the nozzle on the hose is closed, there is still water pressure in the hose, even though no water is flowing.

Electrical circuits work the same way in that there can be voltage present in a circuit, even if no electrons are moving. However, it is important to remember that if there is no voltage in a circuit (no pushing force), no electrons will move.

But, where does voltage come from? To understand that we need to recall our earlier discussion about free electrons. While electrical work is done by electrons moving through a conductor, before anything can move there must first be some electrons to start with. In automotive applications that place is typically the battery.

In a battery, if there are more free electrons on one side than on the other side (between the positive and negative plates), there is said to be a 'difference of potential,' or voltage. The greater the difference between the number of electrons on one battery plate and the number on the other plate, the higher the voltage. As the number of electrons on one plate approaches the number on the other plate, the lower the voltage becomes. A dead battery is one that has the same number of electrons on the positive plates as on the negative plates.



As we work with electricity, we will see that this electrical pressure has a number of different names, all of which mean the same thing. They are:

- Voltage or 'V'
- Electrical potential
- Potential difference
- Electromotive force or 'EMF' or 'E'

For the purposes of this course, we will use the term voltage and either the 'V' or 'E' designation.

Note: Remember that voltage is merely a pushing force and does not perform the real work in an electrical circuit; that comes from electron flow.

Items to remember about voltage and electron flow:

- Voltage (electrical pressure) is required for electrons to flow.
- An electrical circuit can have voltage with no electron flow, but it cannot have electron flow without voltage.

Source Voltage

Source voltage is a term used to refer to the amount of voltage available to move electrons through a circuit. For most automotive applications, source voltage should be in the 12-14 volt range.

> Source voltage is the voltage applied to a circuit when there is no electron flow.

However, many of today's sensors operate on a 5V supply, while certain actuators use 7, 8, or 10 volts. It is important for electrical technicians to be aware of the amount of voltage that should be applied to a circuit to ensure that misdiagnosis does not occur.

Current

We have examined the movement of electrons through a conductor, and how they perform work in electric circuits. That movement of electrons has a name: **current**.

Current is the movement of electrons through a conductor.

Returning to our water hose analogy from the previous section, current would be compared to the actual water moving through the hose. It is current, rather than voltage, that causes the lights to shine, the motors to turn, and the fuses to blow.

Current is measured in amperes, or amps, and is a measure of the number of electrons that move through a circuit. In actual numbers, one ampere is defined as 6.24×10^{18} electrons (a coulomb) moving past a certain point, in one second. That is 6,240,000,000,000,000,000 electrons in just one AMP!

Automotive systems vary from very high to very low current. For instance, the starter system is typically very high current, being in excess of 100 Amps, whereas computer current is very low, at much less than one amp.

Unlike voltage, which is the presence of electrons, current is the movement of electrons through some sort of conductor. The greater the number of electrons past a certain point, the greater the current, or amperage.

Current is generally referred to in one of two terms:

- Amperes, amperage, amps, or 'A'
- Intensity or 'I'

For our purposes, 'A' and 'I' will be used interchangeably.

Direct Current (DC) and Alternating Current (AC)

The current in any circuit will be one of two types: direct current (DC) or alternating current (AC).

Types of Current:

Direct Current always flows in the same direction.

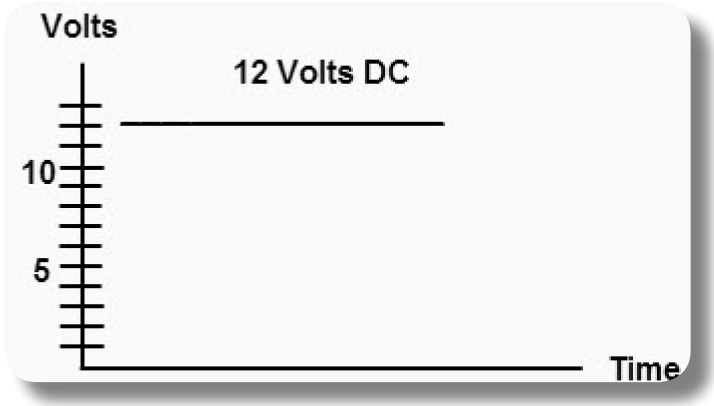
Alternating Current changes direction.

Direct current (DC) always flows in the same direction in a circuit, while alternating current (AC) flows in one direction, then reverses itself, and moves in the opposite direction.

Batteries and other steady state devices produce DC while AC always comes from a moving device, such as a generator.

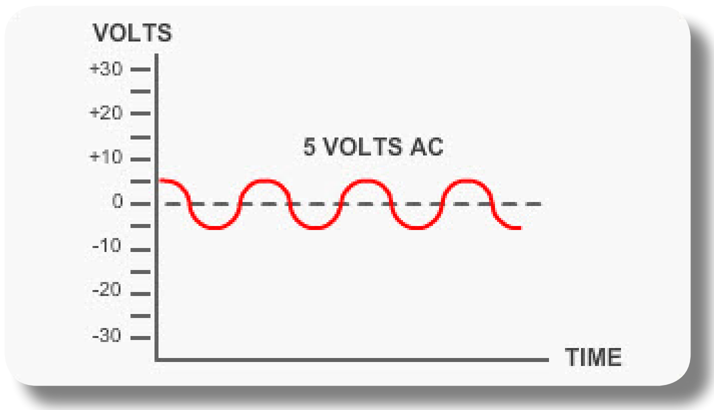
Technicians will find that the vast majority of automotive circuits are DC, whereas all household current is AC.

Direct Current (DC) Flow



Recall that in order for a current to be AC, the current flow in a circuit must actually change direction. In automotive applications, alternators and wheel speed sensors are examples of devices that produce AC Current.

Alternating Current (AC) Flow



Resistance

In an electrical circuit, anything that opposes the flow of electrons is called **resistance**. Just as voltage pushes current through conductors, resistance limits or reduces the number of electrons flowing in a circuit. In that way, the correct amount of current needed to operate a load (bulb, motor, etc.) is provided without damage to the circuit.

From this we can see that as resistance in a circuit is decreased, the amount of current will increase, and as the resistance increases, the current will decrease. Returning once again to our water hose analogy, a spray nozzle with a large opening (less resistance) has a larger flow of water (more current). Conversely, a smaller nozzle opening (higher resistance) has a smaller flow of water (lower current).

Resistance:

Resistance is anything that opposes the flow of electrons in a circuit.

Some resistance is necessary in any electrical application as it is used to convert electrical energy to other forms such as heat (defogger grids), light (bulbs), or motion (motors). It also serves to limit current so a circuit doesn't overheat.

These are some of the factors that determine a material's resistance:

- The number of free electrons in the outer shell of the atom
- The length of the conductor - a longer wire will have a higher resistance
- Cross-sectional area: The larger the cross-sectional area of a conductor, the lower its resistance will be. Example: A 1.0 mm^2 wire has less resistance than a .35 mm^2 wire.
- Temperature - generally, as a material is heated, its resistance increases (exceptions to this rule will be seen later).

Other factors can also affect the resistance in a circuit, such as loose connections, corrosion, broken wire strands, etc. In contrast to the useful applications of resistance mentioned before, these will cause a circuit to operate inadequately, or not at all.

The standard unit of measure for resistance is known as the **ohm**, and is shown either by the capital letter **R**, or the Greek letter omega (**Ω**). An ohm is defined as the amount of resistance that, when applied to a one-volt circuit, will limit the current to one amp. Thus, one volt through one ohm equals one amp.

The unit of measure for resistance is the ohm, indicated by the Greek letter omega: **Ω**

General Rules

General Rules of Electricity

As a result of this study of electrical circuits, it can now be seen that there are some general rules (later called Ohm's Law) that govern the relationships between voltage, current, and resistance.

The General Rules of Electricity describe the relationships between voltage, current, and resistance in an electrical circuit

They are:

Resistance:
If the **resistance** in a circuit remains the same:

- As voltage increases, current increases
- As voltage decreases, current decreases

Voltage:

If the **voltage** in a circuit remains the same:

- As resistance increases, current decreases
- As resistance decreases, currect increases

Voltage Drop

Voltage drop is a term that may be unfamiliar to new technicians, but it is important in the diagnosis of electrical circuits.

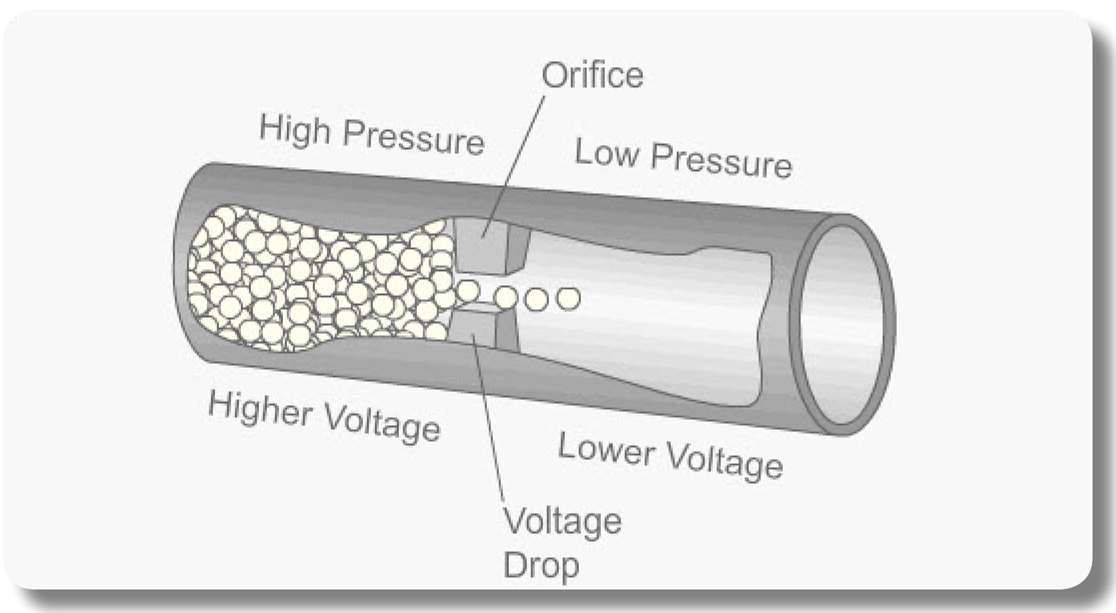
Voltage drop is the difference in electrical pressure between the two sides of a device.

To explain voltage drop, let's return to our water hose analogy once again.

At one time or another, we've all folded a hose in half to stop the water flow so we could relocate a sprinkler or as a joke to someone trying to wash their car. When that happens, the water pressure remains the same between the kink in the hose and the faucet, while the pressure on the other side of the kink drops to zero, or almost zero. This difference is called the pressure drop, and it is essentially the same as in electrical applications.

Voltage drop is the difference between the voltage on the inlet side of a device compared to the voltage on the outlet side. Comparing that value to a written specification will assist technicians in determining the fault with an electrical system.

Voltage Drop



Digital Multimeters

This section concentrates on the equipment and procedures used for testing electrical circuits.

Introduction

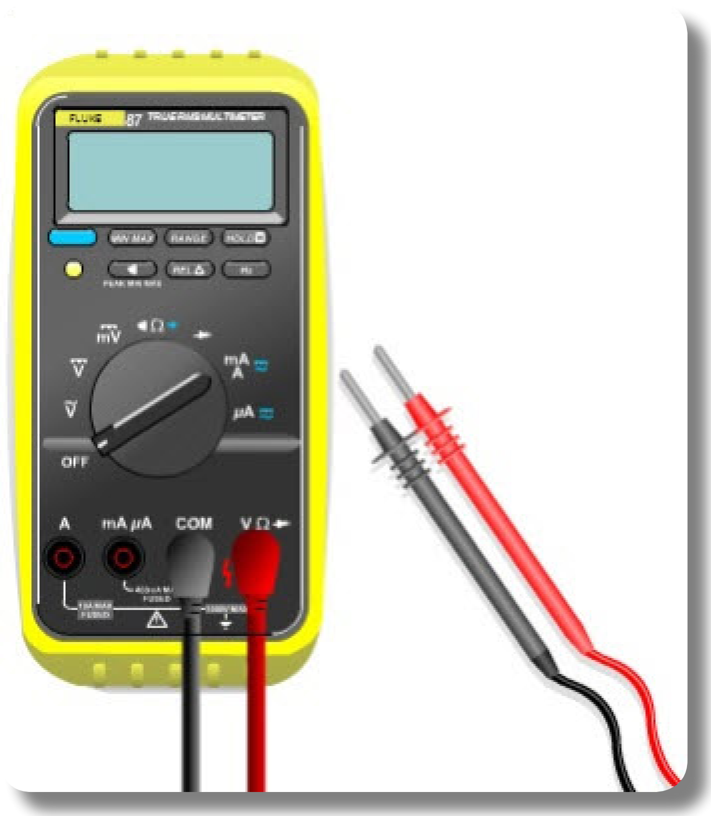
Introduction to Multimeters

In order to diagnose and repair automotive electrical problems, technicians must be able to test the systems for malfunctions.

For the most part, the majority of our electrical testing will be done with a **digital multimeter** (DMM), sometimes also called a **digital volt-ohm-meter** (DVOM). A DMM is a versatile tool used for measuring voltage, current, resistance, capacitance, frequency, pulse width, and other aspects of electricity.

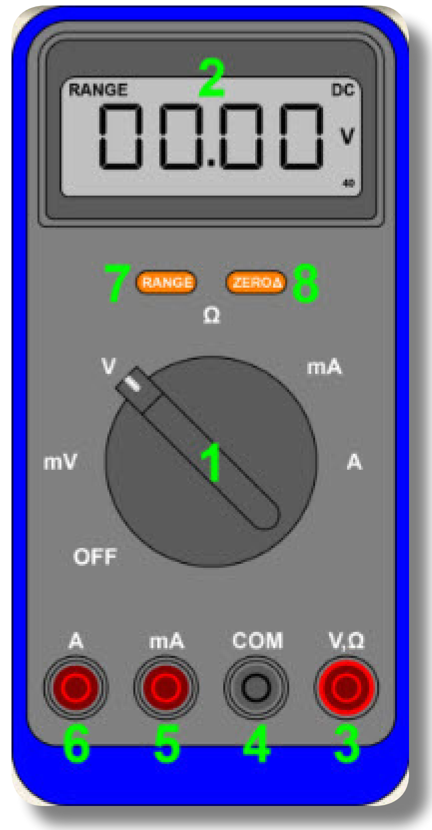
DVOMs come in many different sizes and capabilities; however, for our purposes we will use the following example which has features and operational characteristics that are typical of today's meters. Students should familiarize themselves with both the representative meter on the next page, and the one they will actually be using for circuit testing.

Digital Multimeter



DIGITAL MULTIMETERS

Typical Digital Multimeter



Although there are a large variey of DMMs available, most of them include as least eight common features as shown on the representative example shown here.

1. **Rotary dial** – Selects the attribute to be measured. The different positions include off, milliVolts (mV), volts (V), resistance (Ω), milliamps (mA) and amps (A).
2. **Four digit display** – This LCD readout can display up to four numerical values. It also has a moving decimal point for multiplication values and a range readout to show which value range is currently in use.
3. **Volt-ohm jack** – The meter's red test lead is placed in this terminal when measuring voltage, milliVolts, or resistance.
4. **Ground jack** – The meter's black test lead is placed in this terminal for all measurements.
5. **Milliamp jack** – When measuring small currents, typically less than 400 mA, insert the red test lead into this terminal.
6. **Amp jack** – When measuring larger currents, up to about 10A (depending on the meter), the red test lead will be inserted into this terminal.
7. **Range button** – This button allows the user to select among the various attribute ranges in order to get the most accurate reading possible. Many meters have AutoRange functions or buttons that change ranges automatically. Using a meter with AutoRange requires users to be vigilant about the range being used as it makes misreading easy to do. Be aware also that the various ranges represent the maximum amount which can be measured on that scale (e.g. a 40 Ω scale will allow readings only up to 40 Ω). Any measurement in excess of the range value will display OL, or Out of Limits.
8. **Zero button or relative delta (Rel Δ) button** – When making very small resistance measurements, it is sometimes necessary to remove any resistance in the test leads from the readout value. Before making those small measurements, touch the two leads (red and black) together and press the zero button. This action will remove any test lead resistance for more accurate measurements.

Meters come with different levels of features, quality, and prices. A technician considering the purchase of a digital meter should keep two things in mind:

- Does it have all the functions I need?
- What is its input impedance?

Choosing a Good Digital Multimeter:

A good digital multimeter must have a high input impedance of at least 10 MΩ.

Impedance is the measure of a meter's input resistance. A higher input impedance will prevent the meter from becoming part of a circuit during testing, and affecting the circuit operation.

Some lower-quality meters have a tendency to 'load' the circuit being tested and thus affect not only the operation of the devices itself, but also cause incorrect readings to be displayed. To prevent this 'loading' problem from occurring, always look for a meter with a high input impedance, preferably in the range of 10,000,000 ohms (10MΩ) or higher.

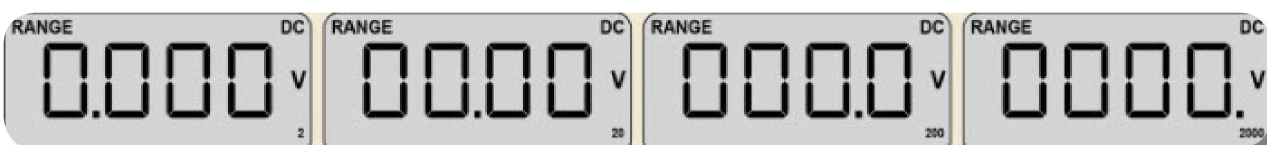
Input impedance becomes even more critical when measuring electronic components, as some low impedance meters can actually cause damage to those circuits.

Scaling

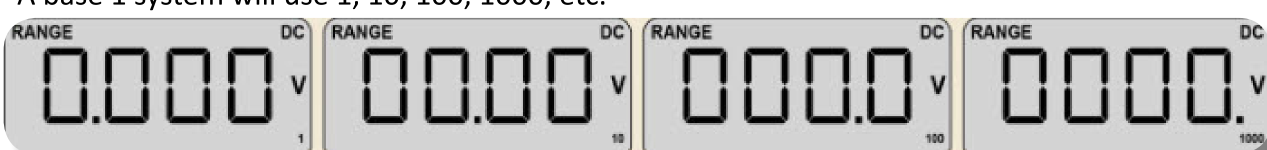
Meter Scaling or Base Numbering Systems

All DVOMs operate on a base numbering system that can be base 2, base 3, base 4, base 8, or base 10 (sometimes called Base 1). A base numbering system tells the user that all of the available ranges on a particular meter will begin with that number, and that they will be increments of that number. Students should, however, familiarize themselves with whatever system their individual meter uses.

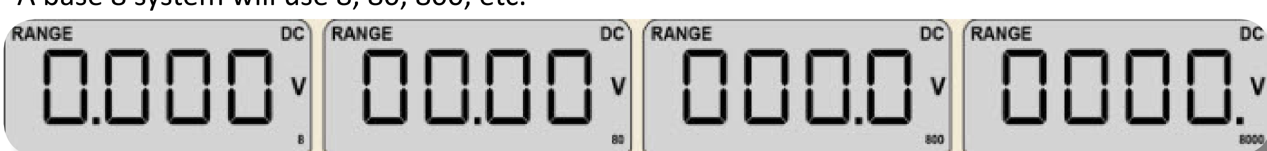
For example, a base 2 number will use ranges of 2, 20, 200, 2000, and so on.



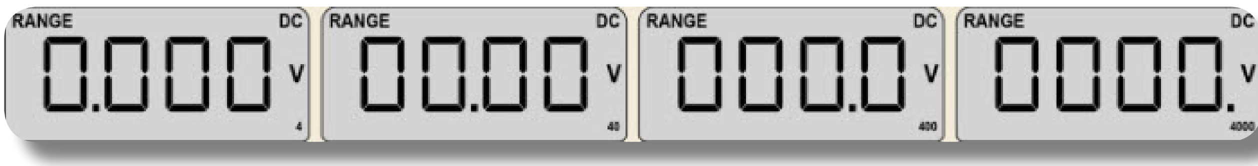
A base 1 system will use 1, 10, 100, 1000, etc.



A base 8 system will use 8, 80, 800, etc.



This course will use a base 4 system (4, 40, 400, 4000), since it is one of the more common systems in use today.



Notice that in all of these examples there is a number in the lower-right corner such as 4, 40, 400, 4000, etc. Those numbers designate the maximum amount that can be measured on that scale.

For instance, when testing voltage, the maximum value that can be measured will be 4V, 40V, 400V, or 4000V, depending on the scale selected. The same will apply for current and resistance measurements.

Scaling:

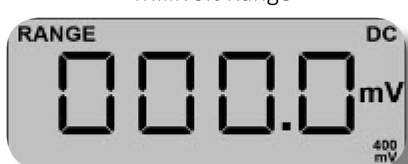
Always use the correct range to prevent reading errors.

The decimal point moves when the measurement range changes to reflect the correct number of digits.

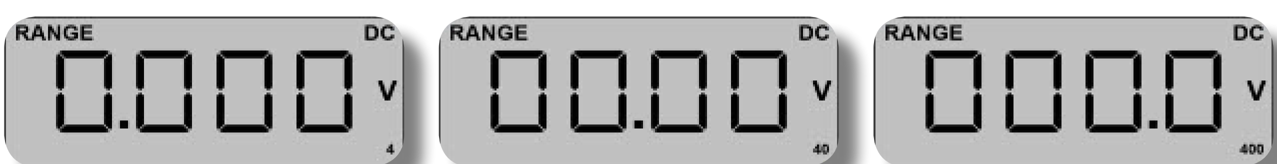
When manually selecting meter ranges for an unknown quantity, always start with the largest range and work down to lower ranges as needed. Keep in mind that using the lowest possible range will give the most accurate reading.

The screens below show the functions and ranges of a typical base 4 meter.

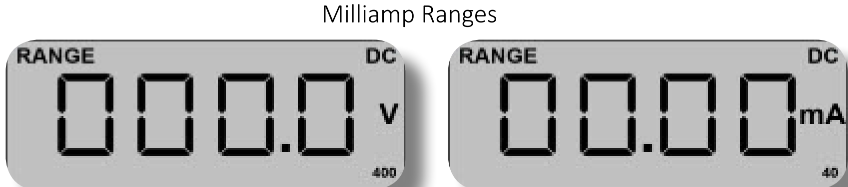
Millivolt Range



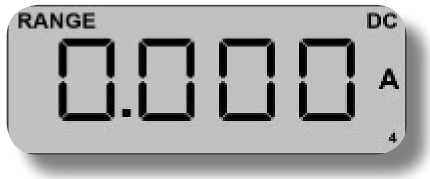
Voltage Ranges



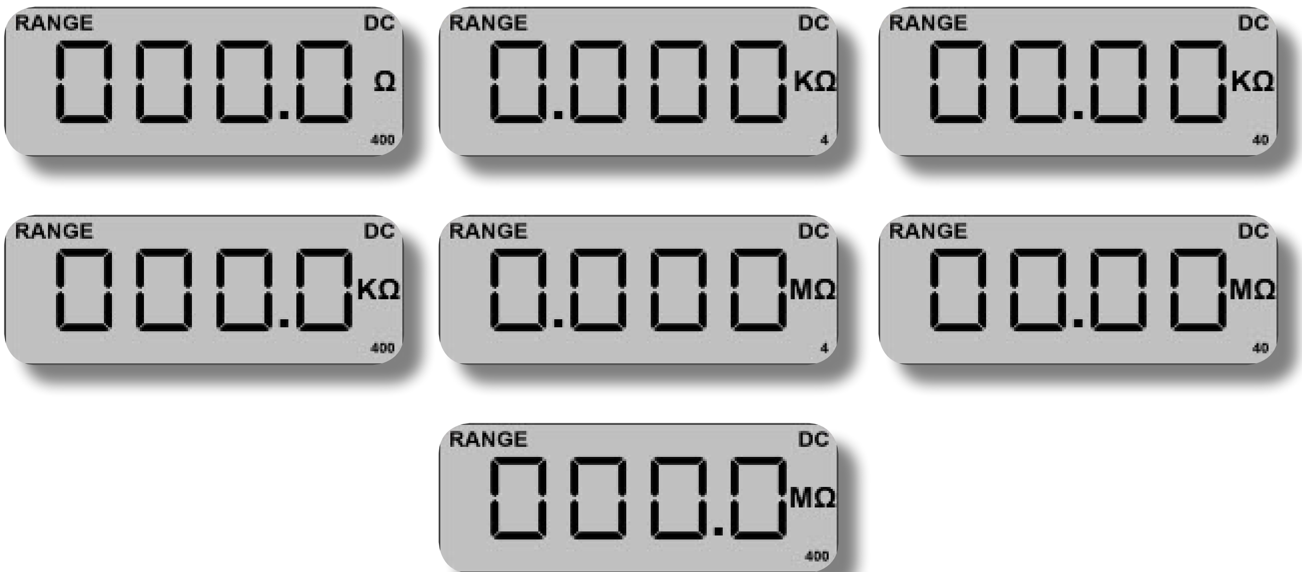
Milliamp Ranges



Amp Ranges

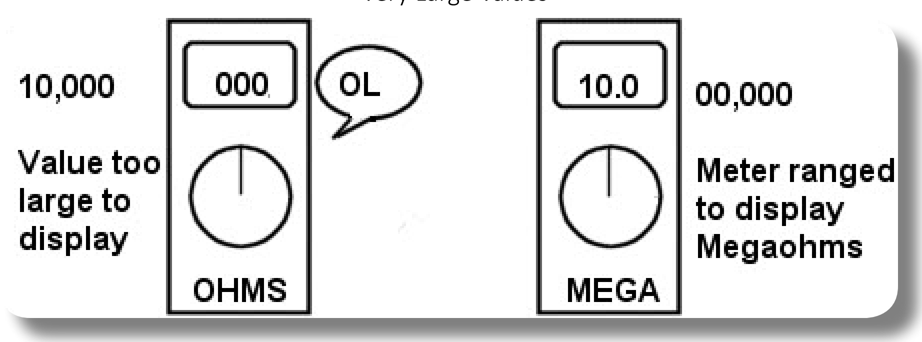


Resistance Ranges



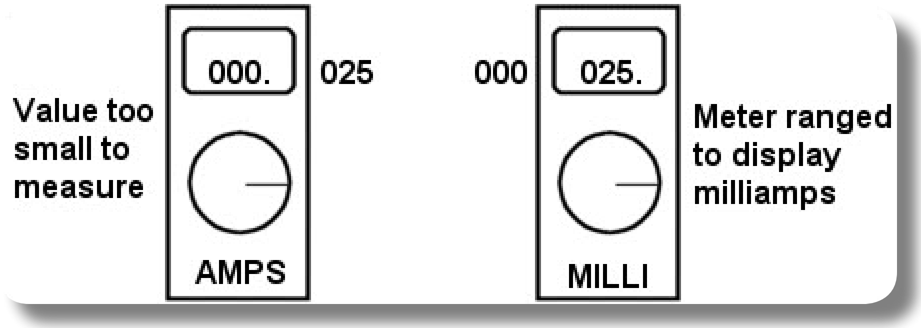
Example: If a technician is trying to measure 10,000,000 ohms with the meter set on a 400 Ω range, the display will read OL (Out of Limits) since the maximum readable value is 400 ohms. After switching the meter to the 40 megaohm range, the display will show 10.00. This reading indicates 10 MΩ; do not confuse this with 10 ohms! This is the reason why it is so important to be aware of the scale being used, especially if Auto-Ranging is active.

Very Large Values



The opposite condition can also be confusing in dealing with small values. Imagine you are trying to measure 25 mA on a 40 A scale. The meter would basically display zero (00.03). However, by switching to a 4A (4000mA) scale, the readout now shows 0025 mA, which is accurate.

Very Small Values



A technician who is careful to use the correct unit setting (volt, amp, ohm) and the right scale can consistently rely on the meter information to assist in proper diagnosis.

Digital Meter
Displaying Readings

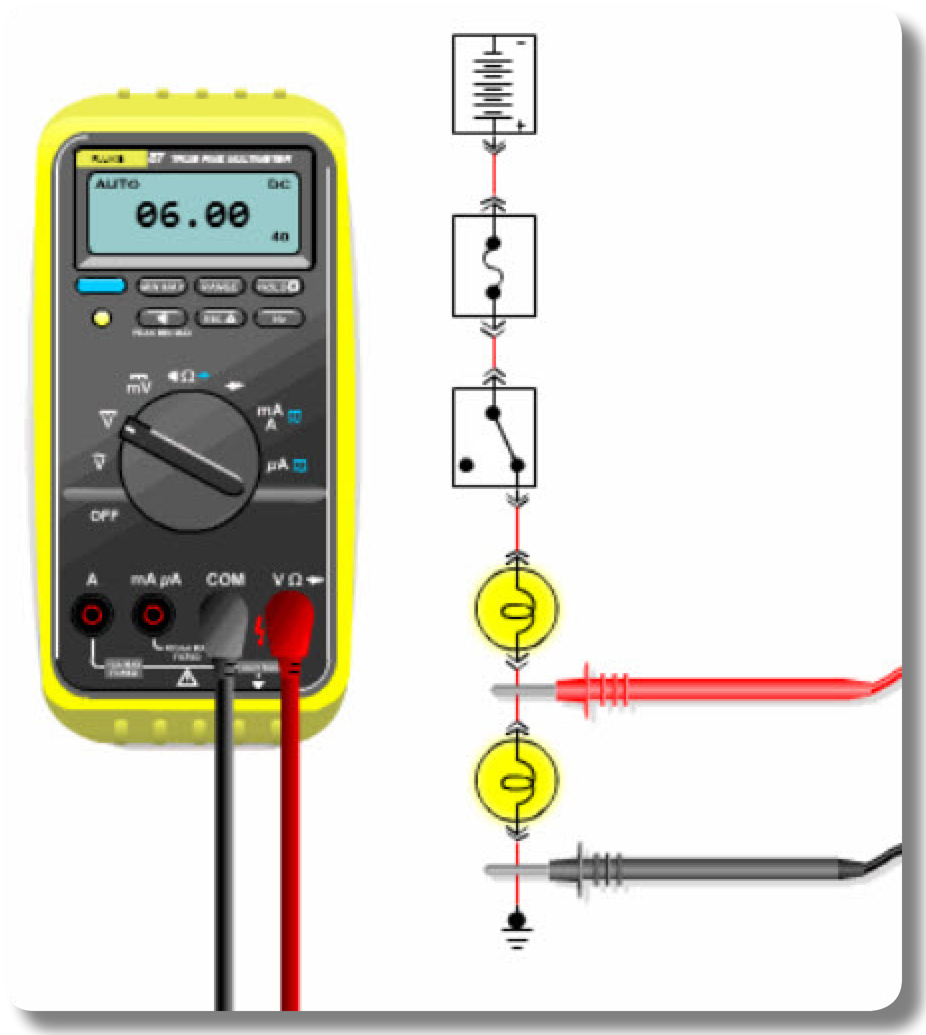
Measurements

DMM Measurements

Voltage Measurement:

To properly configure a meter for voltage measurements, follow these steps and refer to the figure shown here.

1. Insert the meter leads into the COM and VΩ inputs.
2. Turn the rotary dial to the AC or DC volt position.
3. Apply power to the circuit.
4. Place the leads across the component to be tested (voltage drop).



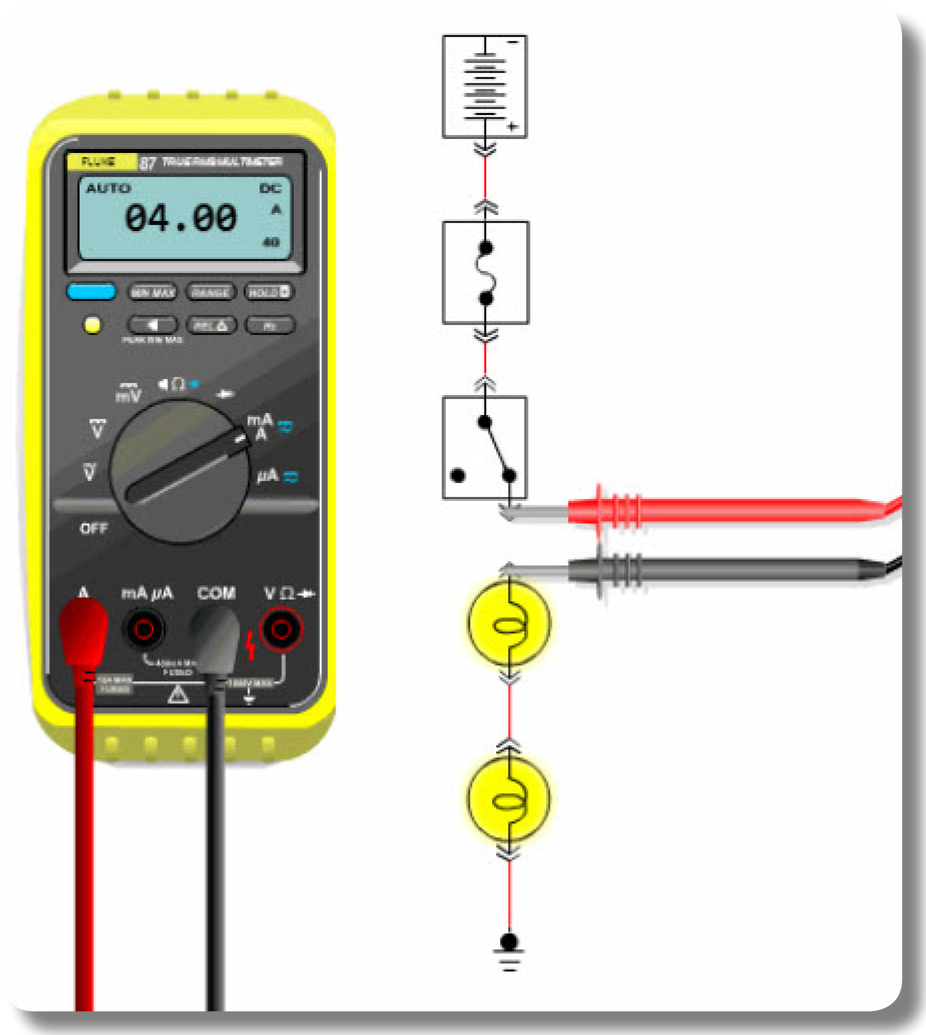
Current Measurement:

To measure current, follow this procedure and refer to the figure shown.

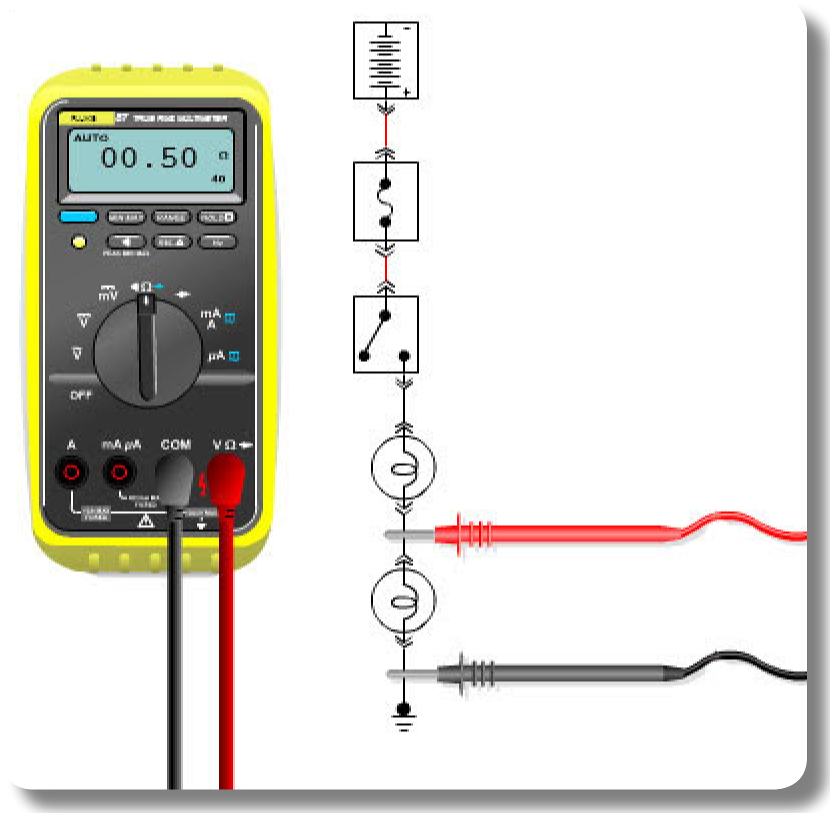
1. Insert the meter leads into the A and COM inputs.
2. Turn the rotary dial to the mA/A position.
3. Break the circuit by making an open.
4. Place the meter leads to complete the circuit (leads must be inserted so that all current flows through meter).
5. Apply power to the circuit.

CAUTION: To prevent blown fuses, check your meter installation thoroughly before applying power. Remember, in this mode, all of the current in the circuit will pass through the meter.

CAUTION: Never place leads across a component when measuring amperage.



When measuring circuit current, always begin with the red lead in the A (typically 10A) input terminal. The lead may be moved to the mA input only after you have determined that the current is below the maximum (typically 1A) rating for that terminal.

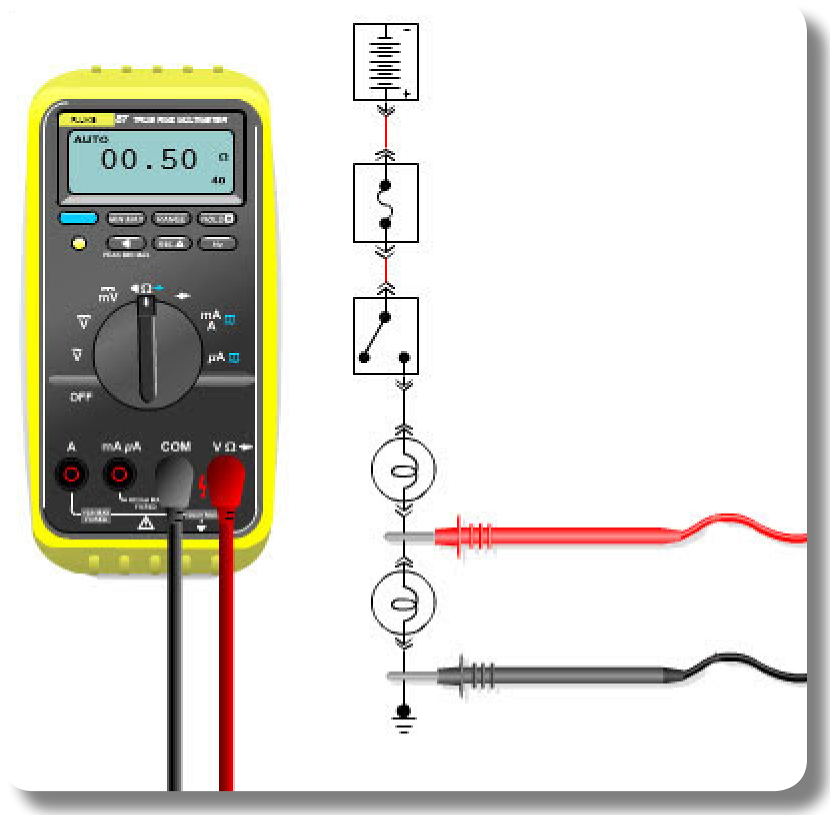


Resistance Measurement:

Resistance measurements are made according to these steps and shown in the figure.

1. Power must be OFF.
2. Insert the meter leads in the COM and VΩ inputs.
3. Turn the rotary dial to the Ω position.
4. Place the leads across the component.
5. Do not allow your fingers to touch the ends of the leads since it can change the reading!

Note: When measuring resistance, it is important to make sure the power is OFF. This is done not because it will damage the meter, but because it will give incorrect readings.



Converting Values

Converting Measurement Values

Meter Prefixes

When working with electrical circuits and measurement values, some of the numbers are either very large or very small and it may be necessary to convert a meter reading to either a higher or lower unit of measurement. To simplify these large or small values we use prefixes. A prefix is a letter or symbol that is placed in front of a base unit (volts, ohms, or amps) that signifies the actual size of a value while using fewer actual digits.

The four prefixes used in electrical designations are:

1. **Mega** - designated by the capital letter M, and equal to 1 million (1,000,000) times a base value. In electrical applications it is used almost exclusively with resistance measurements and is written as MΩ (megaohm). One MΩ is equal to 1,000,000 ohms.
2. **Kilo** - written as the capital letter K, and equal to 1 thousand (1,000) times a base value. It is also applied mostly to resistances, given as KΩ, but sometimes also to voltages where it is written KV. One KiloOhm (KΩ) is equal to 1000 ohms while one kilovolt (KV) is equal to 1000 volts.
3. **milli** - shown as a lower case m, and equal to 1 one-thousandth (1/1,000) of a base value. Milli tends to be used with either voltage or current measurements and is designated as mV and mA respectively. A millivolt is equal to .001 volts while a milliamp is .001 amps.
4. **micro** - designated by the symbol µ (mu), and equal to just 1 one-millionth (1/1,000,000) of a base unit. Micro is typically applied only to current values and is written as µA (microamps). One µA is the equivalent of 1/1,000,000 amp.

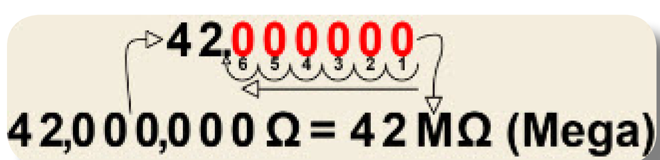
1,000,000 Base Units= 1 Mega (M)
1,000 Base Units= 1 Kilo (K)
.001 Base Units= 1 milli (m)
.000001 Base Units= 1 micro (µ)

Converting Prefixes

Now that we know all of the electrical value prefixes, how do we convert from one value to another? We just shift the decimal point.

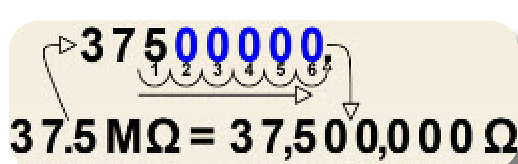
For example, if we begin with a value of one million ohms (1,000,000), and wish to convert to megaohms (MΩ), we simply move the decimal place six places to the left to get one MΩ.

Example: 42,000,000 Ω = 42 MΩ



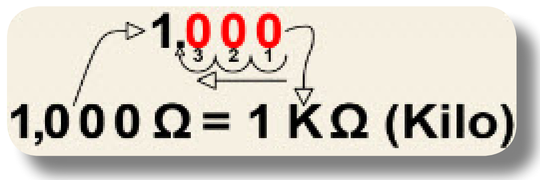
To go the other way and convert from megaohms to ohms, we move the decimal point six places to the right.

Example: 37.5 MΩ=37,500,000 Ω



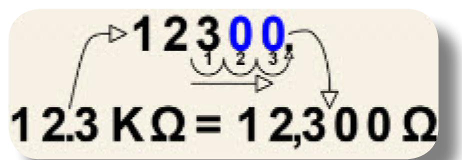
For kilo conversions the procedure is nearly identical. To change from base units such as ohms to KΩ, we only need to shift the decimal point three places to the left.

Example: 1,000 Ω = 1 KΩ



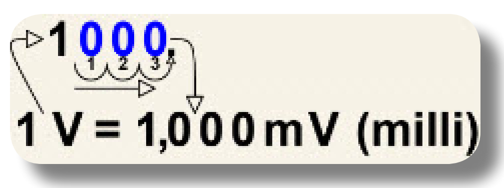
Likewise, a move from kiloohms (KΩ) to ohms is found by moving the decimal point to the right three places.

Example: 12.3 KΩ = 12,300 Ω



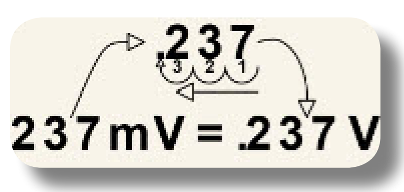
Milli and micro work in much the same way as mega and kilo except the decimal movement is opposite relative to the base units. When converting from volts to millivolts, the decimal point is shifts three places to the right instead of left as we saw previously.

Example: One V = 1000 mV



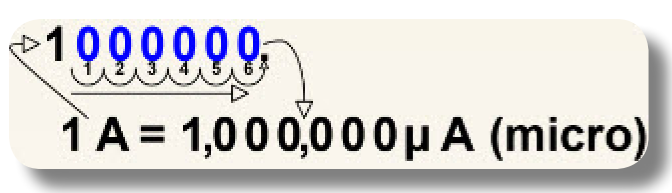
Moving from millivolts to volts will require the decimal point to be shifted three places to the left.

Example: 237 mV = .237 V



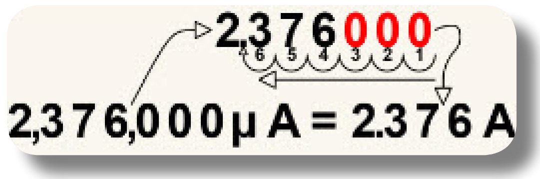
When converting amps to µamps, the decimal place will be moved six places to the right.

Example: One amp = 1,000,000 µA



And to move from µamps to amps the decimal shifts six places to the left

Example: 2,376,000 µA = 2.376 A



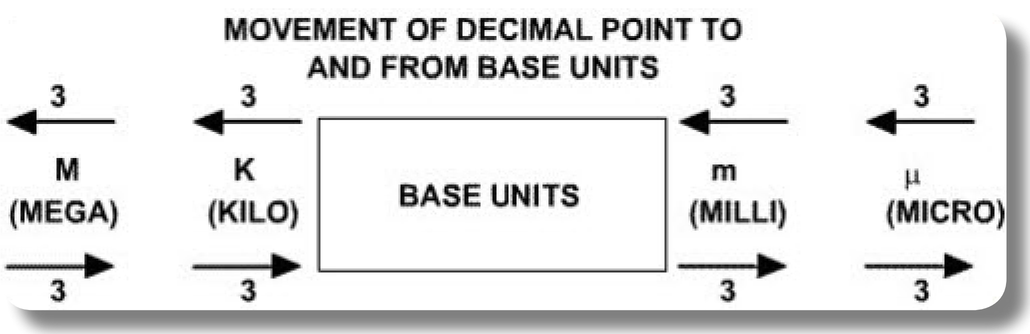
While all of the previous examples have been conversions from base units to prefix units or vice versa, what if we need to convert between prefix units? To convert from:

1. Mega (M) to kilo (K) – move the decimal three places to the right
2. Kilo (K) to mega (M) – move the decimal three places to the left
3. milli (m) to micro (µ) – move the decimal three places to the right
4. micro (µ) to milli (m) – move the decimal three places to the left

If any other conversions are required, such as milli to mega, simply change one to base units first, then to the other prefix.

The image below may come in handy when doing conversions. In this table, the base unit represents the number you are starting with. By moving the decimal point right or left, you can easily convert from a base unit to the appropriate prefix measurement.

Prefix Conversion/Decimal Movement Diagram



UNIT 2: ELECTRICAL CIRCUITS AND DEVICES

The following topics are addressed in this unit:

Series Circuits

- Introduction
- Circuit Elements
- Voltage Drop
- Series Circuits

SERIES CIRCUITS

This section involves the structure and testing of the simplest forms of electrical circuits.

INTRODUCTION

INTRODUCTION TO ELECTRICAL CIRCUITS

There are three basic types of electrical circuits, and all of them are used in automotive applications:

- **Series circuits**
- **Parallel circuits**
- **Series/parallel circuits**

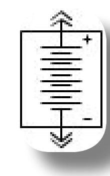
We will cover all of the different circuit types, beginning with the simplest. But first let's take a refresher on the elements that make up a circuit.

CIRCUIT ELEMENTS

Before we can understand the characteristics of circuits, we must first have a knowledge of the basic circuit elements.

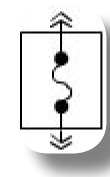
Source

The first requirement for any circuit is a source of power. Automotive applications generally have two primary power sources: the battery and the generator (or alternator).



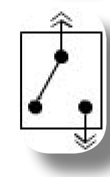
Protection

A fuse, circuit breaker, or fusible link is needed to prevent wiring damage from excessive circuit current.



Control

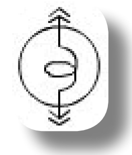
A control device can either turn a load ON and OFF, or it can vary its output.



Loads, such as headlights or fan motors, are either ON or OFF and use switches or relays as controlling devices. However, applications such as instrument panel dimming, fuel injection, and transmission valves have variable outputs and are controlled by potentiometers, transistors, and pulse width modulation computer signals.

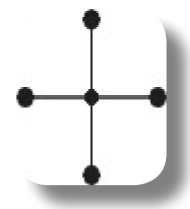
Load

A load is any part or component in a circuit that converts electric energy (moving electrons) into another form such as light from bulbs, rotary motion from motors, linear motion from solenoids, or heat from grids. A load will also add resistance to the current flow in a circuit. As mentioned before, loads can be devices such as bulbs, motors, and actuators or they can be unintentional items including bad connections and corrosion.



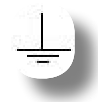
Conductors

A conductor is any component, device, or method that carries electron flow. Although almost anything will conduct electricity if the voltage is high enough (air is the conductor for lightning), in automotive applications, conductors are typically limited to two varieties: wires and the metal components of a vehicle's chassis or body.



Ground

All circuits must have a complete path to operate and automotive applications all terminate at ground, or battery negative. A ground return can be either hardwired to the battery negative or chassis grounded through the metal pieces of the vehicle. Case-grounded components have an internal connection to their metal casing and become chassis grounded when installed in the vehicle.



Note: In this course, we will show some circuits that make a loop and connect to the battery negative terminal, as well as some circuits that are straight and end with a ground symbol. Any circuit that has a ground symbol at the end reconnects to the negative terminal of the battery through the vehicle's metal body.

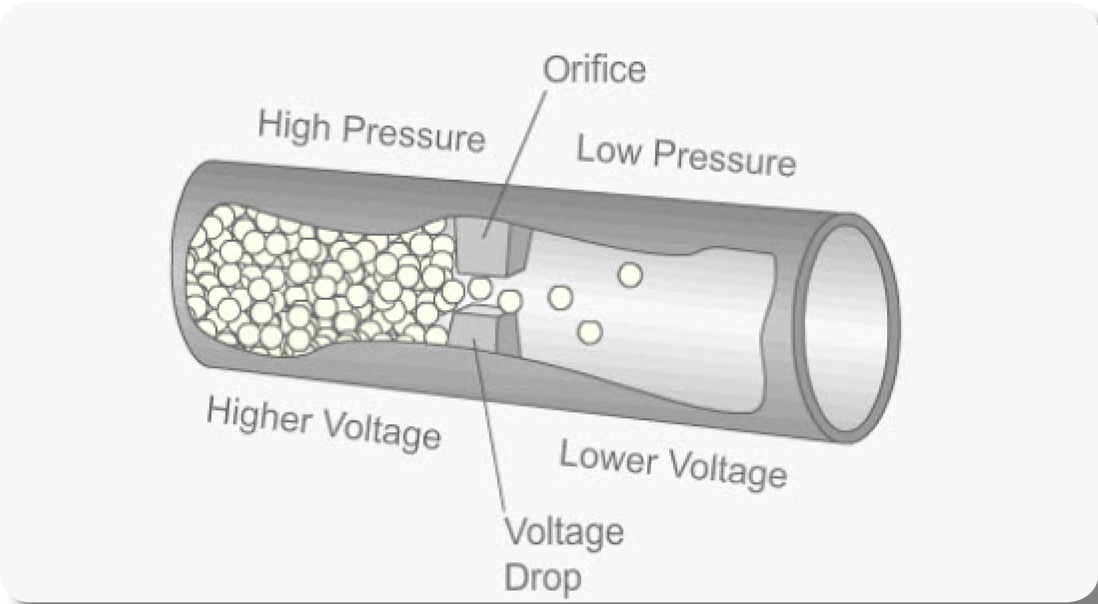
Voltage Drop

Voltage drop is the loss of electrical pressure (voltage) that results from trying to push electrons through a resistance.

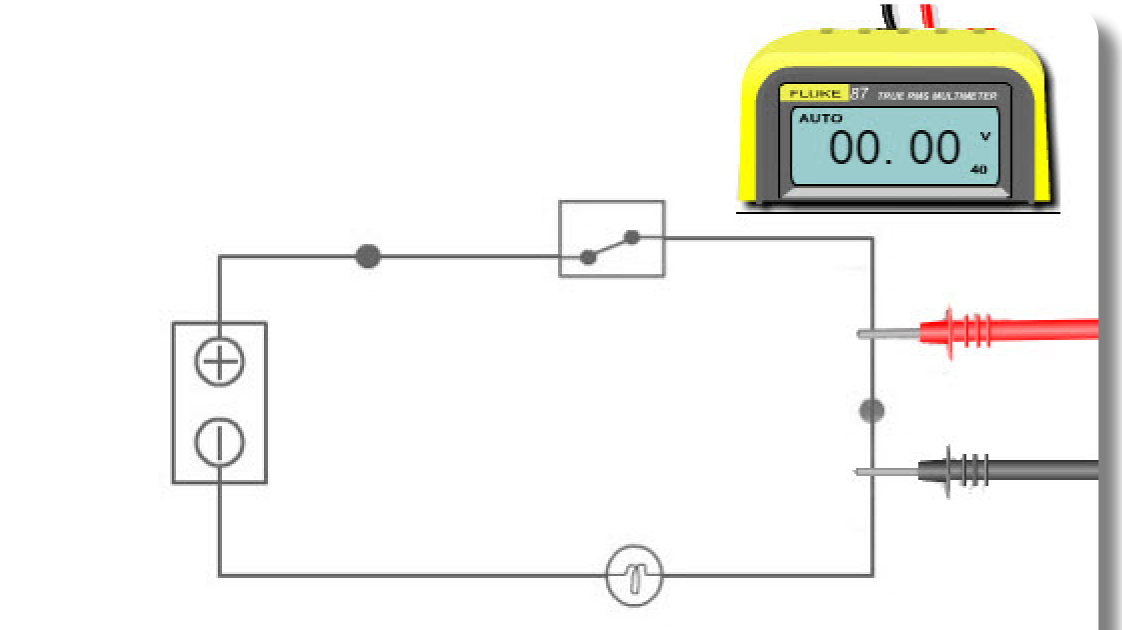
As explained earlier in this course, voltage drop is like the pressure loss in a hose with a crimp in it. It can also be defined as the difference between the voltage on the inlet side of a device as compared to the voltage on the outlet side. Comparing measured voltage drops to written specifications will assist technicians in diagnosing system faults.

Voltage drop is the difference in electrical pressure between the two sides of a device.

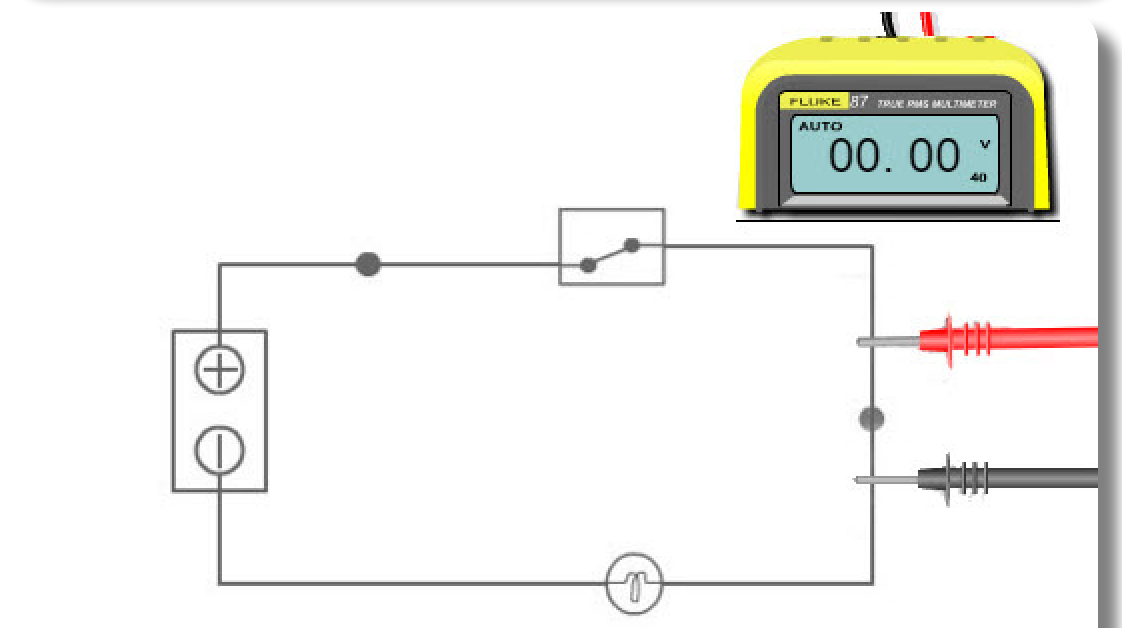
Voltage Drop



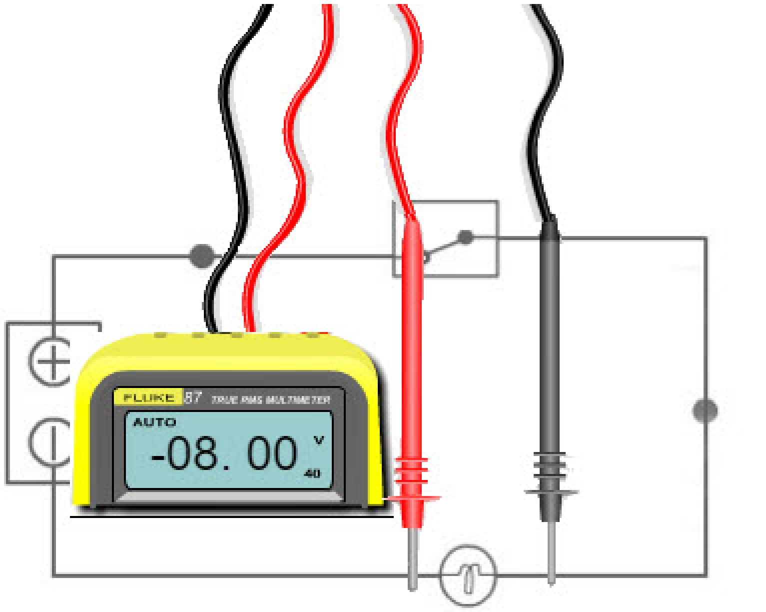
The images below give an example of how to use a digital multimeter to determine voltage drop.



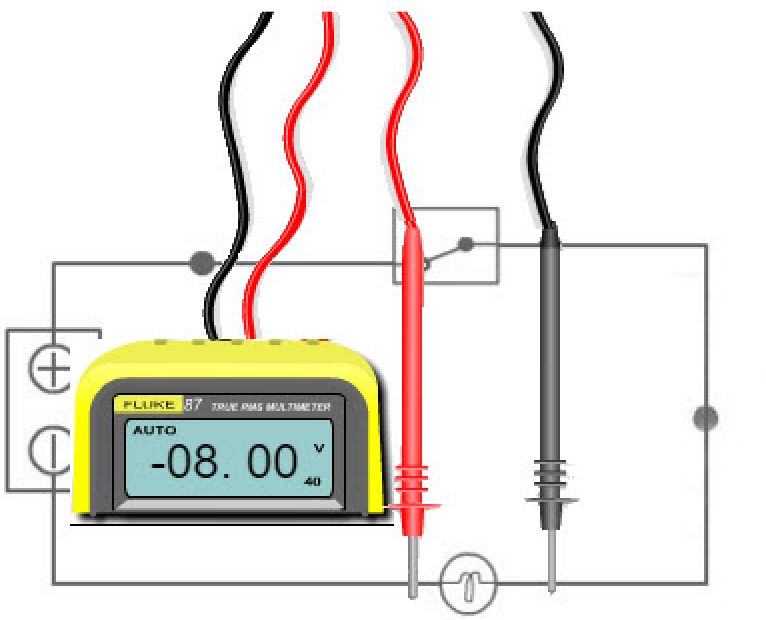
Q. Is meter 2 showing a normal reading?



A. Yes.



Q. Why is meter 3 showing negative voltage?



A. The probes are reversed; however, the meter is accurately showing a voltage drop of 8V. If the connector between points A and B were good, the meter in this diagram would show a voltage drop of 12V. With the bad connector, this bulb would be glowing dimly.

SERIES CIRCUITS

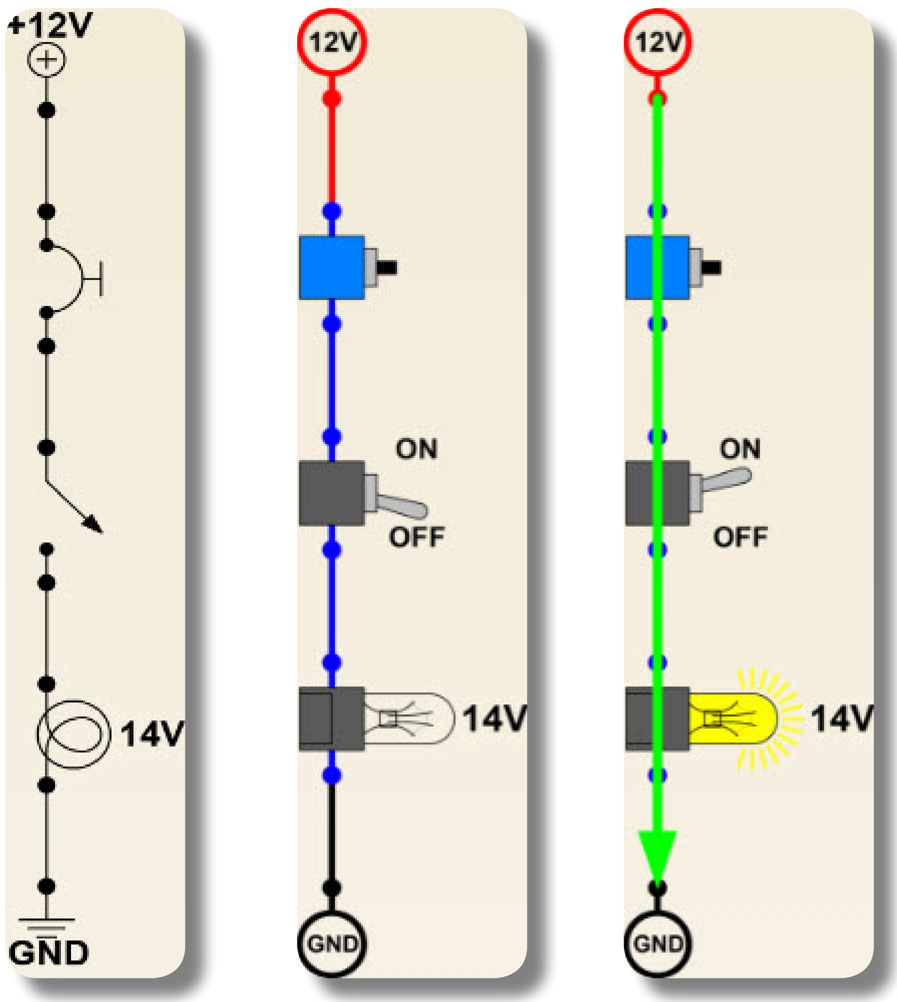
Now that we understand the basic components that make up circuits, as well as how to measure voltage, current, and resistance, let's begin building and testing the different types of circuits. For that we will start with the simplest type of circuit, the SERIES circuit.

A series circuit is any circuit that has only one path for current to flow.

This definition holds true regardless of the number of components in a particular circuit. Series circuits also have three rules that govern their behavior regarding voltage, current, and resistance.

> A series circuit has only one path for current to flow.

Simple Series Circuit (OFF and ON) and its Schematic



The three rules of series circuits are as follows:

1. **Rule #1**: The sum of the individual voltage drops in a series circuit is always equal to the source or applied voltage.

   Recall from the section on digital meters how to make Voltage measurements, and apply that to this circuit. Rule #1 tells us that the voltage drop across the circuit breaker, plus the voltage drop across the switch, plus the voltage drop across the bulb, will equal the source voltage, or 12 volts.

2. **Rule #2**: The sum of the individual resistances in a series circuit is always equal to the total circuit resistance.

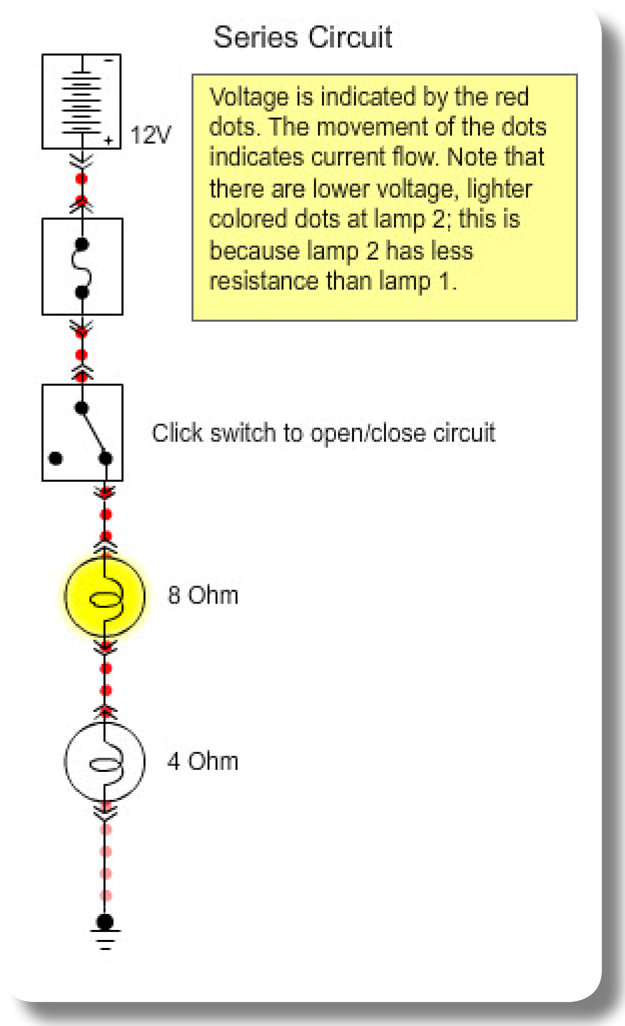
   Similar to the voltage checks, if we measure the resistance across the circuit breaker (power OFF!), plus the resistance across the switch, plus the resistance across the bulb, it will equal the total resistance of the circuit, from top to bottom.

3. **Rule #3**: Current is the same everywhere in a Series Circuit.

   Since the current only has one path to flow in this type of circuit, it must be the same everywhere. No matter where you test the current in a Series Circuit, the same value should be displayed. If it isn't, there is a problem in the circuit.

There are two other facts about series circuits to remember:

- The higher the resistance in a series circuit, the higher the voltage drop.
- Any opening will disable the entire circuit



UNIT 3: ELECTRICAL RELATIONSHIPS AND EQUATIONS

The following topic is addressed in this unit:

Ohm's Law

- Ohm's Law
- Relationships and Formulas
- Calculations for Circuits

Ohm's Law

In this unit, we find and evaluate the relationships between the electrical entities.

Ohm's Law

In 1827, a German physicist named Georg Simon Ohm discovered that relationships exist between **voltage**, **amperage**, and **resistance**, as well as between those three and **power**.

These discoveries were so significant that the unit of resistance, the ohm, was named in his honor. The relationships, and their coinciding mathematical equations, are called Ohm's Law

Ohm's Law:

Defines the relationships between voltage, current, and resistance

In order to adequately understand the electrical relationships of Ohm's Law and the corresponding equations, we need to first recall the three primary electrical attributes:

1. Voltage is ***applied*** to circuits.

   For Ohm's Law calculations, we will use the letter '**E**' to designate voltage or **electromotive force**.

2. Resistance ***exists*** in a circuit because of the material from which it is made.

   The mathematical symbol for **resistance**, in Ohm's Law, is '**R**.'

3. Current is the ***result*** of the applied voltage against the resistance.

   The letter **'I'**, for **intensity**, will be used to signify current or amperage.

In electrical circuitry, if any one of the three variables (E, I, R) changes, it will affect at least one of the other two.

Also, a value for any one of these variables can be found, as long as the other two are known.

Relationships and Formulas

Ohm's Law Relationships and Formulas

Relationships

There are two primary relationships defined by Ohm's Law.

1. Voltage vs. current

Assuming resistance remains the same:

- If voltage increases, then current will increase.
- If voltage decreases, then current will decrease.

2. Resistance vs. current

Assuming voltage remains the same:

- If resistance increases, then current will decrease.
- If resistance decreases, then current will increase.

Formulas

The primary formula for Ohm's Law is:

E = I x R

or

Volts = Amps x Ohms.

This tells us that if we multiply the current (in amps) times the resistance (in ohms), we can find the applied voltage or voltage drop.

Ohm's Law Formulas:

Voltage E = I x R

Current I = E / R

Resistance R = E / I

The equations for current and resistance are found by algebraic manipulations of the first equation.

To find an unknown current we use:

I = E/R

or

A = V/Ω

dividing the voltage by the resistance to find the current.

Resistance is found using:

R = E/I

or

Ω = V/A

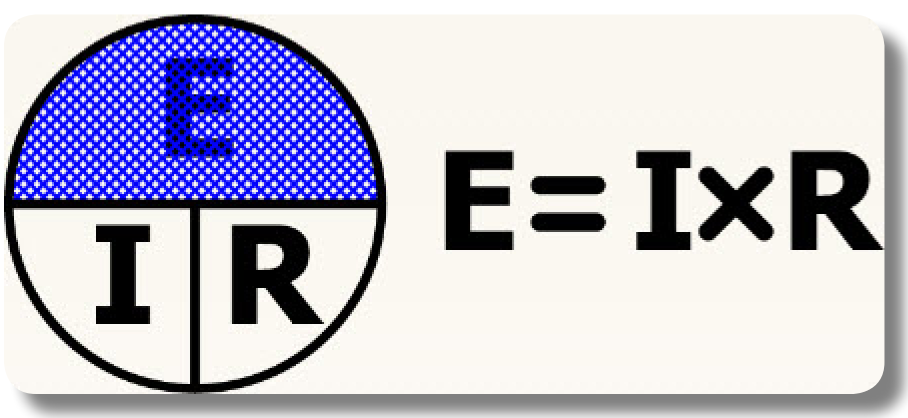
dividing the voltage by the current to find resistance.

Ohm's Law Solving Circle

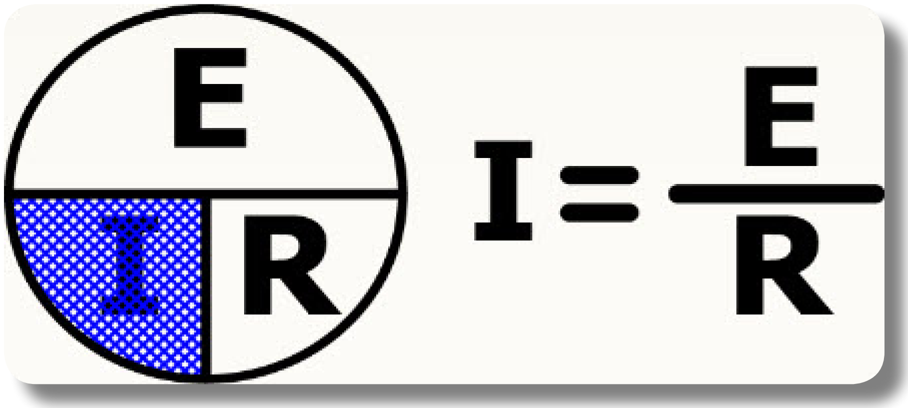
An easy way to remember these formulas is by using a **solving circle** such as this:

In order to use the solving circle, cover up the value you want and the remaining factors will provide the necessary formula.

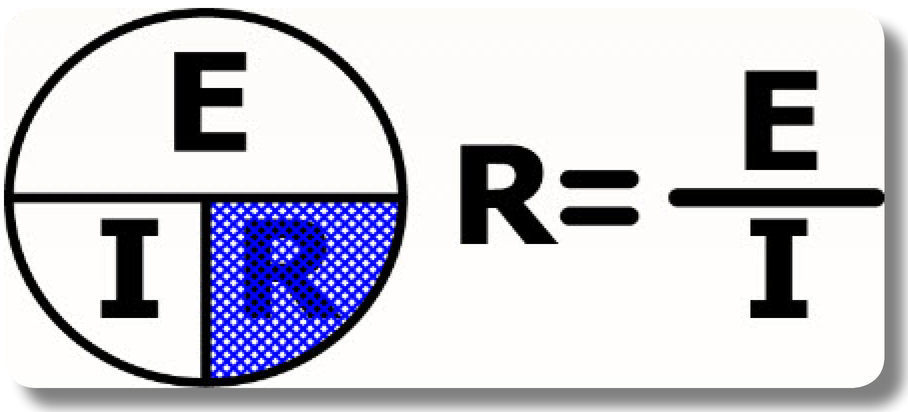
For instance, if you are trying to find an unknown voltage, simply cover 'E' on the circle and the correct formula (I x R) will remain.



Likewise covering the 'I' for an unknown current leaves E/R,



and covering the 'R' for an unknown resistance leaves E/I.



Important - All Ohm's Law calculations must be made using only base units (volts, ohms, and amps). Any values that are not in base units, such as KΩ, mV, mA, etc., must first be converted to base units before applying an Ohm's Law formula.

Calculations for Circuits

In the series circuit to the right, we have:

$\mathbf{R}_T$ = 12 ohms (lamp 1 resistance 8 ohms + lamp 2 resistance 4 ohms)

$\mathbf{I}_T$ = 1 amp (12 volts / 12 ohms)

$\mathbf{E}_T$ = 12 volts (source voltage)

(T = total)

Applying Ohm's Law to this circuit:

What is the voltage drop at Lamp 1?

E = I x R

E = 1 amp x 8 ohms = **8 volts**

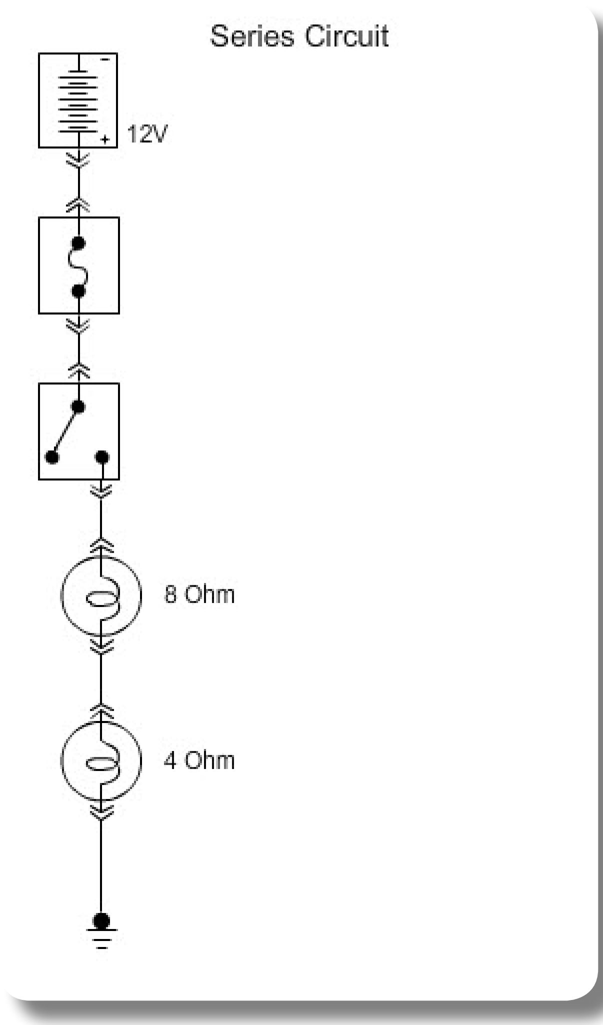
What is the voltage drop at Lamp 2?

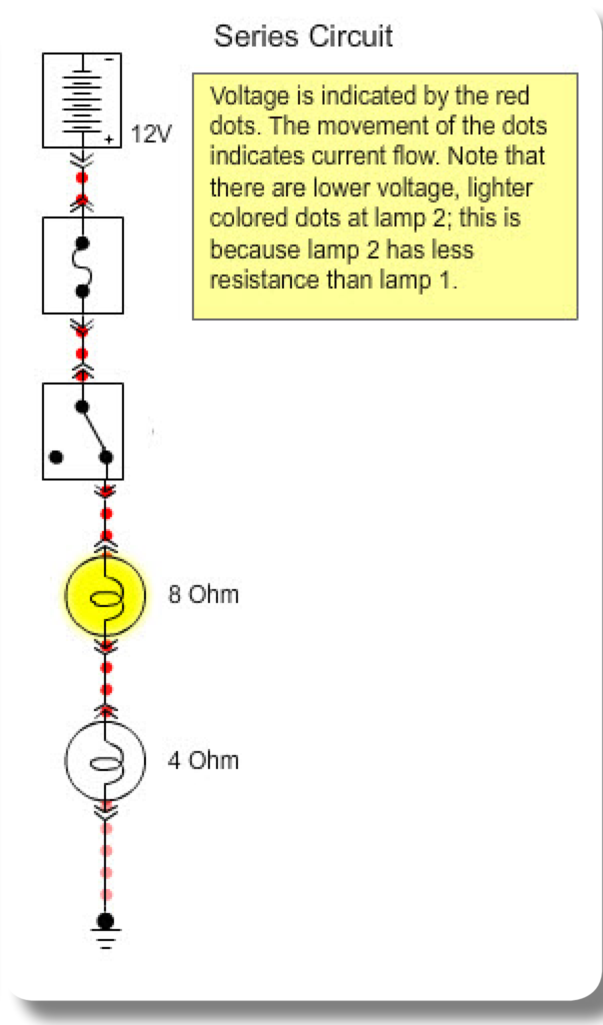
E = I x R

E = 1 amp x 4 ohms = **4 volts**

Remember!

In a series circuit, amperage remains the same throughout the circuit.





UNIT 4: ADVANCED ELECTRICAL CIRCUITS

The following topics are addressed in this unit:

Parallel Circuits and Series-Parallel Circuits

- Parallel Circuits
- Ohm's Law for Parallel
- Series-Parallel Circuits

Parallel Circuits

Parallel and Series-Parallel Circuits

This unit deals with increasingly complex electrical circuits.

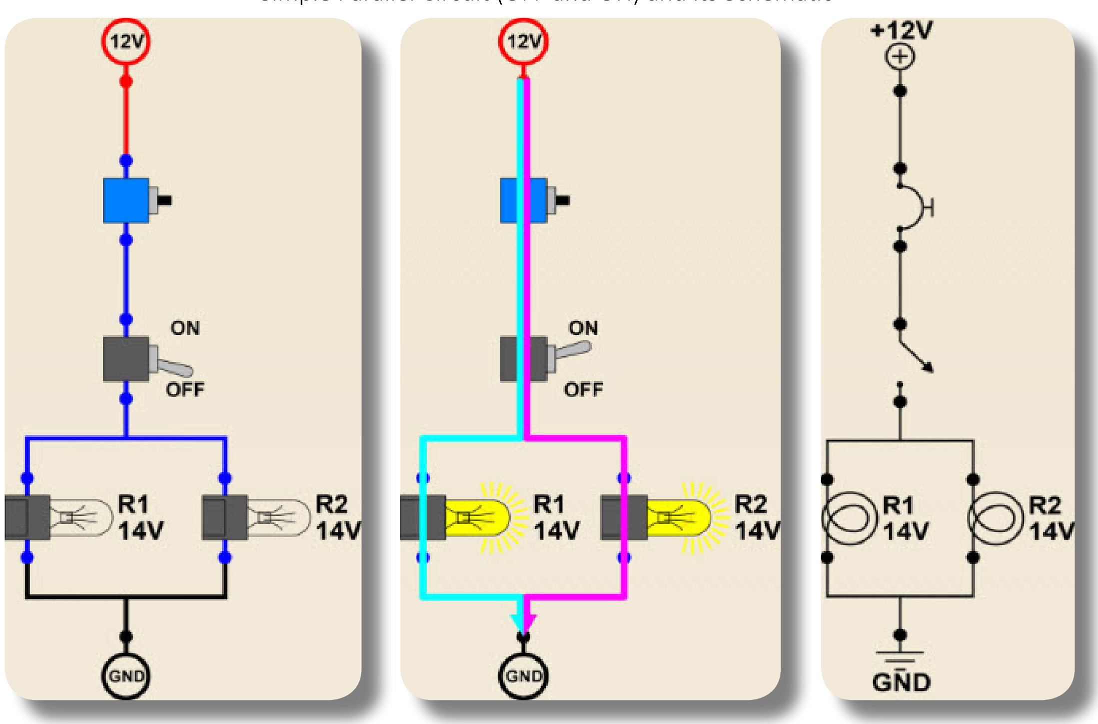
Parallel Circuits

Up to this point we have dealt only with series circuits, which are any circuit that has only one path for current to flow. Now we will expand on what we have learned to include parallel circuits. First, a definition of parallel circuits:

A parallel circuit has more than one path for current to flow.

A parallel circuit is any circuit that has more than one path for current to flow. As with series circuits, this definition holds true regardless of the number of components in a particular circuit.

Simple Parallel Circuit (OFF and ON) and its Schematic



Notice in this circuit that current has only one path in which to flow as it passes through the circuit breaker and the switch. After that, however, it can go in either of two directions, through R1 or R2. Each of the paths that current can take through the loads is called a circuit branch' or just branch.

Because it has multiple paths to follow, the current will split between the two branches, depending on the resistances of each branch. If the loads (resistances) are equal, the currents through each branch will be equal. However, if the loads are not equal, the branch with the larger resistance will have a lower current flow and the branch with the lowest resistance will have the largest current flow.

Also, because there are multiple paths for current to flow, the resistances of the branches will not be added together as we found in series circuits. Rather, the overall total resistance of the branches (also called equivalent resistance or REQ) will be less than any of the branch resistances.

Like series circuits, parallel circuits have three rules that govern their behavior regarding voltage, current, and resistance:

1. **Rule #1**: The voltage drop across any branch of a parallel circuit is always equal to the voltage drop of every other branch of that Circuit.

   Rule #1 tells us that the voltage across the circuit breaker, plus the voltage across the switch, plus the voltage across any of the branches will equal the source voltage, or 12 volts. It doesn't matter which branch you choose since the voltage drops across each branch will be the same, regardless of the resistance of the branch.

2. **Rule #2**: The total resistance of the branches in a parallel circuit (or equivalent resistance) is always LESS than the resistance of the lowest resistance branch.

   At first, this rule doesn't seem to make sense, especially since adding resistances in series circuits increased the overall resistance. However, every branch that is added to a parallel circuit provides an additional path for the electrons to flow, which makes it easier for them to move. That is why the overall resistance actually drops when branches are added.

3. **Rule #3**: The total current, I_T, in a parallel circuit is equal to the sum of the branch currents.

   It might be helpful to view this circuit as if it were water pipes. While the water could certainly travel through any of the 'branch pipes,' all of it would have to move through the single sections both before and after the branches. Electrons will behave the same way.

There are two other facts about parallel circuits to remember:

- Adding additional branches will reduce the overall resistance, regardless of the value of the branch resistance.
- An opening in any branch will not disable the entire circuit or any of the other branches.

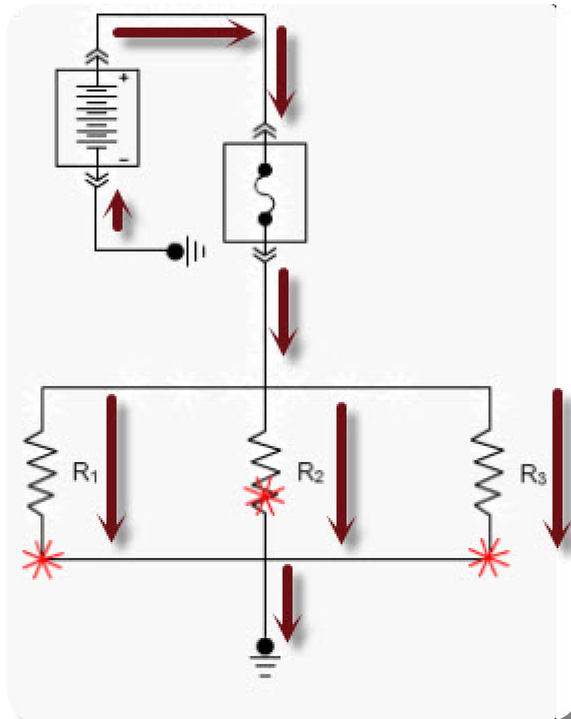
Parallel Circuit Resistance

To calculate total resistance in a series circuit, we can simply add the values of the individual resistances; however, in a parallel circuit, it is a little more complex. For example, in a parallel circuit with three branches having 10, 20, and 30 ohms respectively, we know the total resistance must be less than 10 ohms (Rule #2 - the value of the smallest branch) rather than the 60 ohms we would have in a series circuit.

Parallel Circuit Resistance

Parallel circuit total resistance must be less than the resistance of the smallest branch resistance.

Current Flow in a Parallel Circuit



To find the Total Resistance (RT) in a parallel circuit we must use the formula:

$1/\mathbf{R}_T = 1/\mathbf{R}_1 + 1/\mathbf{R}_2 + 1/\mathbf{R}_3 + 1/\mathbf{R}_4 + \ldots$

Where R1, R2, R3, etc. are the resistances of branches 1, 2, 3, etc. respectively.

Again assuming that R1 = 10Ω, R2 = 20Ω, and R3 = 30Ω, we apply our values to find:

$1/\mathbf{R}_T = 1/10\Omega + 1/20\Omega + 1/30\Omega$

$1/\mathbf{R}_T = .1\Omega + .05\Omega + .033\Omega$

$1/\mathbf{R}_T = .183\Omega$

$\mathbf{R}_T = 1/.183\Omega$

$\mathbf{R}_T = 5.46\Omega$

The Windows calculator on your computer can be used to make these calculations. You can open the Windows calculator by clicking on Start, and then Run. Type the word "calc," without the quotes, in the space provided and then click the OK button. Try both of these methods using our example numbers of 10, 20, and 30 ohms.

If your calculator has a 1/x (inverse) key, the formula can be entered by pressing the calculator keys (shown in parentheses) in order as follows:

$\mathbf{R_1}$ (1/x) (+)

$\mathbf{R_2}$ (1/x) (+)

$\mathbf{R_3}$ (1/x) (+)

(1/x) answer

If no inverse key is available, then figure the resistances by pressing the calculator keys (shown in parentheses) in order as follows:

1(÷) $\mathbf{R_1}$ (=) (M+)

1(÷) $\mathbf{R_2}$ (=) (M+)

1(÷) $\mathbf{R_3}$ (=) (M+)

1(÷) (MRC or MR) (=) answer

(1/x is the inverse key, + is the addition key, M+ is the Memory Add key, MRC or MR is the Memory Recall key, is the Division key, and = is the Equals key)

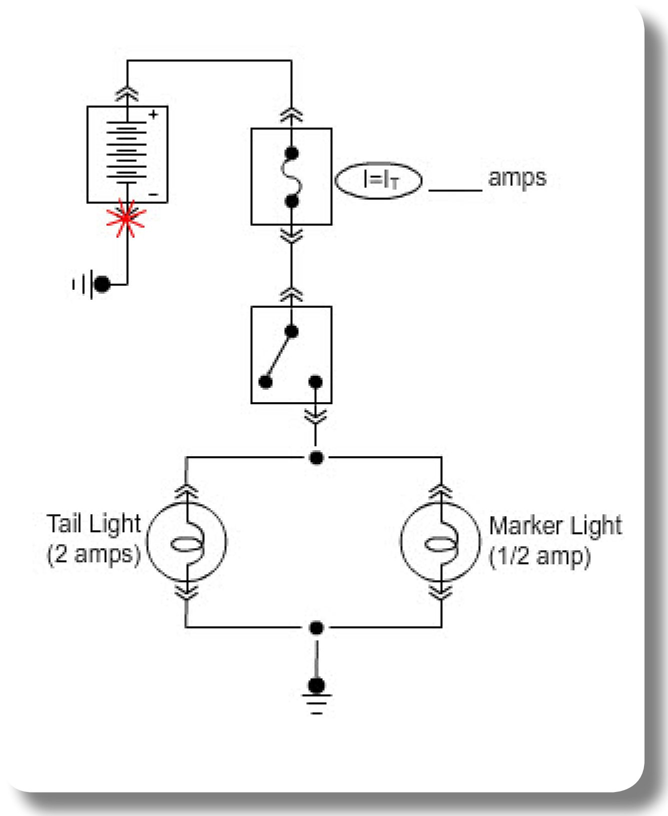
Parallel Circuit Current

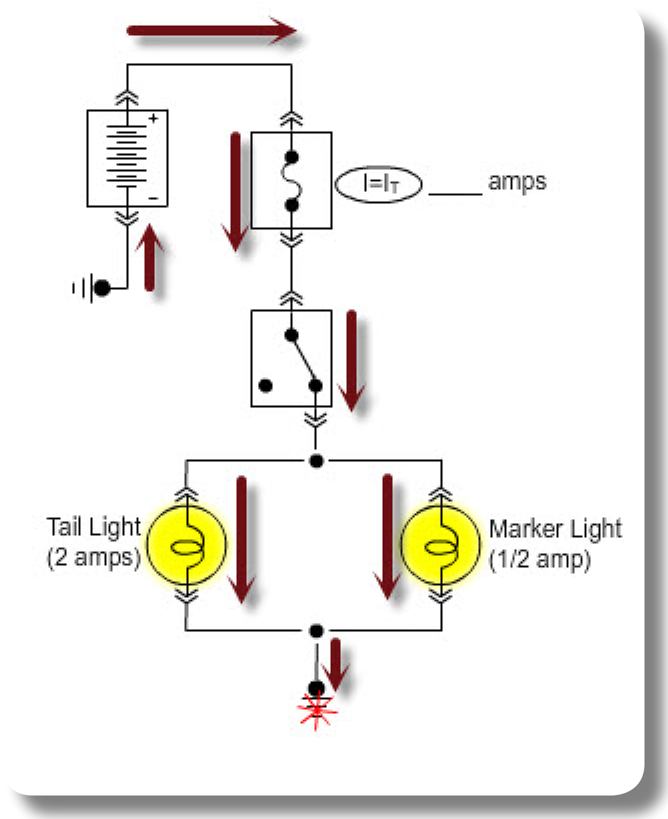
Just as parallel circuit resistance is calculated differently than series circuit resistance, parallel circuit current must also be calculated differently.

Unlike series circuits where current is always the same, parallel circuits can have different amperage values for each branch in the circuit. Recall that the voltage drop is the same for each parallel branch, but if the branches have different resistances, then Ohm's Law can be used to determine that the branches have different currents. The total circuit current can then be found simply by adding the branch currents.

Parallel Circuit Current

The sum of the branch currents adds up to the total current.


I=I_T
amps
Tail Light
(2 amps)
Marker Light
(1/2 amp)


I=I_T
amps
Tail Light
(2 amps)
Marker Light
(1/2 amp)

What is the total current for this circuit?

We know that since the two bulbs are in parallel, their voltage drops are equal; in this case they are 12V each.

The bulb on the left has a resistance of 6Ω and applying Ohm's Law we find:

$\mathbf{I_1 = E_1/R_1}$

or

$I_1 = 12V/6\Omega$

so

$I_1 = 2$ Amps

Similarly, the 24Ω right bulb has a current given by:

$\mathbf{I_2 = E_2/R_2}$

or

$I_2 = 12V/24\Omega$

so

$I_2 = .5$ Amps

Total current is therefore: $I_T = I_1 + I_2 = 2A + .5A = 2.5$ Amps

Now, calculate the total current if the left bulb is 2Ω and the right bulb is 12Ω...

Some things to remember when working with **parallel circuits**:

- Voltage drop is the same across each branch.
- Amperage changes; the higher the branch resistance, the lower the current flow will be in that branch.
- Total branch resistance will be less than any individual branch resistance.
- Any opening in an individual branch will not disable the entire circuit.
- Two or more load devices are required for a parallel circuit.

Ohm's Law for Parallel Circuits

Ohm's Law Calculations for Parallel Circuits

In the parallel circuit to the right, we have two branches

of 8Ω and 4Ω respectively.

Applying our formulas from the previous section we find:

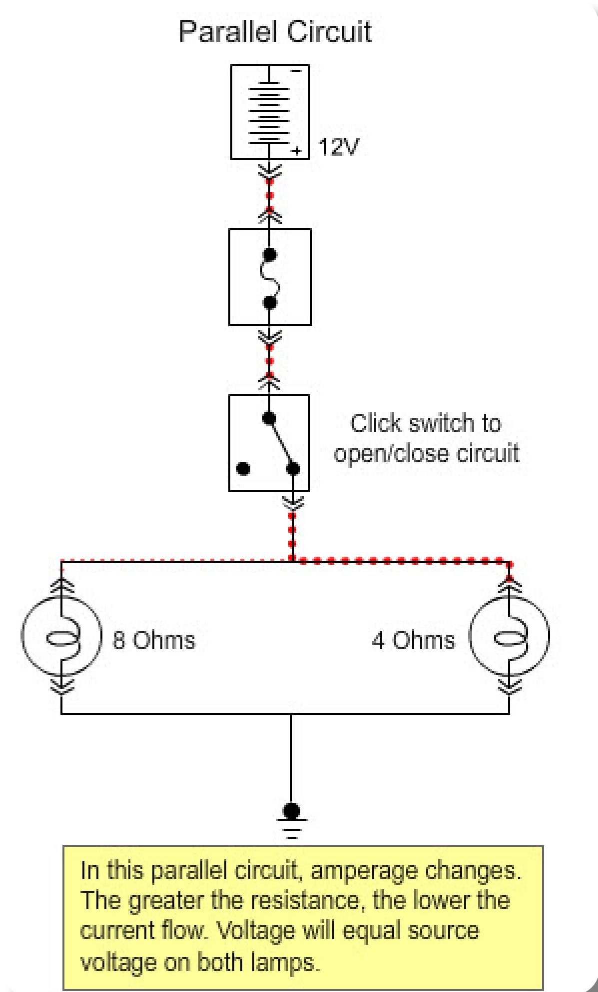
R_T = 2.6 ohms

E_T = 12 volts (source voltage)

I_T = 12 volts / 2.6 ohms = **4.5 amps**

(T = total)

A Two-Branch Parallel Circuit



Remember!

In a parallel circuit, voltage remains the same across each branch.

Can you determine the following?

What is the current flow through Lamp 1?

$I_{L1} = E_{L1} / R_{L1}$

I_{L1} = 12 volts / 8 ohms = **1.5 amps**

What is the current flow through Lamp 2?

I_{L2} = EL2 / RL2

I_{L2} = 12 volts/ 4 ohms = **3 amps**

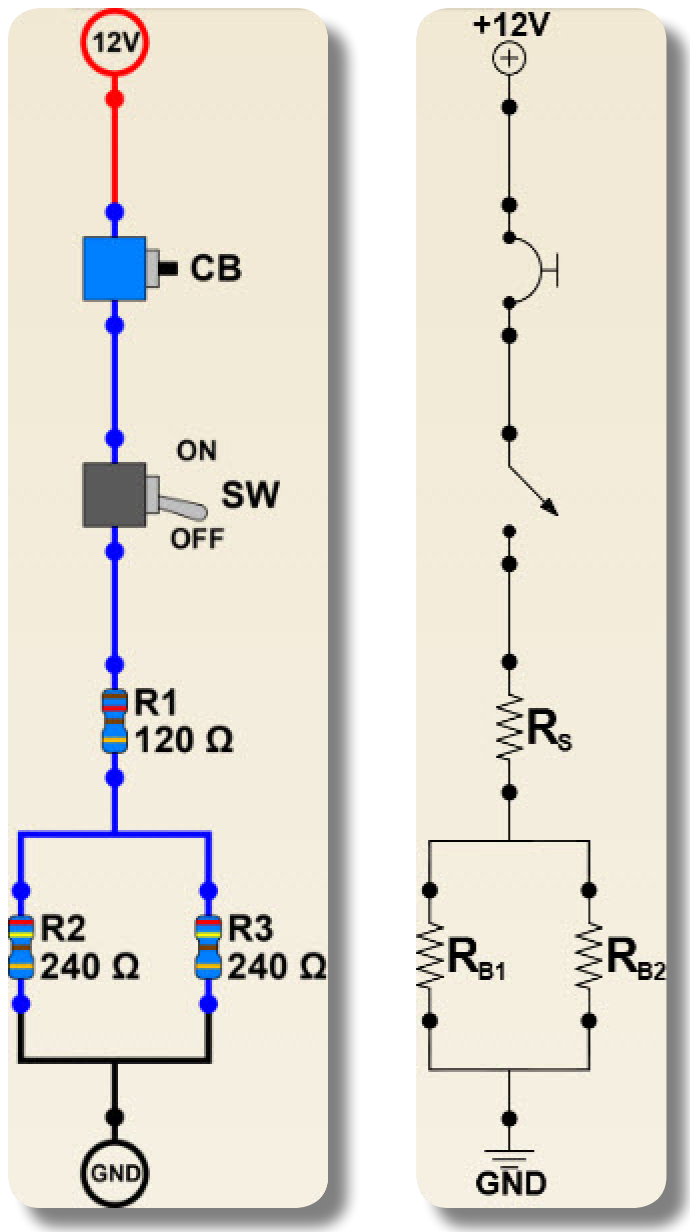
From the equations used above, you can see that current flows through Lamp 1 and Lamp 2 equaled the total amperage.

You can also see how amperage is different through each lamp. Current is lower in Lamp 1 because its resistance is greater than that of Lamp 2.

Series-Parallel Circuits

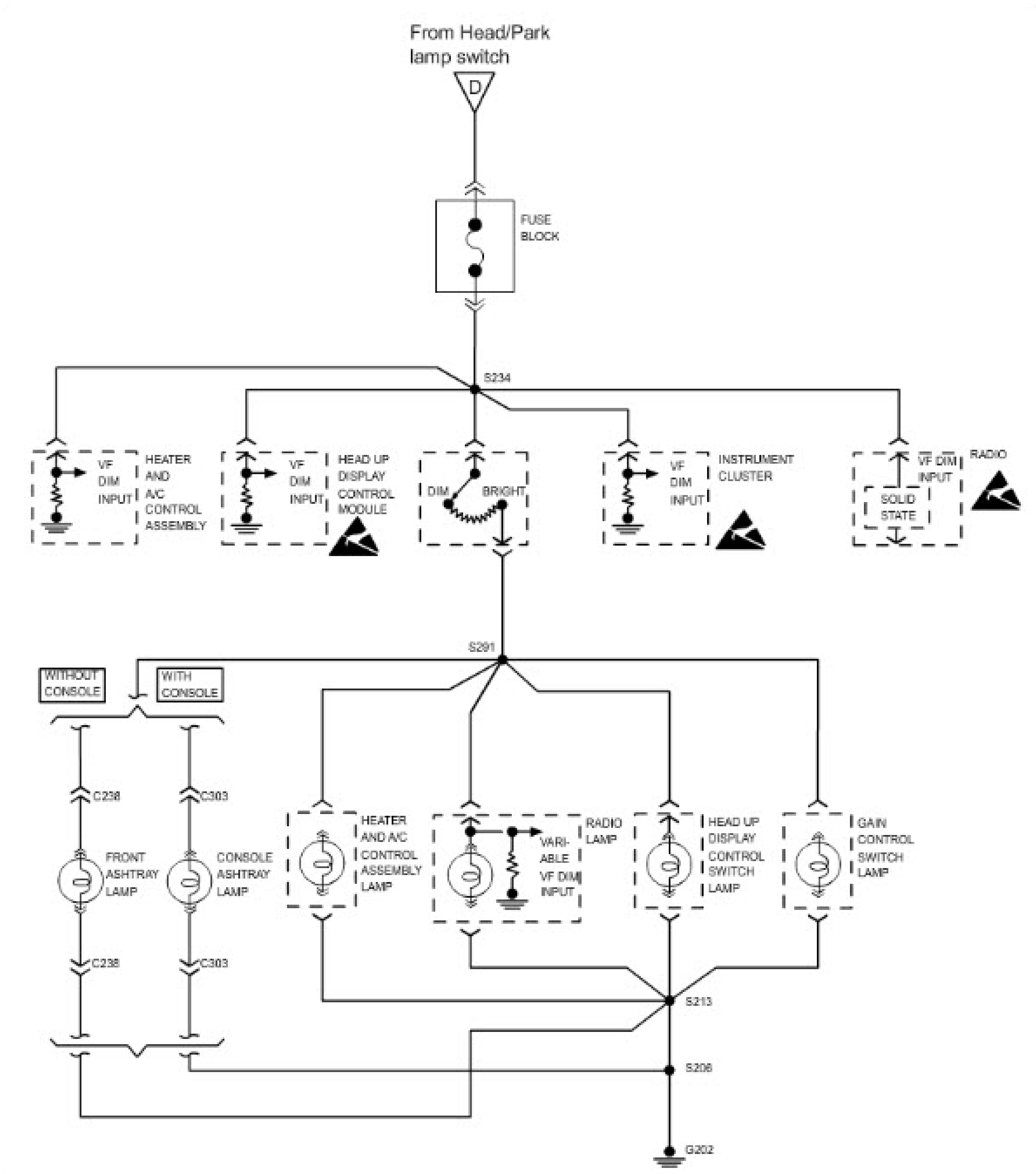
Sometimes it is necessary to reduce the amount of voltage drop across the branches of a parallel circuit to less than source voltage. To accomplish this, we use a circuit called series-parallel. A series-parallel circuit works by inserting a resistor in series with a parallel network. The series resistor will cause a voltage drop that leaves less voltage available to the branch loads, and therefore reduces their currents.

A series-parallel circuit and schematic



Notice in this circuit that all of the current must pass through the series resistance before it splits into the individual branches. Also note that there will always be a voltage drop across the series resistor, as with all series resistances, and therefore the voltage drop across the branches will be less than applied voltage. Additionally, by changing the series resistance we can vary the voltage drop of the series resistor and, in turn, to alter the branch voltages. Because of that capability, series-parallel circuits are often used as dimmer circuits to control the brightness of lighting (shown below).

Series-Parallel Dash Light Dimmer Circuit



This illustration of a dash-light circuit shows how changing the resistance of the rheostat (dimmer control) varies its voltage drop and, in turn, changes the voltage available to the dash bulbs, which controls their brightness.

Question:

How would you calculate the total resistance of a series-parallel circuit?

Answer:

Calculate the parallel portion of the series-parallel circuit just as you would for a parallel network, and then add the series resistance to that total.

Question:

How would you calculate the total current?

Answer:

Use the Ohm's Law formula I=E/R just as you would for any circuit. In this case, the voltage is the 12 volt source and the resistance is the series-parallel value determined in the last step.

UNIT 5: ELECTRICAL DIAGNOSIS AND WIRE REPAIR

The following topics are addressed in this unit:

Electrical Diagnosis

- Circuit Faults
- Test Lights
- Headlight Circuits
- Wiring Diagrams

Wire and Wire Repair

- Wire Applications
- Stripping
- Splicing
- Terminals

Electrical Diagnosis

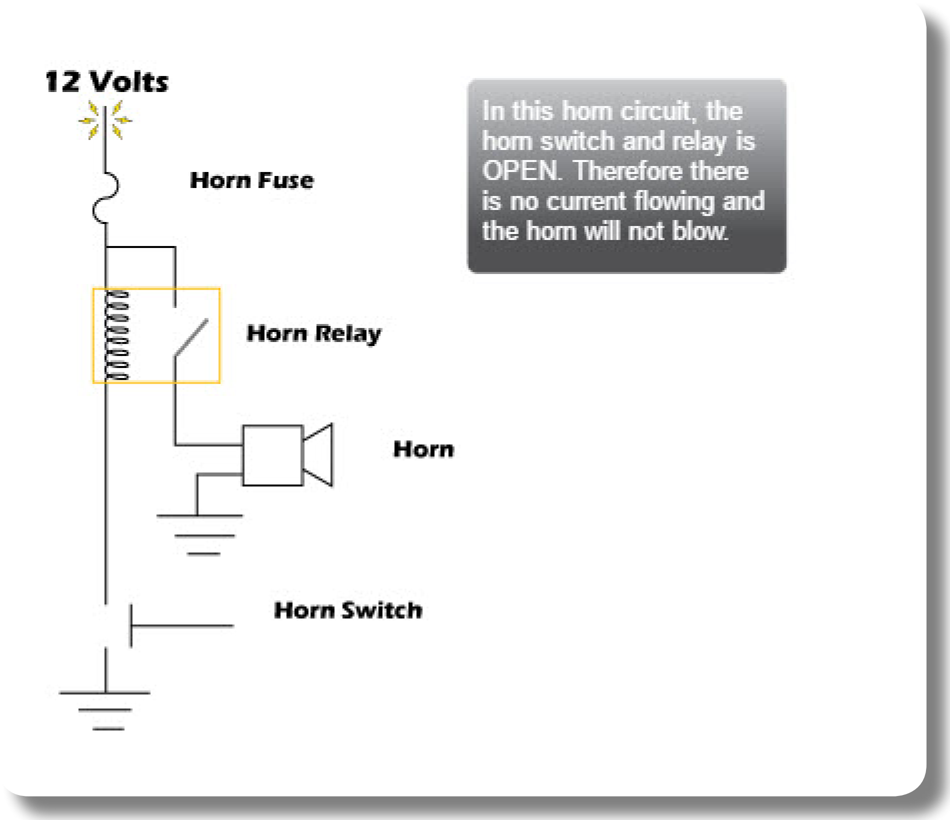
In this unit we will examine circuit diagnosis.

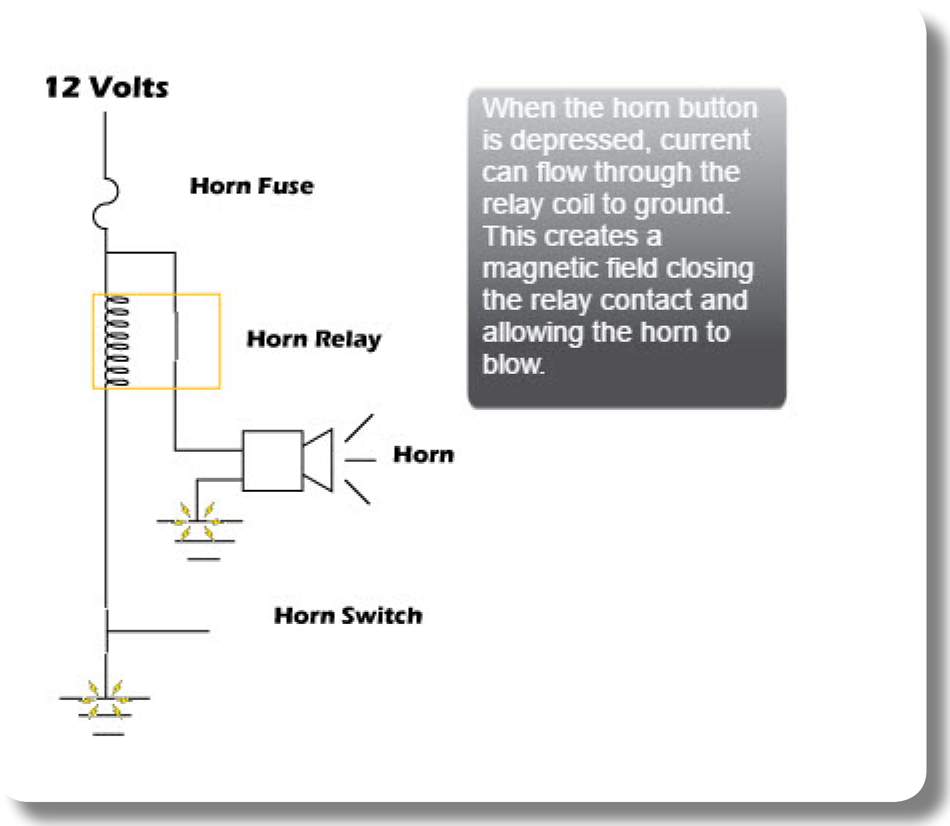
Circuit Faults

Circuit Faults and Failures: Opens, Shorts, and Grounds

Electrical circuits can fail in several different ways. The most common types of failures are open circuits, short circuits, and grounded circuits.

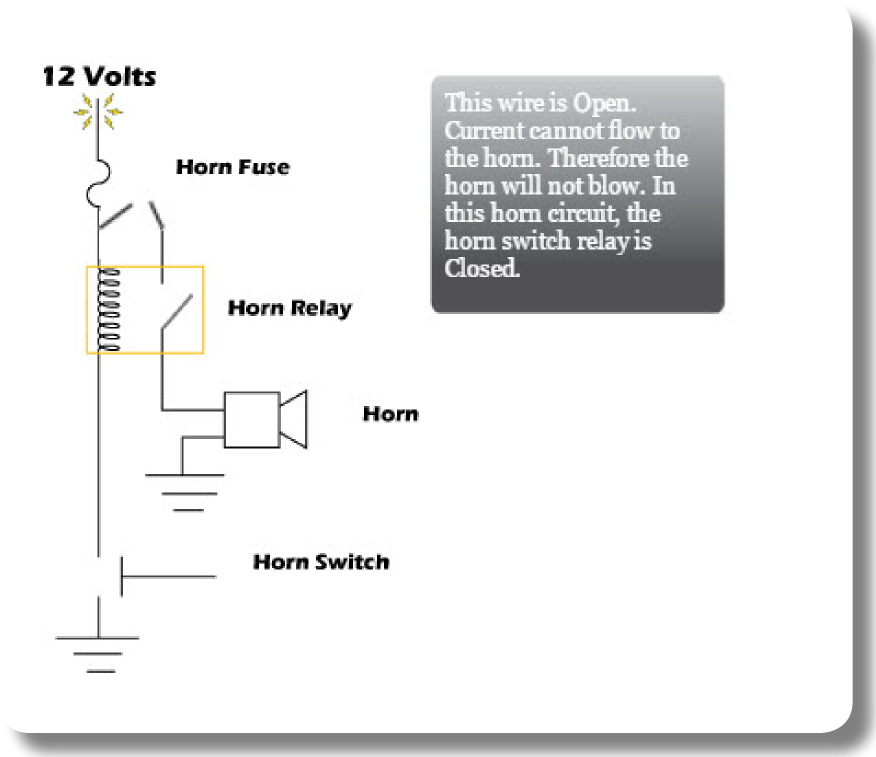
We'll use this simple horn circuit to first show normal operation, then the same circuit with different electrical faults.

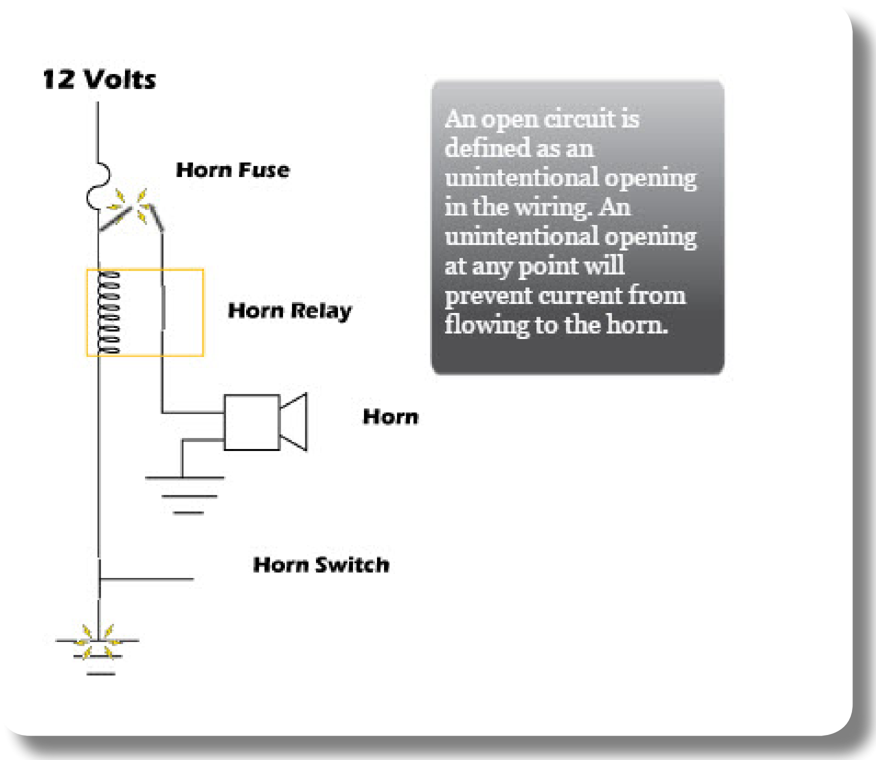

12 Volts
Horn Fuse
Horn Relay
Horn
Horn Switch
In this horn circuit, the horn switch and relay is OPEN. Therefore there is no current flowing and the horn will not blow.


12 Volts
Horn Fuse
Horn Relay
Horn
Horn Switch
When the horn button is depressed, current can flow through the relay coil to ground. This creates a magnetic field closing the relay contact and allowing the horn to blow.

Open circuits: An open circuit does not always indicate a fault. For example, a horn circuit is normally open until the horn button is depressed. An open circuit that results in circuit failure is an unintentional opening in the circuit, such as severed wiring or a faulty switch.

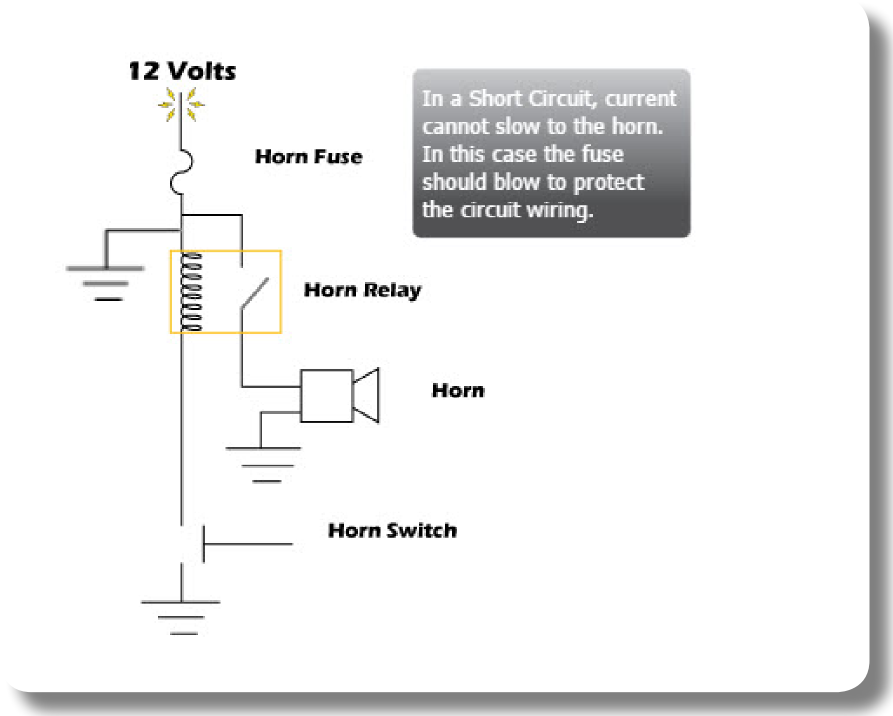
Open Circuit

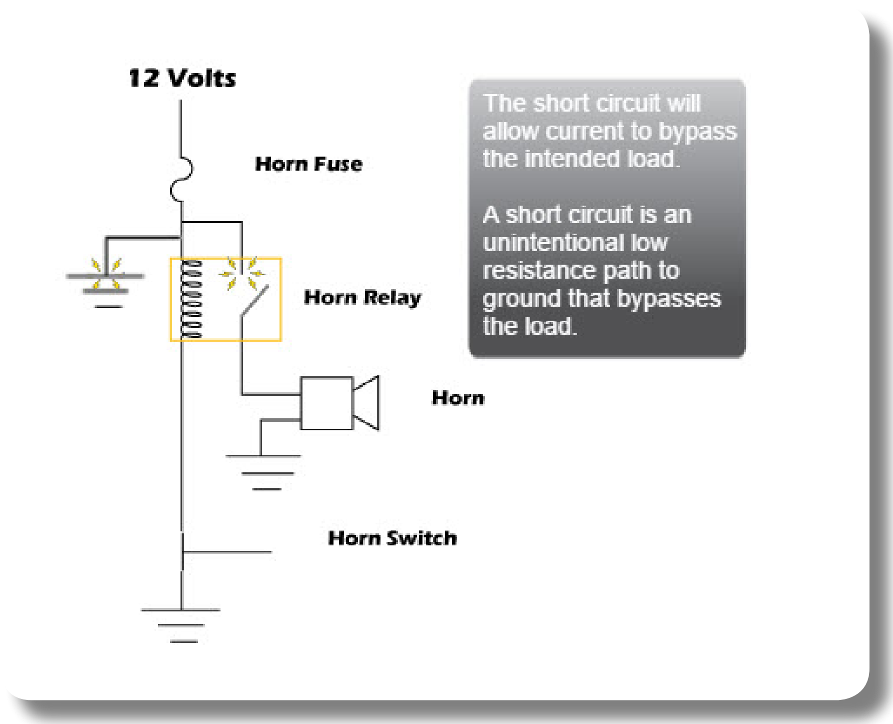




Short circuit: A short circuit will allow current to flow directly to ground (or to power) by providing a path out of the circuit that has less resistance than the circuit itself. As a result, shorted circuits have low resistance and, as we learned when we covered Ohm's law, this results in high current flow. Fuses and circuit breakers were designed specifically to protect against the severe consequences this high current flow can have. The normal result of a short circuit is a blown fuse or a tripped breaker. However, short circuits can still result in major circuit meltdowns and fires.

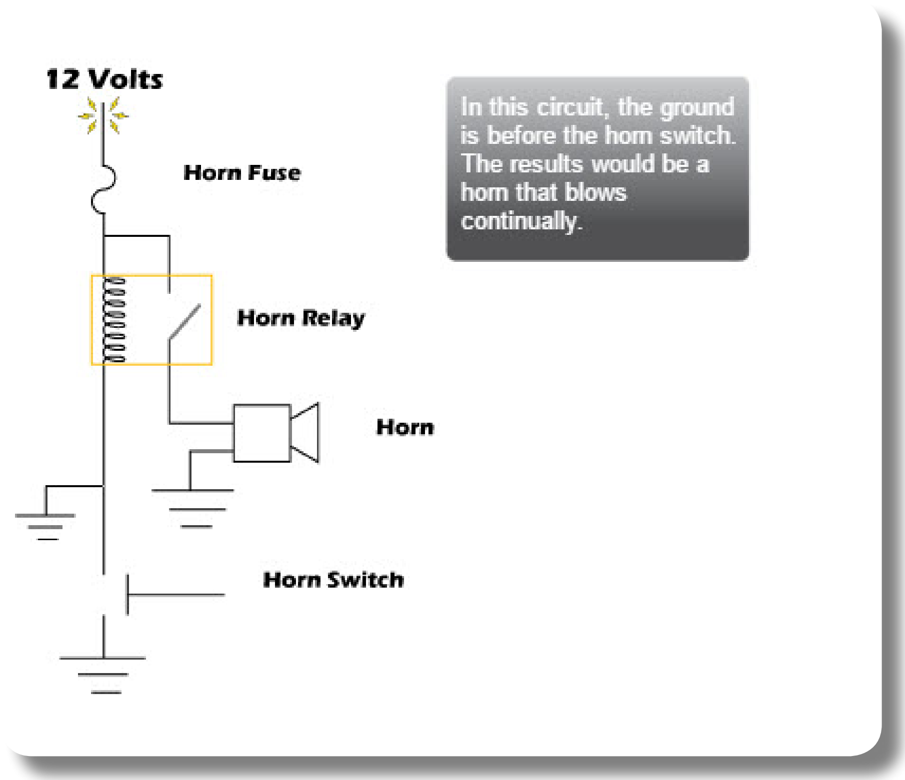
Short Circuit

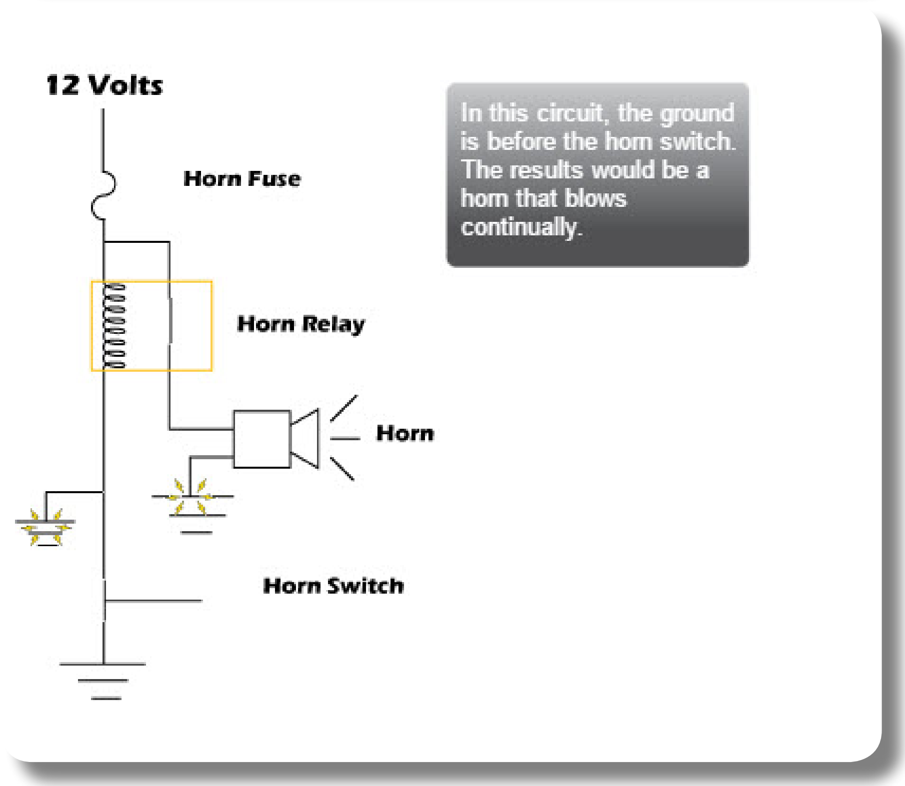




Grounded circuit: In an unintentionally grounded circuit, there is an unintended current path to ground **after** the load. A component that is grounded in this way will operate continually until either the ground or the source of power are removed.

Grounded Circuit





High resistance circuit: is the final type of fault that is usually caused by corrosion, dirt, rust, or a loose connection. It is neither an open fault nor a shorted fault. Typically a high resistance fault won't blow fuses, but the device being operated (fan, bulb, solenoid, etc.) will run slowly, be dim, or operate sluggishly, if at all.

When diagnosing opens, shorts, and grounds, always use a wiring diagram to first determine the correct voltage drops throughout the circuit.

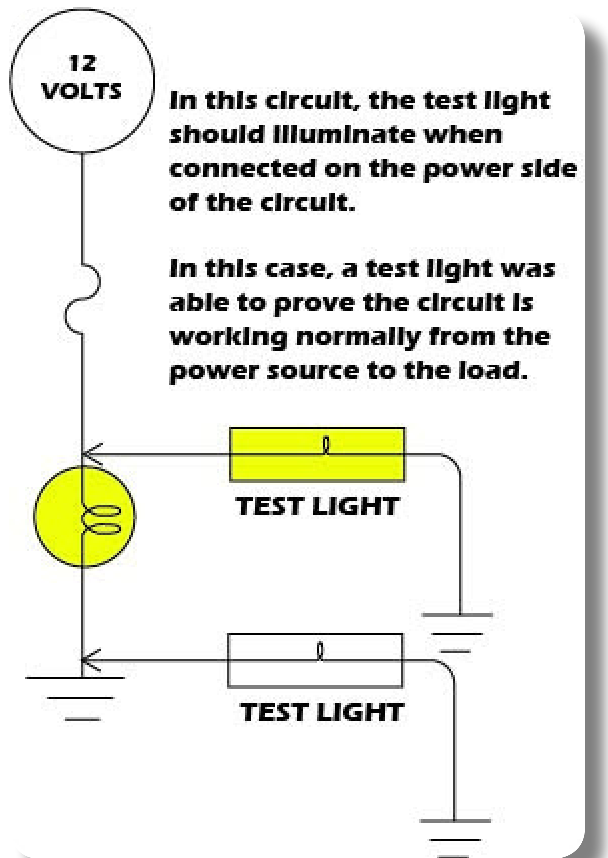
Test Lights

Using a Test Light to Diagnose Electrical Circuits

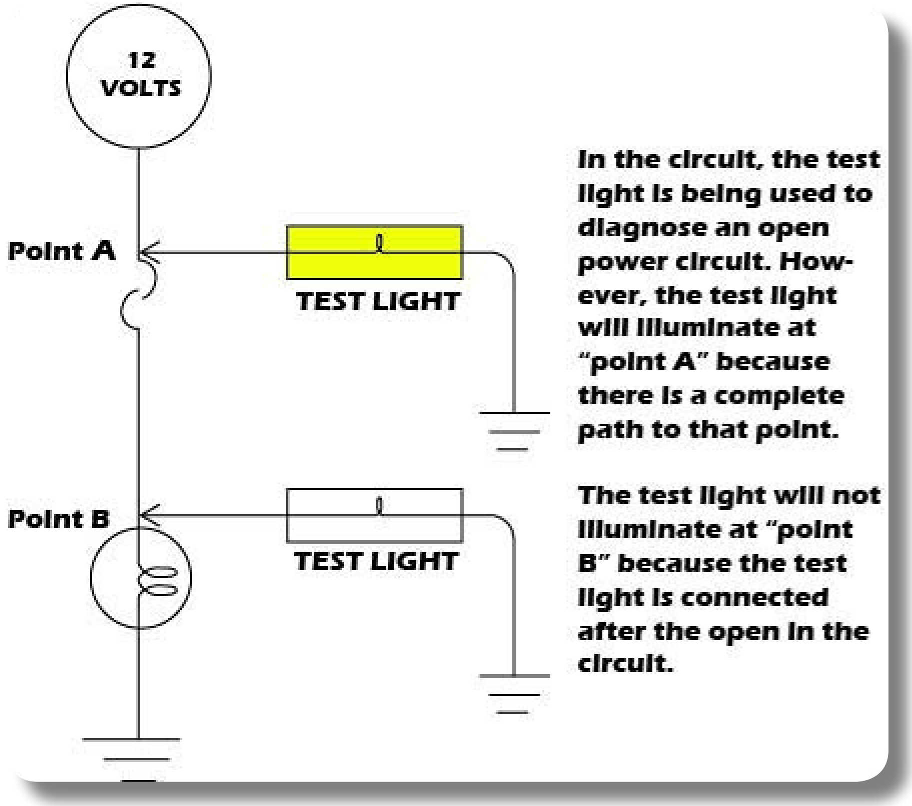
CAUTION: Never use a test light to test low voltage circuits. Doing so may damage or destroy expensive electronic components. On vehicles equipped with electronic control modules, only use a test light when directed by a manufacturer's diagnostic test procedure.

A test light is a useful and reliable tool, when used correctly, to test for open, closed, and shorted circuits. In a closed circuit, the test light will illuminate when connected to a circuit that has a current flowing on the power side. On an open circuit, a test light will not illuminate if there is no current flowing when connected after the opening in the circuit. A test light can be used to test for a short circuit if connected in series with the short circuit.

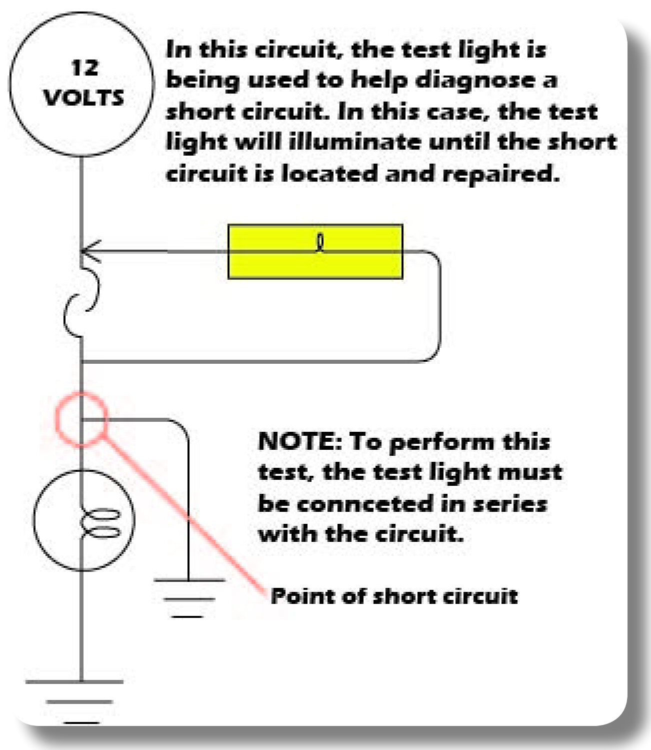
Normal Circuit



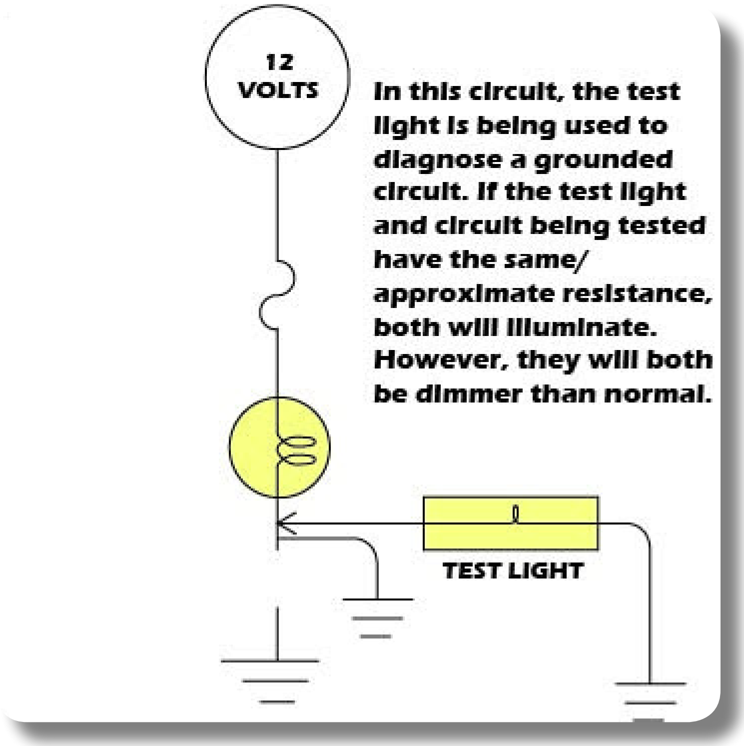
Open Circuit



Short Circuit



Grounded Circuit



Headlight Circuits

Headlight System Operation and Service Precautions

Headlights

Certain modern vehicles are equipped with daytime running lights and therefore use the headlights for both day and night driving. While some manufacturers use the same lamps for both day and night driving, others use separate lamps. Systems that use the same headlamps for day operation will typically wire the front lamps in series, dropping 6 volts at each headlamp. Whereas the others may incorporate different lamps altogether.

There are several precautions that should be followed when servicing headlamps.

1. Avoid touching the glass of any headlamp bulb. A thin film of oil from your hands and fingers can cause the lamp to operate at a higher temperature, and shorten the life of the lamp.
2. When servicing or changing headlamps, handle all lamps, new or old, with great care. Headlamp bulbs are under pressure and breaking them can cause an explosion, sending sharp pieces of glass flying.
3. Install new lamps immediately after removing from packaging. Leaving them to lay on a workbench too long will allow them to attract dust and moisture.
4. Always replace a lamp with one of the correct part number. Never install a lamp that is not the correct wattage and/or voltage rating.
5. Always ensure the headlamp socket is installed and sealed properly after replacing a headlamp. Failure to do so will allow the lens to become cloudy or the headlamp assembly cover may fill with water, thus shortening the life of the lamp.

Headlight circuits on most vehicles are protected by a circuit breaker. This is a safety precaution that allows them to operate ON and OFF, **momentarily**, in case there is a short in the headlight circuit. If this condition should occur, do not operate the vehicle until repaired.

HID Headlights

High intensity discharge headlamps are automotive lights that work using an arc between two electrodes, rather than a filament in a bulb. Unlike standard 12 volt headlamps, these units operate on approximately 30,000 volts.

CAUTION: Never test high intensity discharge (HID) headlamps using a DMM or test light, as their voltage is too high. Also, never touch the high voltage sockets on any vehicle equipped with HID headlights, as serious personal injury could occur.

Test and inspection procedures for HID headlights can be performed as follows:

1. Turn the headlamps off and allow them to cool completely.
2. After they have cooled, turn them ON for 15 minutes.
3. After 15 minutes, turn them OFF and ON quickly 10 times, in about a 15 second period.
4. If one headlamp does not obtain full brightness, or burns dimly, the headlamp is nearing the end of its useful life.

It is recommended by manufacturers that HID headlights be replaced in pairs. Over time, HID headlights will not illuminate as brightly as they did when new.

Wiring Diagrams

Electrical Wiring Diagrams

A wiring diagram is an extremely valuable tool to use when diagnosing electrical concerns in any type of equipment or vehicle. The proper use of a wiring diagram can reduce diagnostic time, as well as reduce comebacks and increase income.

Electrical Diagnosis

Always follow the manufacturer's procedure when diagnosing electrical systems.

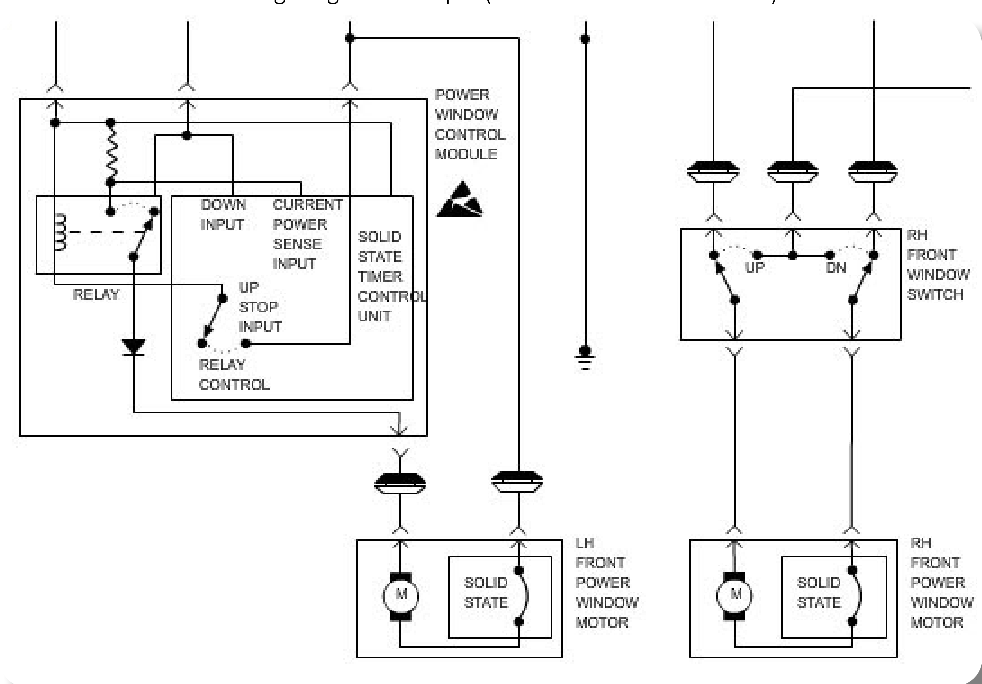
There are a number of different methods advanced by automotive manufacturers and textbook authors in regard to proper wiring diagram use and diagnostics. Some recommend always starting at the power source while others suggest starting at the malfunctioning component and working backward. Still others recommend starting at the fuse box or relay.

However, before beginning diagnostics on any electrical circuit technician must understand the operation of the circuit being tested. *If you don't know how the circuit is supposed to work, you can't know if it is not working properly*.

In addition, always follow the manufacturer's procedure when diagnosing electrical systems. Failure to do so could result in damage to the electrical system, improper diagnostics, personal injury or even death.

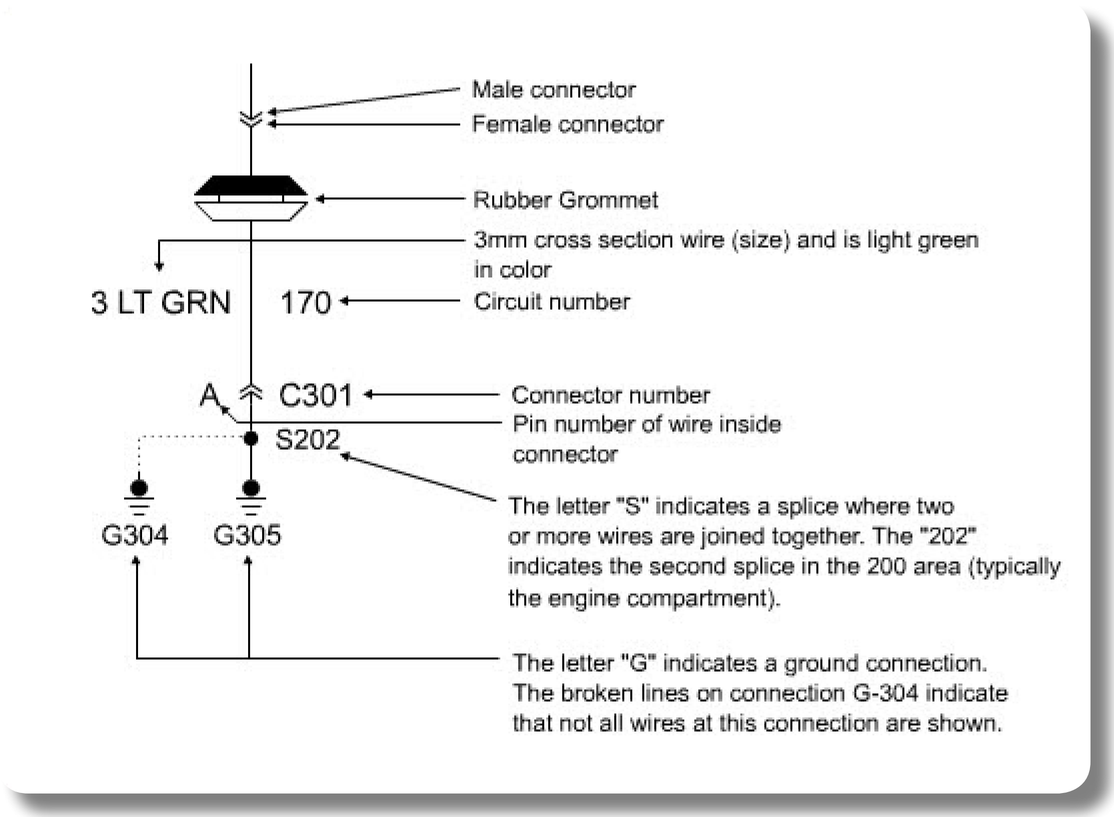
Note: Some manufacturers may use slightly different schematic symbols to identify components.

Wiring Diagram Example (Power Window Schematic)

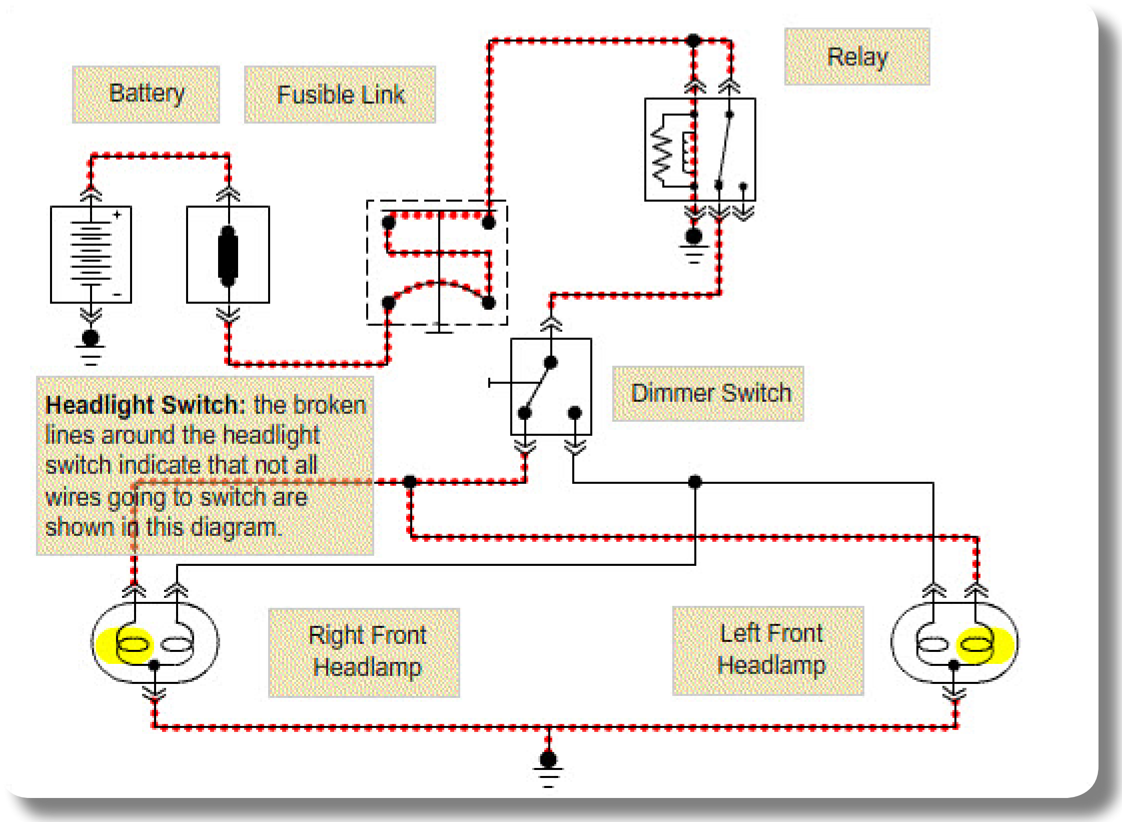


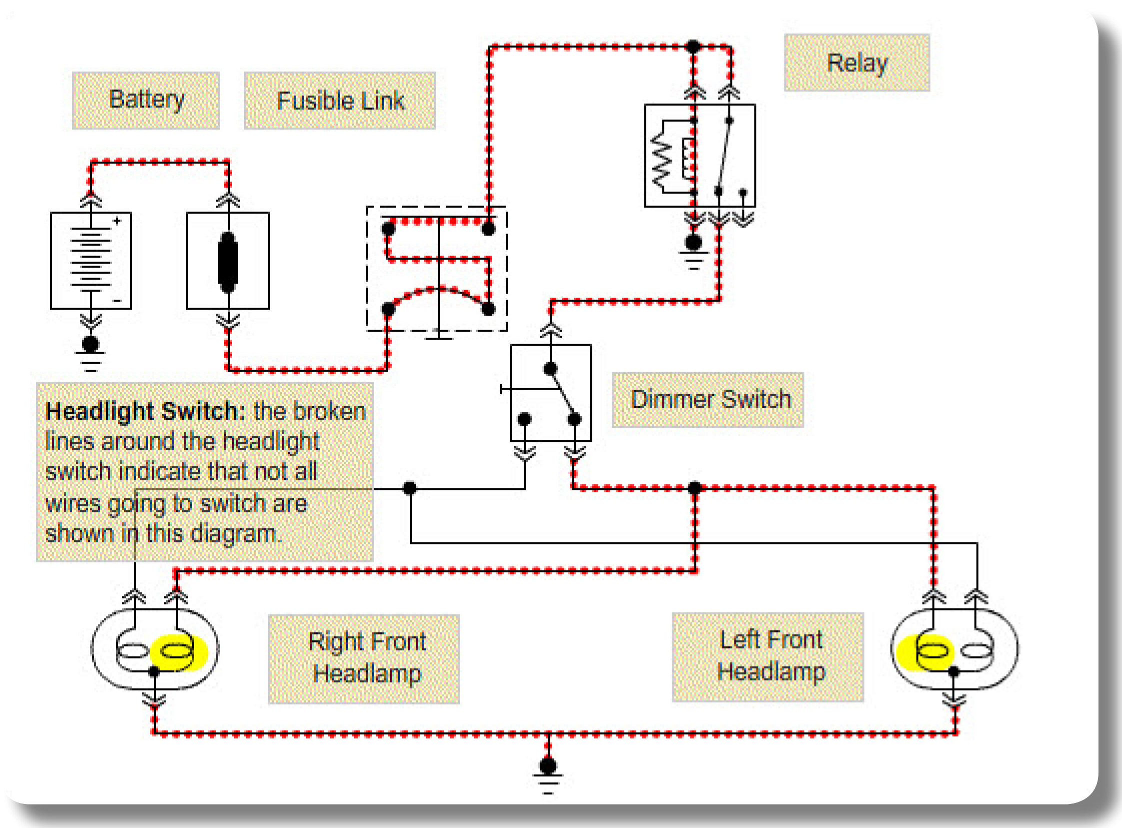
In an electrical diagram, it's important to become familiar with connectors, splices, and ground locations. The following image is a typical section of a wiring diagram. Please take the time to become familiar with these symbols. When working with an electrical system, it's sometimes necessary to perform voltage drop or continuity tests and wiring diagrams use numbers and letters that help identify circuit connector locations.

Electrical Schematic Symbols



How many electrical symbols can you name in the diagram below? Many electrical diagrams will also contain additional information such as component location and wire size. Depending on the application, most modern wiring diagrams are drawn to be read from the top of the page to the bottom. On a diagram, any component that is not drawn showing all of its electrical wires will often have a 'continued' page reference number beside it.


Battery
Fusible Link
Relay
Dimmer Switch
Headlight Switch: the broken lines around the headlight switch indicate that not all wires going to switch are shown in this diagram.
Right Front Headlamp
Left Front Headlamp


Battery
Fusible Link
Relay
Dimmer Switch
Headlight Switch: the broken lines around the headlight switch indicate that not all wires going to switch are shown in this diagram.
Right Front Headlamp
Left Front Headlamp

Wire and Wire Repair

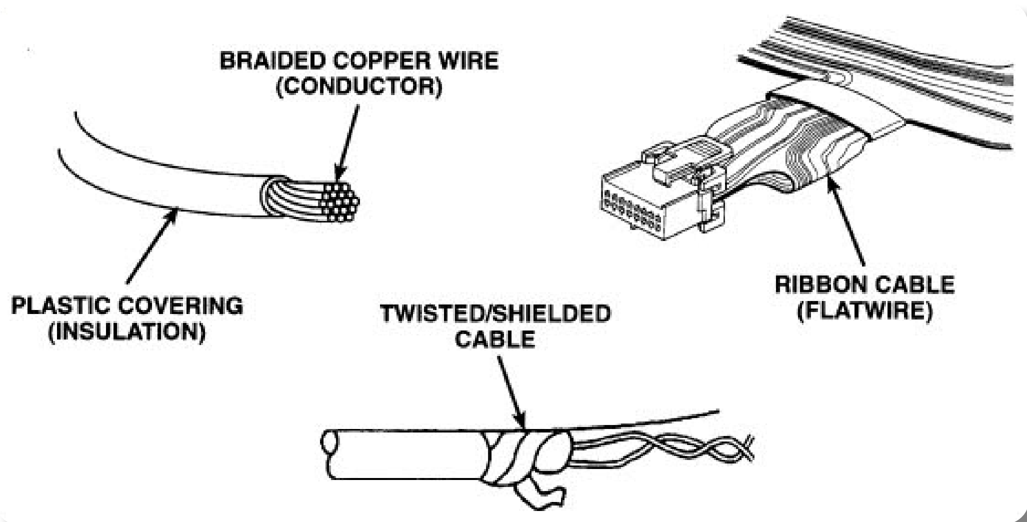
This unit introduces methods for repairing electrical circuits.

Wire Applications

Automotive Wire Applications

Wires in automotive applications typically come in one of three different configurations: braided, twisted/shielded, and ribbon cable. Braided, or multi-strand, wires are made of copper or aluminum and are the most widely used because of their current carrying capacity and flexibility. Twisted or shielded wires are used in places where electric noise may be present and the wires need to be protected. The third type, ribbon cable, is used between electronic printed circuits or computers.

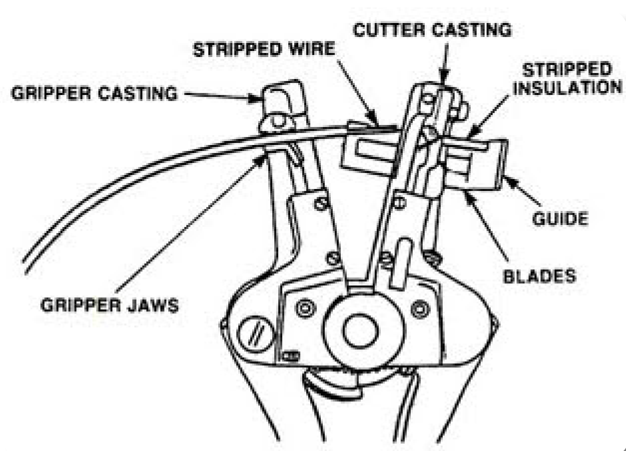
Automotive Wire Applications



Stripping

Every technician knows that in order to join two wires together, or to install a new terminal on a wire, some insulation must first be removed from the wire. It sounds simple enough; unfortunately, bad stripping technique often causes the connection to be less than ideal and possibly inoperative.

Typical Wire Strippers



The first thing to remember with wire stripping is to remove only as much insulation as necessary to do the job. Too little bare wire may cause a bad connection while too much bare wire may expose the circuit to inadvertent contact with another circuit or to ground.

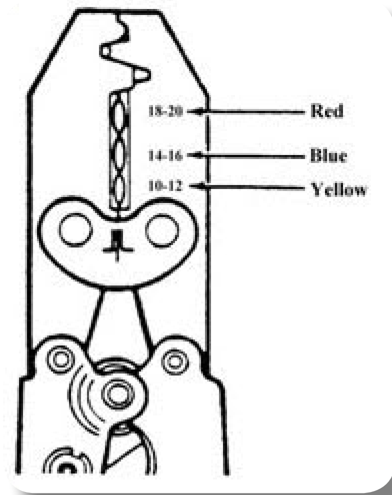
Secondly, always use a proper stripping tool in good condition. Do not use a knife, a pair of side cutters, or any other type of sharp instrument as these can nick or cut some of the strands (called ringing the wire) and reduce the amount of amperage the circuit can carry. Using a good pair of wire strippers also reduces the chance of stretching and weakening the strands.

SPLICING

Using Splice Sleeves

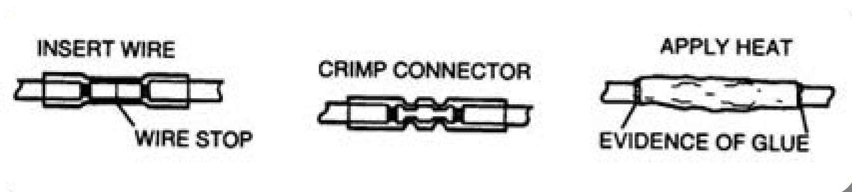
Whenever two wires need to be joined, it is advisable to crimp the wires into a splice sleeve. Splice sleeves are connectors that have both a metal insert to make the electrical connection and a special glue that, when heated, will hold the wires together by the insulation. The glue will also protect the connection against exposure to weather that could corrode or break the wires. Splice sleeves come in three sizes: small, medium, and large, and in the colors red, blue, and yellow, respectively. Refer to this figure for an illustration of the proper procedure for splice sleeve installation.

Splice Crimp Tool



Splice Sleeve Installation

Splice Sleeve Crimping Steps



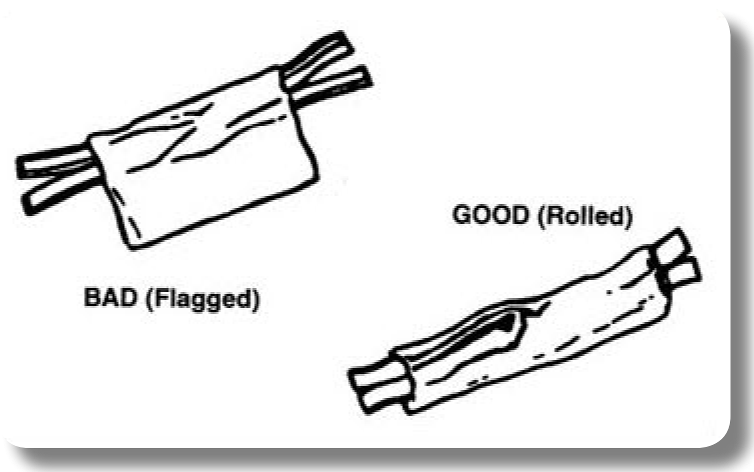
- Strip each wire just enough that the bare wire is exposed outside of the metal insert. The notch in the middle of the connector will prevent the wire from entering the sleeve too far. Do not twist the wires as that will cause less contact area with the metal insert and reduce its capacity.
- After both wires are inserted, apply a firm crimp **just once** on each side of the notch. Multiple crimpings will actually weaken the connection. Crimping tools will either be color coded or labeled by wire size to ensure the correct jaws are used on the tool. Do not use pliers, vise grips, or other improper tools for crimping as these will damage the sleeve.
- Use a proper heating tool, such as a shielded butane torch, to heat the splice, always working from the center of the sleeve outward. A proper seal will allow a small amount of glue to seep out of each end. Cigarette lighters, propane torches, and soldering irons are not adequate for heating splice sleeves since they are too hot and will make the connection brittle.

Soldering

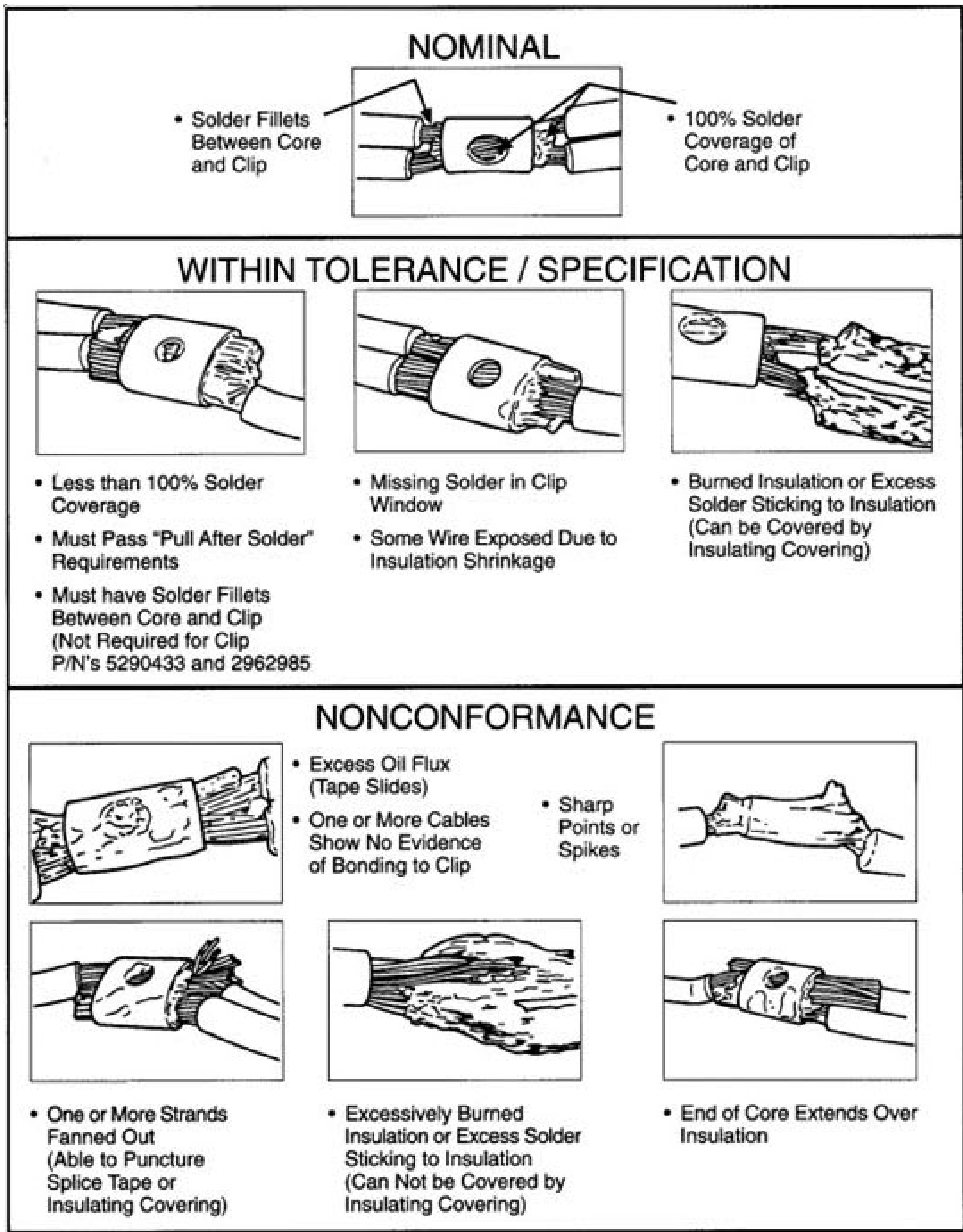
Soldering can be used if two or more wires need to be joined without terminals (a splice), or to insure a better electrical connection between wires and terminals. When properly applied, solder will fill all of the air cavities in wires and permit better metal-to-metal connection. Soldering done improperly, however, results in bad connections, melted insulation, and improper circuit operation. Some recommendations for soldering:

- Choose a soldering iron or torch with enough heat to do the job but not enough to damage smaller wires. Soldering irons are usually rated in watts.
- Apply some solder to the tip and wipe it clean. This is called tinning and helps to transfer heat to your work.
- Apply heat directly to the terminal or 'splice clip' and feed the solder into the connection as the heat transfers to the wires.
- Do not use an excessive amount of solder. Too much may not allow pins to fit into the connector cavities and it also just looks messy.
- Do not allow the soldering iron to burn the connection or insulation; too much heat for too long a period of time can cause a bad connection.
- Ensure that your solder is smooth and doesn't have any points that might stick through the tape.
- Never solder a powered circuit, especially with an electric soldering iron.
- Do not wiggle the wires or terminals until the solder has cooled completely. To do so may result in a 'cold' solder joint that could adversely affect the connection.
- After the solder has cooled, apply electrical tape to splices to prevent inadvertent contact with other metal surfaces. Insure that the tape wrap is smooth and does not leave any 'flags', which may cause the tape to come loose. Although tape wrap sealing is acceptable, the seal of choice is heat shrink tubing. Heat shrink is similar to the splice cap but is a different style of repair. After manually soldering the connection, slide the shrink tube over the repair and then shrink the tube with a heat source.

Taping Standards



Acceptable/Unacceptable Soldering Standards



Terminals

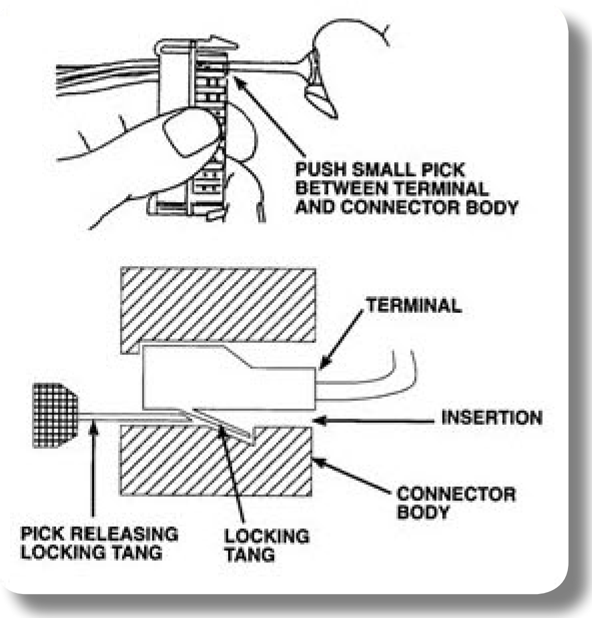
From time to time, it will be necessary to replace terminal pins for loose connections, corrosion, or breakage. It is important that technicians follow a correct procedure in replacing terminals to reduce the possibility of a repeat failure. Some of the problems to be avoided include stripping too much insulation, stripping too little insulation, excessive crimping force that bends and weakens the terminal, and too little crimping force that causes a bad connection.

Releasing Terminals

There are many types of connector terminals used throughout the automotive industry, and there are numerous methods for the removal and replacement of those terminals. Most terminals will have a 'tang' or finger that holds the terminal once it is clicked into place. Others use some form of cap or wedge that is inserted to hold several terminals all at once. Some use a rubber insulator that seals numerous wires, while others have individual insulators for each wire.

Most of the terminals, however, will have a tang and can be removed by inserting a small pick between the connector and terminal, and compressing the tang (see illustration).

Using a Pick for Terminal Removal



Technicians need to be aware that there are two types of these terminals: one with the tang facing rearward (toward the wires) and one with the tang facing forward. It's important to note that those terminals with the tang facing rearward (sometimes called push-to-seat) are inserted from the back of the connector while those terminals with the tang facing forward (pull-to-seat) are inserted from the front of the connector. Attempting to remove a terminal in the wrong direction will obviously cause damage to the terminal and possibly the connector. Pull-to-seat terminals must also have their wires pushed completely through the connector before a terminal is attached. In short, a great deal of frustration can be avoided by verifying the type of terminal being used before attempting to remove it.

Terminal Crimping

Let's cover some good crimping techniques:

- Strip an amount of insulation such that the bare wire shows on both sides of the 'core' crimp but does not extend into the insulation crimp area. The core should also not be long enough to interfere with the mating end of the terminal (see illustration). If it is a 'pull-to-seat' terminal, the wire must be inserted through the connector first. Do not twist the wire ends, as that will result in less wire-to-terminal contact.
- Select the proper anvil on the crimping tool and crimp the terminal, using firm, but not excessive, force. Too much force will bend the terminal and pliers are never to be used for terminal crimping. It is also necessary to crimp the core first, since crimping the insulation first will cause the strands to spread and make core crimping more difficult.
- Next, select the correct anvil to crimp the insulation wings (if the terminal uses an individual insulator, slide it into place first). This crimp is used to hold the terminal in place, rather than for electrical contact, and therefore will not need to be quite as firm as the core crimp.
- After crimping, gently tug on the wire and terminal to check for proper tension, and apply solder if required. Reinsert the wire into the connector.

Proper Crimping Position