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BASIC ELECTRICITY

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Basic Electricity

Model: All

Production Date: All

Objectives

After completing this module you should be able to:

- Understand the theory of Electron Flow vs “Conventional Current Flow”.
- Recognize the different types of electrical circuits.
- Perform Ohms law calculations.
- Relate Ohms law to practical use in the workshop.
- Understand how different electrical components operate.
- Recognize circuit numbers and abbreviations on ETM’s.

Basic Electricity

Electricity is defined as the movement of electrons from one atom to another. In order to understand electricity a basic explanation of the atom is needed.

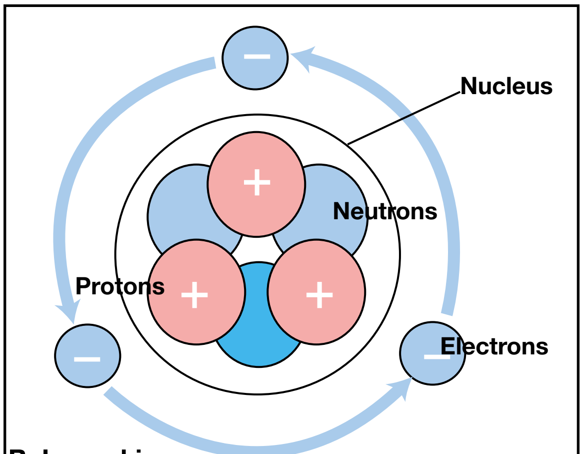
All matter is made up of molecules. An atom is the smallest particle to which a molecule can be reduced.

Atoms consist of:

Electrons - Negatively charged particles orbiting around a nucleus.

Protons - Positively charged particles in the nucleus.

Neutrons - Uncharged particles in the nucleus that stabilize the protons.

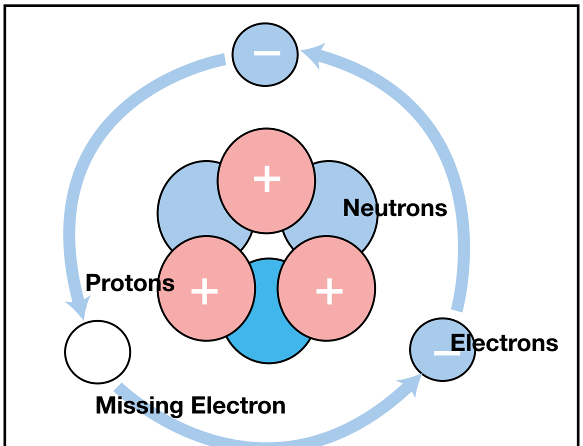


Balanced ion 12510154.eps

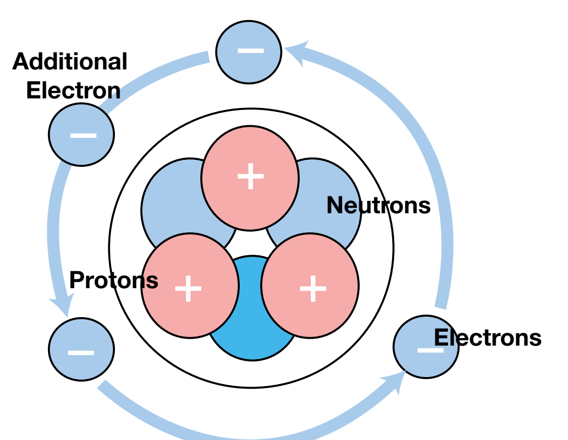
An atom is balanced or displays a neutral charge when the number of protons and electrons are equal.

Through various means (e.g. A chemical reaction in the the automotive battery) electrons are displaced from their normal orbit.

These displaced electrons attach themselves to other atoms, creating an unbalance in the number of electrons and protons in both atoms.



Positive ion 12510155.eps



Negative ion 12510156.eps

Atoms which loose or repel an electron become positively charged because of the greater number of protons. These atoms are called **"Positive Ions"**.

Atoms which pickup or gain extra electrons become negatively charged and are called **"Negative Ions"**.

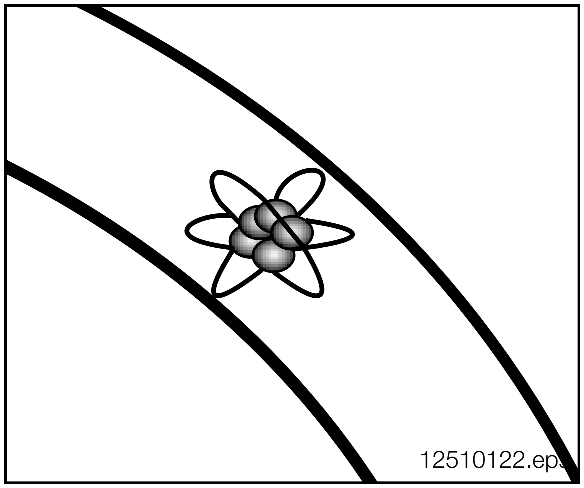
The negative ions will attempt to repel the extra electron and the positive ions will attempt to attract it.

The movement of free electrons from one atom to another is called electron flow or electric current flow.

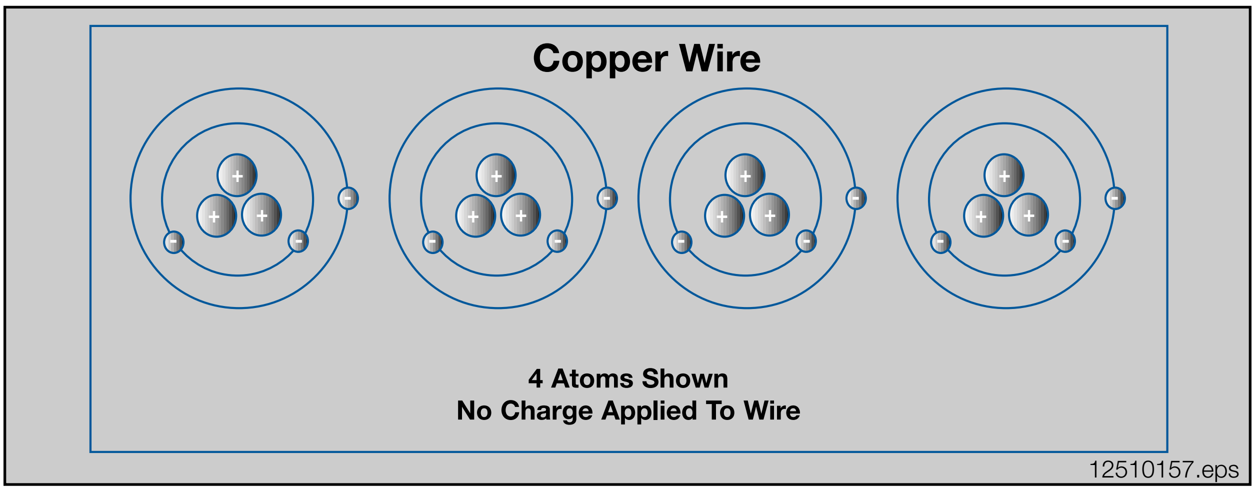
This flow of electrons does not mean that a single electron travels the entire length of the wire.

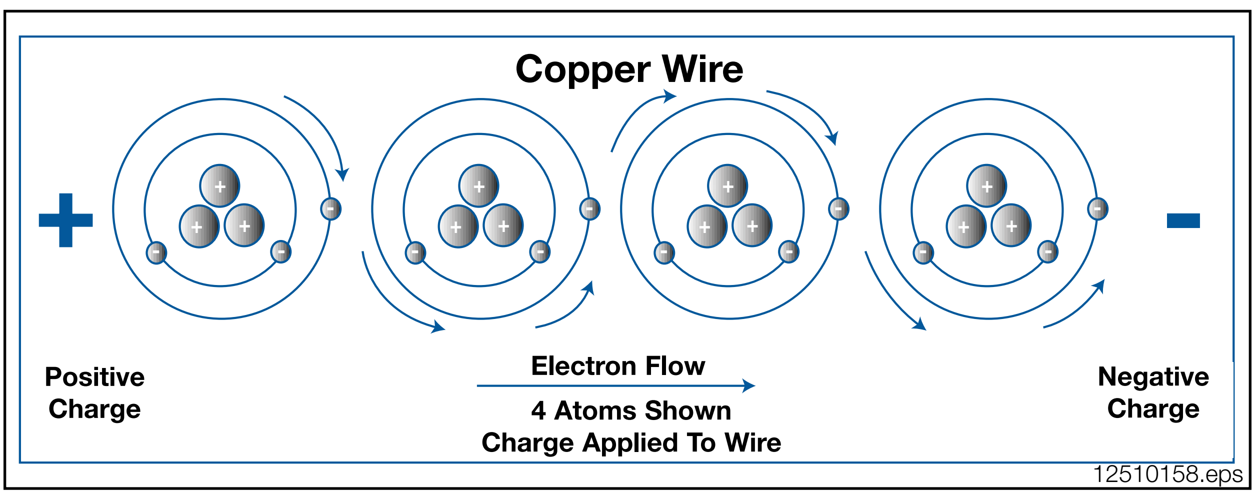
Electron flow is the movement of free electrons from atom to atom and the transmission of an electrical impulse from one end of a conductor to the other.

The constant unbalancing and rebalancing of the atoms takes place in less than one millionth of a second.



A single strand of copper wire contains billions of atoms





Electromotive Force

Friction, light, heat, pressure, chemical reaction or magnetic action are all ways that electrons are freed. The free electrons will move away from the **"Electron Moving Force" (EMF)**. A stream of free electrons form an electrical current.

EMF	Method	Automotive Uses
Friction	Static, Walking Across Carpet	Electrostatic Field, Capacitor
Light	Photoelectric Cell, Light Controls	Headlamp and Mirror Sensors
Pressure	Piezoelectric, Speakers, Microphone	Knock and Side Impact Sensors
Chemical	Dry/Wet Cell Batteries	Primary Automotive EMF, Battery
Magnetic	Electromagnetic Induction, Coils	Secondary Automotive EMF, Generator

The battery and the generator are the primary and secondary means by which free electrons are generated in automobiles.

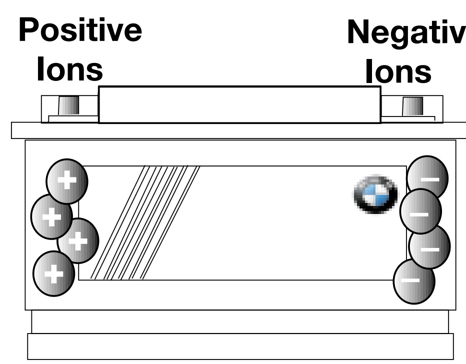
The chemical reaction taking place in the battery creates an **Electromotive Force (EMF)** that provides us with the positive ions and negative ions.

The generator through magnetic induction is our other source of free electrons. (Positive and negative ions)

The positive ions collect at the positive battery terminal and the negative ions collect at the negative battery terminal.

The positive and negative ions provide no energy unless a path between them is established. This path is normally in the form of a load (e.g. bulb, electric motor or other electrical consumer) placed across the positive and negative terminals of the battery either directly or through wires.

Free electrons are pushed out of the battery negative terminal through a conductor to the positive terminal.



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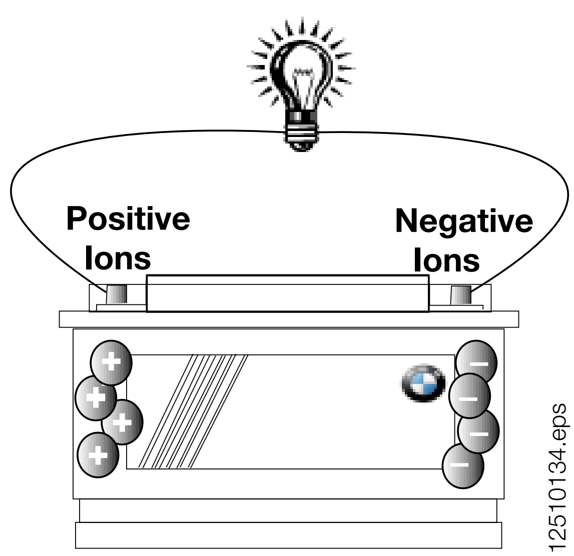

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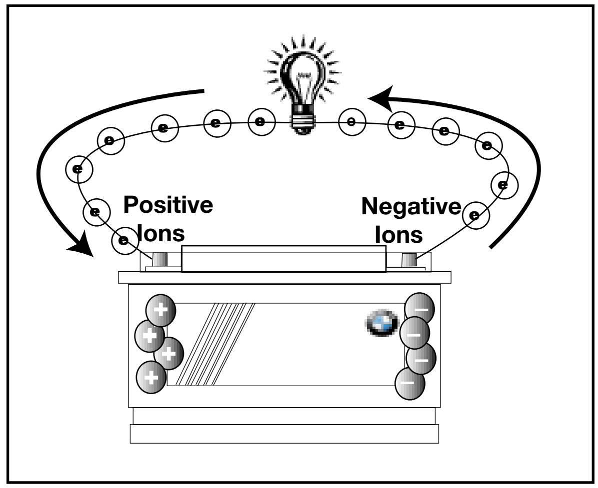
When a path is established electrons have a route from the negative terminal to the positive terminal of the battery.

That route may take the electrons through wires, motors, light bulbs or other electrical consumers.

The mission of the electrons is always to return to the source of their energy which is the battery.

The movement of electrons as discussed in the preceding pages is referred to as the **"Theory of Electron Flow"**. That is the actual path of the electrons in an electrical circuit, from negative to positive.



Theory of Electron Flow

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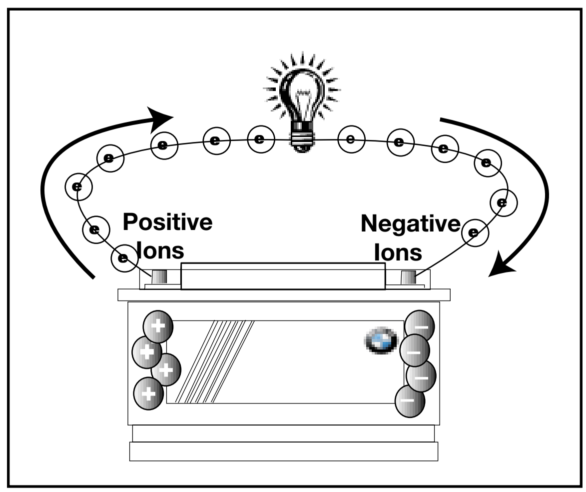
Before Science gave a glimpse of the electron, it was generally believed that electricity (electrons) flowed from the positive charge to the negative charge.

Most electrical symbols, wiring diagrams, and teaching is based on the **"Conventional Theory of Electron Flow"** which states that electrons flow from positive to negative.

From this point on all references to current flow will be defined by the Conventional Theory of Electron Flow.



Conventional Theory of Electron Flow

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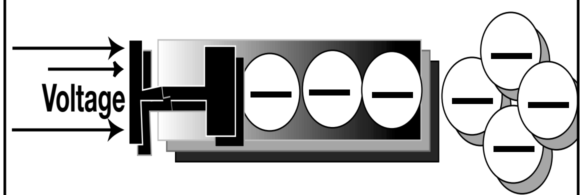
Notes

Voltage

The potential of the electrons to flow is measured in **Volts**.



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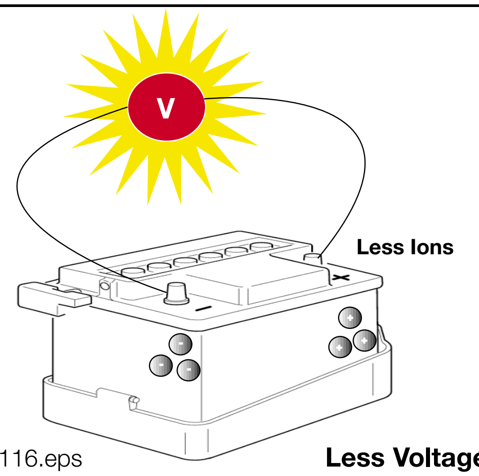
Think of voltage as pressure, the driving force (pressure) pushing the electrons from positive to negative.
"One volt is the potential difference required to push one **Amp** of current through one **Ohm** of resistance."



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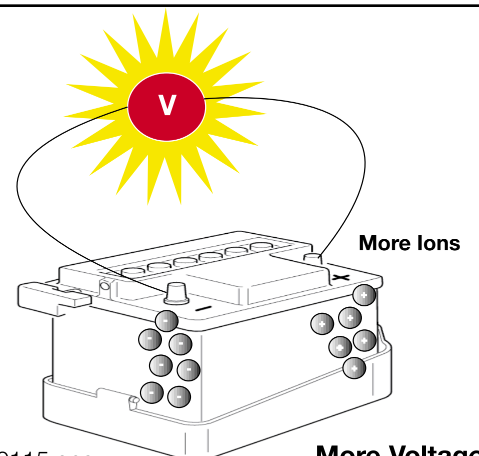
Voltage is present between two points when a positive charge exists at one point and a negative charge at the other point.
The amount of voltage available is dependent on the number of ions at each terminal of the battery.



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Voltage	Percent	Theoretical Current
12.6 Volts	100%	10 Amps
11.6 Volts	92%	9.2 Amps
11.0 Volts	87%	8.7 Amps
10.5 Volts	83%	8.3 Amps

Maintaining proper voltage is important. As voltage drops,so does the capacity for current flow.

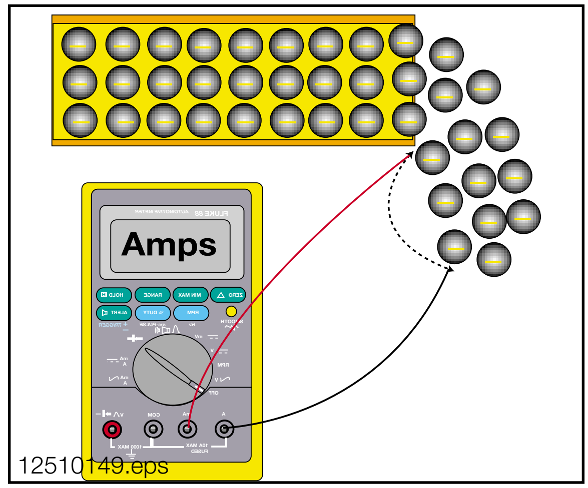
Voltage is the difference in the potential charges between the positive and negative terminals in a battery. If one volt is capable of pushing "x" amount of current, two volts can push 2x, three volts 3x and so on.

Ampere

The unit of measure for current flow is the **"Ampere",** commonly referred to as **"Amps".**

Amps is the counting of electrons flowing on a conductor past a given point. One amp of current flow is equal to 6.23 billion billion (6.23 x 10^{18}) electrons moving past a point in one second.

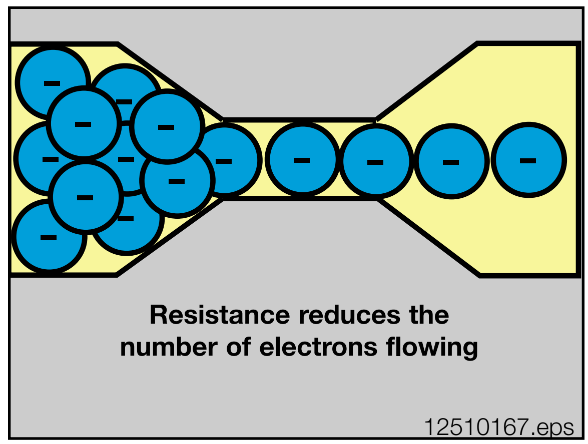
Amps allow you to measure the volume of electrical energy "amperes" flowing through a wire or electrical consumer.



Ohms

The **"Resistance"** of a circuit opposes current flow. The unit of measure for resistance is the **"Ohm"**.

One ohm is defined as the amount of resistance that will allow one amp to flow when being pushed by one volt of pressure.



Resistance reduces the number of electrons flowing

Resistance slows the flow of current (reduces the number of electrons flowing).

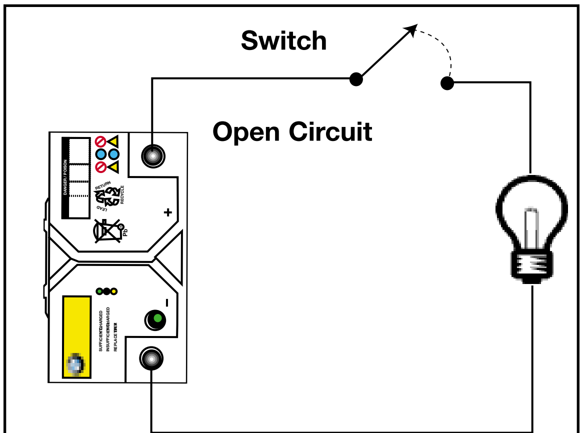
Resistance changes electrical energy into another form of energy (e.g. heat, light or motion).

Electrical Units of Measure			
Unit of Measure	**Symbol**	**Basic Unit**	
Volt	V,U or E	Volt	V = volt = 1 volt mV = millivolt = .001 volt KV = Kilovolt = 1,000 volt
Ampere	Amp, A or I	Amp	A=amp=1 amp mA=milliamp = .001A KA=Kiloamp=1,000 A
Ohm	Ω	Ohm	1Ω = 1ohm mΩ =milliohm=.001 ohm KΩ =Kilo-ohm = 1,000 ohm MΩ=Megaohm=1,000,000 ohm

Circuits

Electricity must have a complete or closed loop circuit to flow. A **"Circuit"** is defined as an unbroken, uninterrupted path which begins and ends at the same point. In the automobile that point is the battery. The electron flow must be from the battery through the wiring and consumers back to the battery. That flow represents a complete circuit.

A typical circuit will contain:
1. A battery and/or generator system (EMF or source of the electrons)
2. Conductors (wiring to deliver the electrons to the consumers)
3. Consumers (the load being placed on the system)
Any break or interruption in this circuit will cause the circuit to cease operation.



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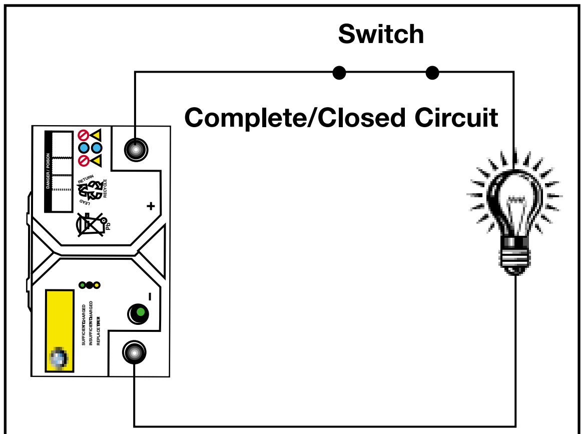

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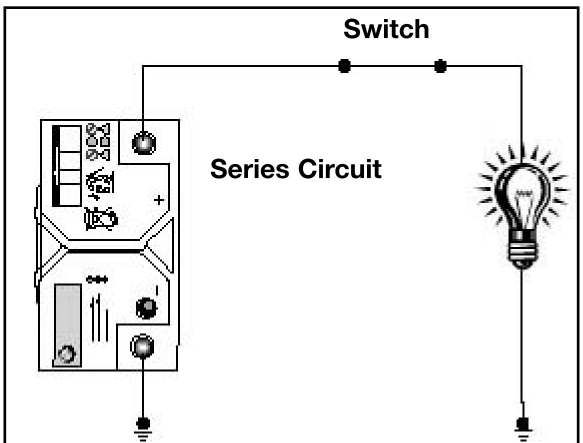
There are four basic types of circuits:
- Series
- Parallel
- Series/Parallel
- Short

Series Circuit

A Series circuit provides one path for the current flow. That path is from the source of the current (the battery) through a conductor, consumer and back to the source.

A Series circuit provides constant current flow (amps) through the entire circuit. Amps measured in any two places in the circuit will be equal.



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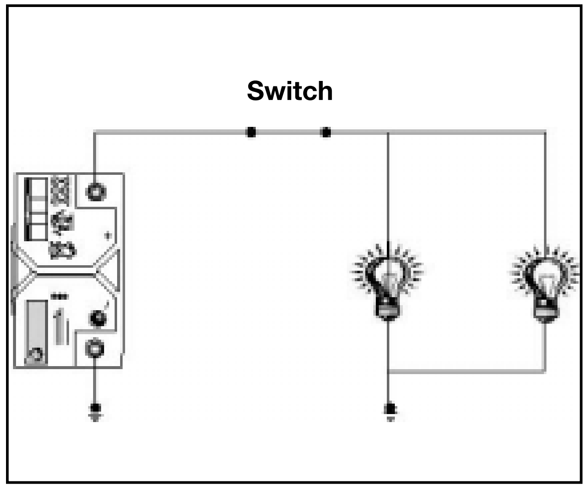
Parallel Circuit

A Parallel circuit provides multiple current paths. In a Parallel circuit, all of the component's positive terminals are connected to one point and all of the component's negative terminals are connected to a different common point. Source voltage is the same at all loads.
The current flow in a parallel circuit will be equal to the sum of the current flowing through each branch of the circuit.



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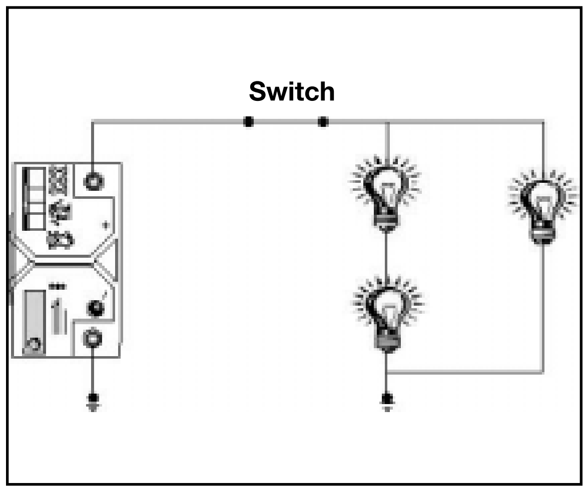
Series-Parallel Circuit

A Series-Parallel circuit contains portions of the current path that are in series with each other and other portions of the path that are parallel with each other. A headlight circuit would typically be this type of Series/Parallel circuit. The headlight switch is in series with the headlights, and the headlights are in parallel branches with each other.



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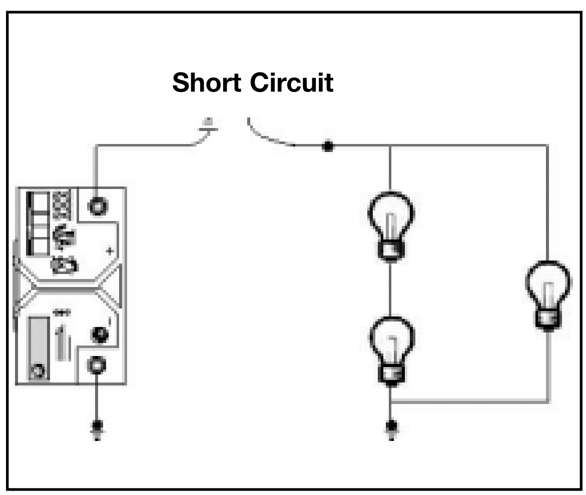
Short Circuit

Another type of circuit found although not by design is the **"Short Circuit"**.
Electricity flows much like water under pressure from the point of highest pressure to the point of lowest pressure.
An unintended path of current flow, such as a grounded conductor or consumer will provide the current flow a short path to home, a "short" circuit.
Short circuits allow unlimited current flow, and with out the protection of a circuit breaker or fuse will allow overloading of the conductor and possible wire meltdown.



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Ohms Law

The key to intelligent troubleshooting of electrical circuits is a thorough understanding of Ohms Law. Ohms Law states that the current flowing in a circuit varies directly with the voltage and inversely with the resistance.
The pressure of one volt applied to one Ohm of resistance will cause one amp of current to flow. If the voltage increases, current will increase. If resistance increases, current will decrease.
Knowing any two of the three factors (volts, resistance or current) enables the third factor to be calculated using Ohms Law.

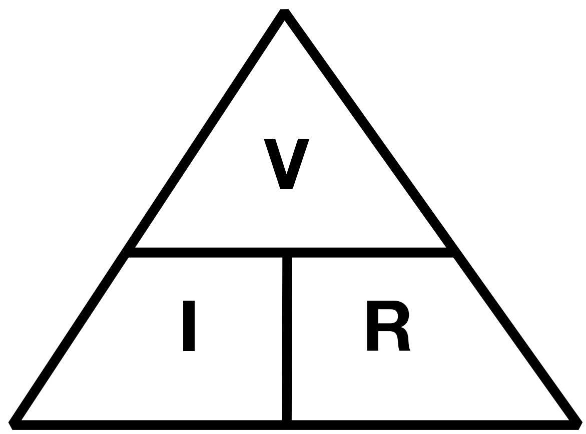
The mathematical expression is:

Volts = Resistance X Current

This formula is expressed in the Ohms Law Triangle.

To find a missing factor, insert the known factors in the appropriate position and perform the math. A horizontal line between two factors means to divide, a vertical line means multiply.

V = Volts **I = Current or Amps (A)** **R = Resistance (Ω)** **Note:** Voltage is sometimes expressed as U or E.



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Ohms Law Triangle

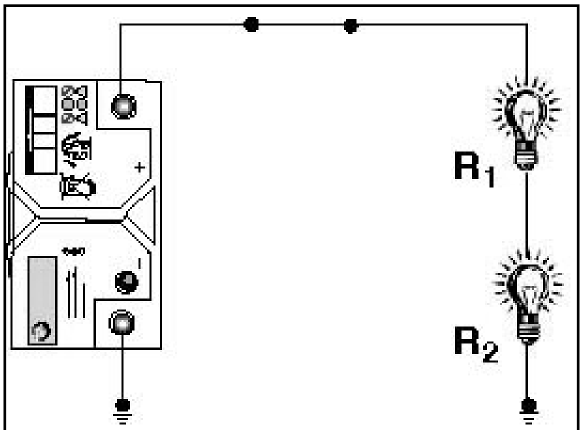
While complete understanding of Ohms Law is essential in the diagnosis of electrical problems, a practical understanding of how the three factors affect each other is equally useful.

Source voltage is not affected by current or resistance. It can only have three states. Too low - Current flow will be low. Too high - Current flow will also be too high. Correct voltage - Current flow will be dependent on the resistance.
Current Flow will be directly affected by either voltage or resistance. High voltage or low resistance will cause an increase in current flow. Low voltage or high resistance will cause a decrease in current flow.
Resistance is not affected by either voltage or current. Resistance like source voltage can have only three states. Too low - current will be too high if the voltage is ok. Too high - current flow will be low if the voltage is ok. Correct resistance - current flow will be high or low, dependent on voltage.

Ohms' Law Series Circuits

Applying Ohms Law in a series circuit is easy. The current has only one path. Circuit resistance total is arrived at by adding the individual resistances. Amperage is calculated by dividing source voltage by the resistance total.

$R_1 + R_2 = R_t$ $V/R_t = A$



Series Circuit

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Key Features - Series Circuit
• Current through each load is the same.
• Total resistance equals the sum of the individual resistances.
• Voltage drop across each load will be different if the resistance is different.
• Total voltage drop equals source voltage.

Example:

If $R_1=2\Omega$

$R_2=2\Omega$

Voltage = 12.0 volts

What would the current be?

2 + 2 = 4 (Resistance Total)

$R_t = 4$

12/4 = 3 Amps (I)

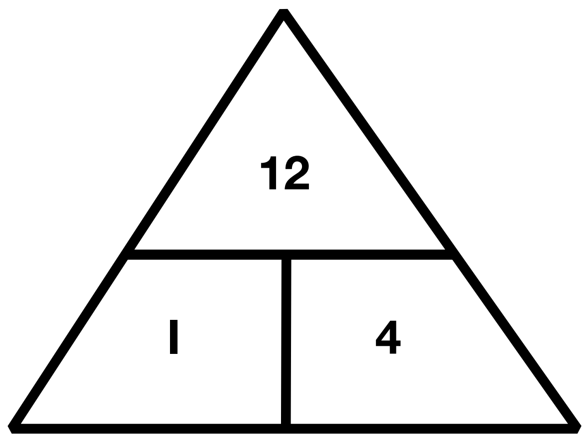
Volts divided by Resistance = Amps

Expected voltage drop at each bulb?

$A \times R_1 : A \times R_2$

3 x 2 = 6 volts

We could expect a voltage drop of 6 volts across each bulb.



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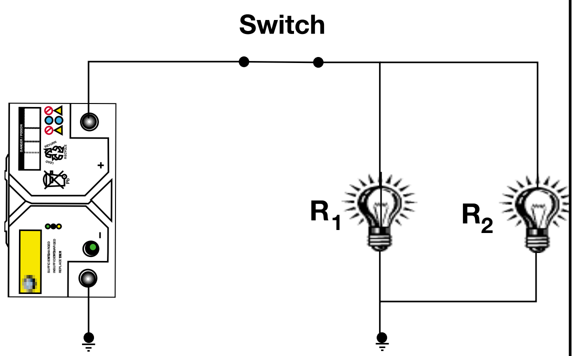
Ohms Law Parallel Circuit - 2 Branches

Working in a Parallel circuit requires a little more math. Each branch of the circuit has it's own path to the voltage source. Before amps are calculated total circuit resistance must be found.

In the diagram of the Parallel circuit both branches have source voltage available. The voltage drop across each branch will be the same regardless of individual branch resistance.



Parallel Circuit

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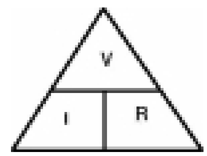
Key Features - Parallel Circuit
• Current flow through each branch can be different if the resistances are different.
• Total Resistance of the circuit is less than the resistance of the lowest branch.
• Voltage drop across each branch circuit is the same.
• Total current is the sum of the branches.



To find the total current draw (amps) in the circuit keep in mind that each branch of the circuit could have different resistance, so the current for each branch could be different.
(Example 13/1)

Example: 13/1

If $R_1 = 3\Omega$

$R_2 = 6\Omega$

Voltage = 12.0 volts

What would the current be for the R_1 branch? The R_2 Branch?

12/3 = 4 amps = R_1 branch current

12/6 = 2 amps = R_2 branch current

What would the total circuit current be?

4 + 2 = 6 amps = Total circuit current

To find the total resistance in the circuit independent of voltage and amperage use these formulas:

Parallel circuit with resistances that are the same on each branch.
Divide the resistance of one branch by the number of branches (Example 13/2).

Example: 13/2

If $R_1 = 2\Omega$

$R_2 = 2\Omega$

$$\frac{2}{2} = 1\Omega$$

Parallel circuit with resistances that are different on each branch (2 branches) (Example 13/3).

$$\frac{R_1 \times R_2}{R_1 + R_2}$$

Example: 13/3

If $R_1 = 3\Omega$

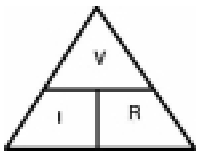
$R_2 = 6\Omega$

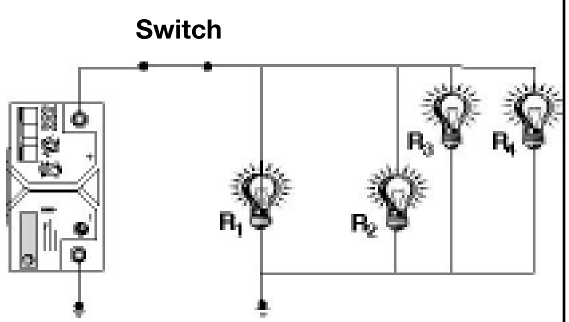
$$\frac{3 \times 6}{3 + 6} = \frac{18}{9} = 2\Omega$$

Ohms Law Parallel Circuit - more than 2 Branches

Calculating circuit resistance in a Parallel circuit with more than 2 branches adds even a little more math.

All the key features for a Parallel circuit still apply.





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There are two methods to calculate the total circuit resistance in a Parallel circuit of more than 2 branches. The formulas are:

Example: 14/1

If $R_1 = 3\Omega$
$R_2 = 3\Omega$
$R_3 = 6\Omega$
$R_4 = 4\Omega$

$$\frac{1}{\frac{1}{3} + \frac{1}{3} + \frac{1}{6} + \frac{1}{4}} = \frac{1}{\frac{4}{12} + \frac{4}{12} + \frac{2}{12} + \frac{3}{12}} =$$

$$\frac{1}{\frac{13}{12}} = \quad \frac{12}{13} = \quad .92\Omega$$

Example: 14/2

If $R_1 = 3\Omega$
$R_2 = 3\Omega$
$R_3 = 6\Omega$
$R_4 = 4\Omega$

$$\frac{3 \times 3}{3 + 3} = \frac{9}{6} = \quad 1.5$$

Then,

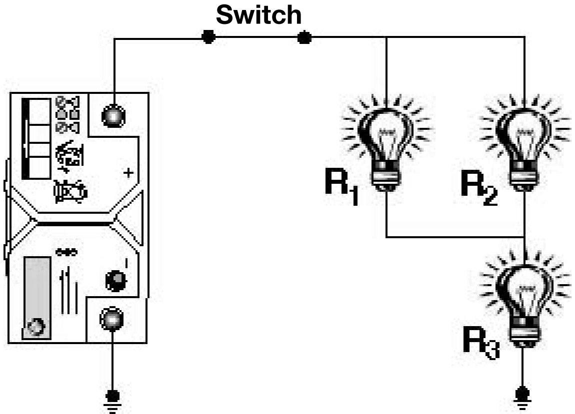
$$\frac{1.5 \times 6}{1.5 + 6} = \frac{9}{7.5} = \quad 1.2$$

Then,

$$\frac{1.2 \times 4}{1.2 + 4} = \frac{4.8}{5.2} = \quad .92\Omega$$

Ohms Law in Series-Parallel circuit

When calculating resistance in a series-parallel circuit, always calculate the equivalent resistance in the parallel portion of the circuit. Then add this resistance (equivalent resistance) to the resistance of the series portion of the circuit.



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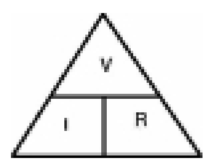
Key Features - Series-Parallel Circuit
• Current in the series portion of the circuit is the same at any point of that portion.
• Total circuit resistance is the sum of the parallel branch equivalent resistance and the series portion resistance.
• Voltage applied to the parallel branch is source voltage minus any voltage drop across loads wired in series to the parallel branch in front of it in the circuit.

Example:

If $R_1 = 4\Omega$

$R_2 = 6\Omega$

$R_3 = 2\Omega$



Calculate the equivalent resistance value of R_1 and R_2.

Remember the resistance of a parallel circuit is lower than the lowest resistance in that circuit. The resistance of this portion of the circuit must be lower than 4Ω, the lowest resistance.

$(4\Omega \text{ X } 6\Omega)/(4\Omega + 6\Omega) = 24/10$

2.4Ω Equivalent Resistance

Now follow the rules of a Series circuit.

The total circuit resistance is equal to the sum of the individual resistances.

$2.4\Omega + 2\Omega = 4.4\Omega$

Total resistance for this series-parallel circuit is 4.4 Ω

Alternate Formula for equivalent resistance: Find the current draw of each parallel branch, add together to get the total current draw of the parallel portion, then using ohms law find the resistance of the parallel branch.

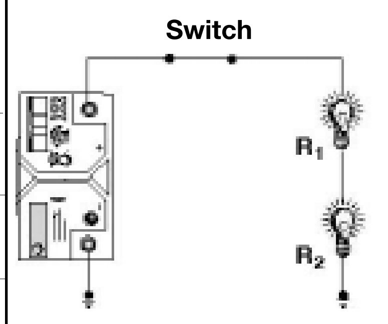
$12/R_1 = 3, \quad 12/R_2 = 2$

$3 + 2 = 5$

$12/5 = 2.4\Omega$

Worksheet

Calculate the missing value using Ohms Law:



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Using the series circuit.

1. A = 2, V = 12, R = ____________

2. R_1 = 4,R_2 = 4, V = 12, A = ____________

3. R_1 = 4, R_2 = 2, A = 2, V = ____________

4. V = 12, A = 6, R = ____________

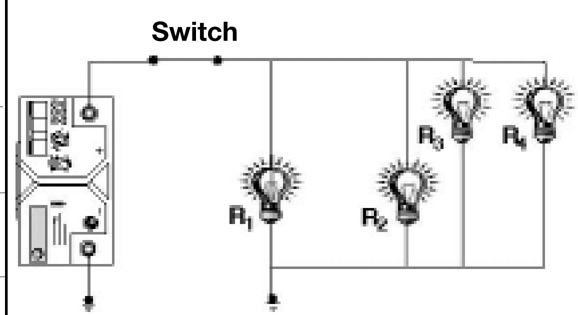
5. A = 3, R = 8, V = ____________

6. R_1 =2, R_2 = 1, R_3 = 3, (Series Circuit) V= 12, A= ____________

7. What would the expected voltage drop be in Question 2 ? ____________

8. What would the expected voltage drop be in Question 3? ____________

Using the Parallel circuit.



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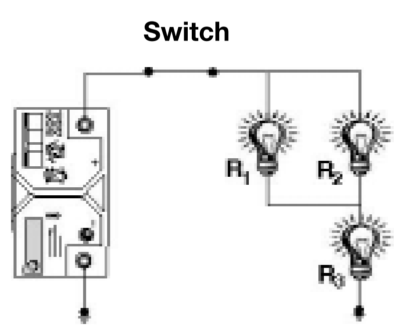
9. R_1 = 2, R_2 = 1, R_3 = 2, R_4 = 1, R_t = ____________

10. Using R_t from Question 9, V=12, A = ____________

11.R_1 = 2, R_2 = 1, R_3 = 2, R_4 = 4, R_t = ____________

12. Using $R_t$from Question 11, V =12, A = ____________

Using the Series-Parallel Circuit.



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13. R_1 = 2, R_2 = 4, R_3 = 2, R_t = ____________

14. Using R_t from Question 13, V =12, A = ____________

15. The resistance on the any branch of the parallel portion of this circuit is reduced. How is the total resistance for the circuit affected ? ____________
How is the amperage affected? ____________

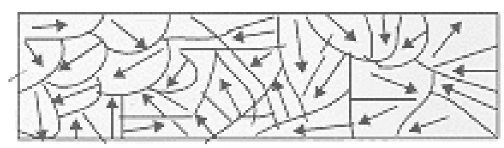
Worksheet Calculations

Electrical Components

Magnetic Theory

The usefulness of electricity is greatly expanded through magnetism. Magnetism enables the existence of electric motors, generators, coils, relays, solenoid, transformers, etc. Magnetism, like electricity, can't be seen, weighed on a scale or measured with a ruler. How it works and is put it to use can be understood.

Two theories exist to explain how magnets work. The first theory states that a large quantity of small magnetized particles exist in a magnet. If the item is not magnetized the particles are arranged in a random order. When the item becomes magnetized the particles align with each other.



Non Magnetized Iron Bar

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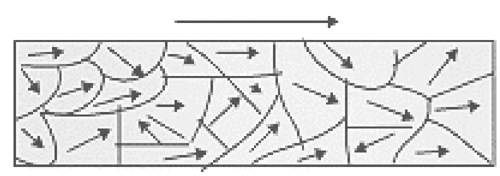
The second theory states that when the electrons of atoms are arranged in a certain order, the circles of force of each atom combine creating the magnetism.



Magnetic Iron Bar

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Fundamentals of Magnetism

- A magnet sets up a field of force.
- Magnetic lines of force form closed loops that flow from North to South.
- The space through which magnetic lines of force flow is called the magnetic field.
- The magnetic field is strongest closer to the magnet and becomes weaker as it gets further away.
- Magnetic lines of force never cross each other.
- There is no known insulator against magnetism.
- Magnetic lines pass more easily through iron and steel than air.
- Opposing forces will occur at opposite ends of the magnet (Polarity). One end is the North Pole (+), the opposite end is the South Pole (-).
- Like poles repel each other, unlike poles attract each other.

Some materials, wood ceramics and some metals, can not be magnetized.

There are two common types of magnets:

•**Permanent Magnets** - made from materials such as hardened steel that become magnetic when subjected to an outside magnetizing force and remain magnetic even after the outside force has been removed.

•**Temporary Magnets** - made from materials such as soft iron that remain magnetic only as long as an outside magnetic force is present.

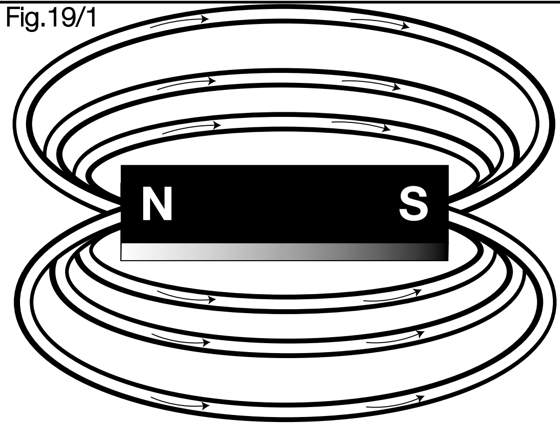
The lines of force of all magnets, either permanent or temporary flow from the North Pole of the magnet to the South Pole. The magnetic lines of force or "flux" are stronger closer to the magnet and get weaker as the distance from the magnet increases. (Fig. 19/1)

Polarity refers to the opposing forces occurring at opposite ends of the magnet. All magnets have a North Pole and a South Pole. Like poles will repel each other and unlike poles will attract. (Fig.19/2)

Most temporary magnetic fields are produced by electricity flow. Whenever current flows through a conductor magnetic lines of force develop around the conductor.

These lines of force form a circular pattern. The lines can be visualized as a magnetic cylinder extending the entire length of the conductor. (Fig.19/3)

Fig.19/1



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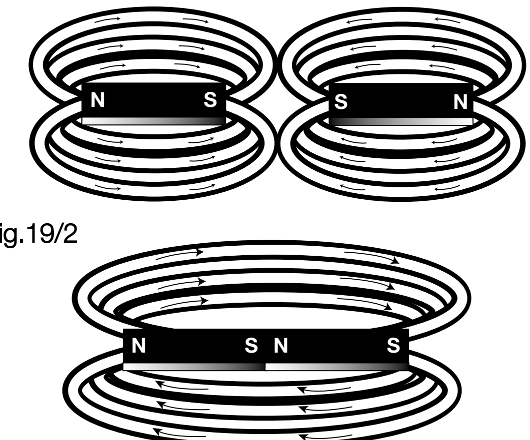

Fig.19/2

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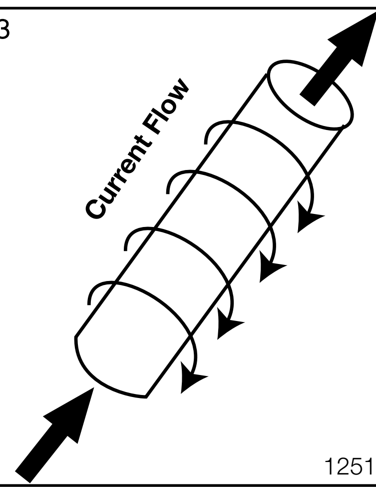
Fig.19/3



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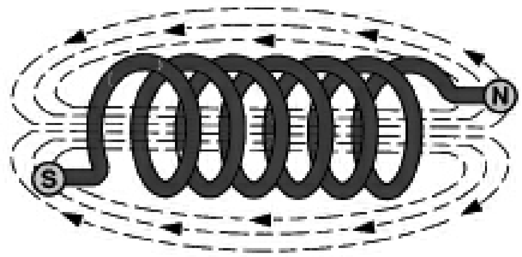
The lines of force have direction and change dependent on direction of current flow.
The density of the lines of force are dependent on current flow through the conductor. The greater the current flow, the stronger the magnetic field that will be around the conductor.

Fig.20/1



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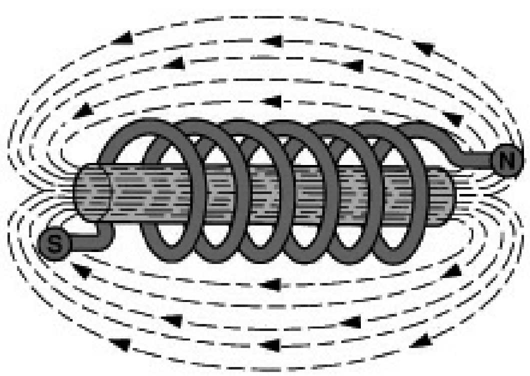


Fig.20/2 12510102.jpg

Passing a current flow through a conductor will not generate a magnetic field strong enough to perform any work.

If the conductor is coiled, the lines of force combine and become more dense forming a stronger field (Fig.20/1).

The greater the number of turns of the conductor or the stronger the current flowing through the conductor the the stronger the magnetic field.

Inserting an iron core in the coiled conductor increases the magnetic field even more as iron makes a better path for the magnetic lines than air (Fig.20/2).

This conductor wound around an iron bar is an “Electromagnet”. A coil with an air core is a “Solenoid”.

Electromagnetic Induction

Producing a magnetic field by flowing current through a conductor is a process that can be reversed. A magnetic field can be set up that will cause current to flow in a conductor. This is called inducing or generating electricity by magnetism.

To induce voltage in a conductor it is necessary to have relative motion between the conductor and the magnetic field. This motion can be in any one of three forms:

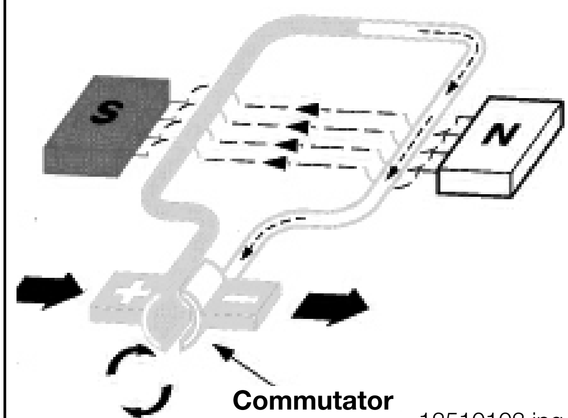
- The conductor moves or rotates in a stationary magnetic field as in a DC Generator.
- The magnetic field rotates in a stationary conductor producing voltage in the circuit as in an AC Generator or Alternator.
- The building or collapsing of a magnetic field across a stationary conductor, as in an Ignition Coil.

Generating Voltage

Generator

In a generator, the conductor moves through a stationary magnetic field inducing voltage at the commutator, which connects to the circuit through brushes.

The voltage induced is direct current.



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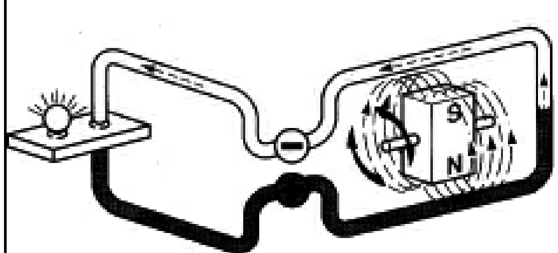
Alternator

In an alternator the magnetic field moves (rotates) through the stationary conductor producing voltage in the circuit.

The voltage induced is alternating current.



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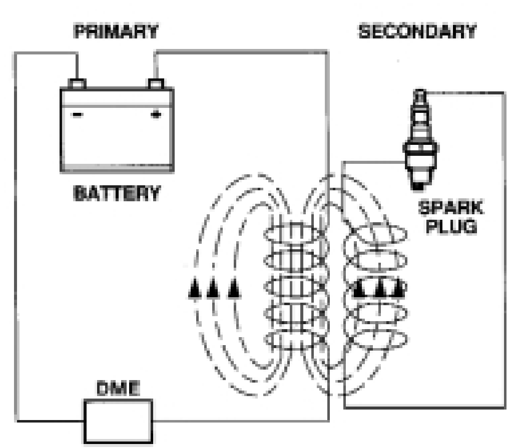
Ignition Coil

Voltage can be induced by the building or collapsing of a magnetic field across a stationary conductor.

B^+ power is supplied by the battery and a magnetic field is set up around the coiled conductor. The DME grounds or pulls low the current from the conductor and the loss of current causes the magnetic field to collapse inducing voltage in the secondary conductor.



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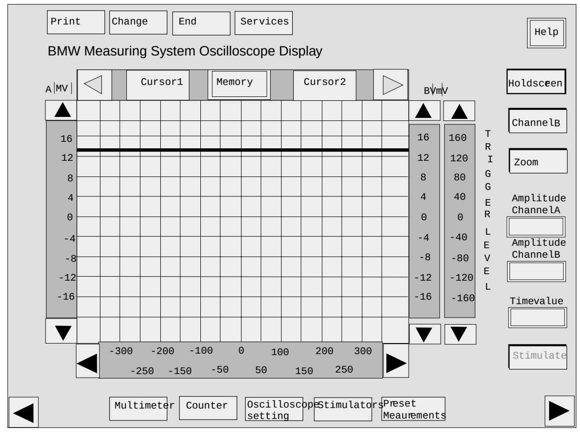
Types of Voltage

DC Voltage

A flow of current that moves continuously in one direction from a point of high potential to a point of low potential is referred to as **DC (Direct Current).**

Most automotive circuits operate on DC voltage as supplied by the battery(s).



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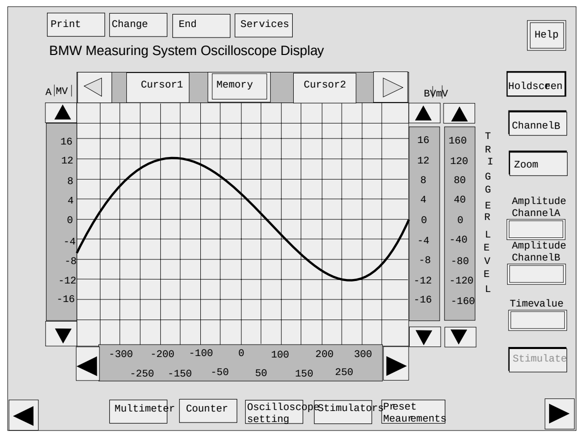
AC Voltage

Current which reverses its direction at regular intervals is called **AC (Alternating Current)**.
This regular and continuous reversal of current flow (cycle) occurs many times per second.
AC voltage as produced by an automotive alternator must be changed to direct current so that the battery can be charged.



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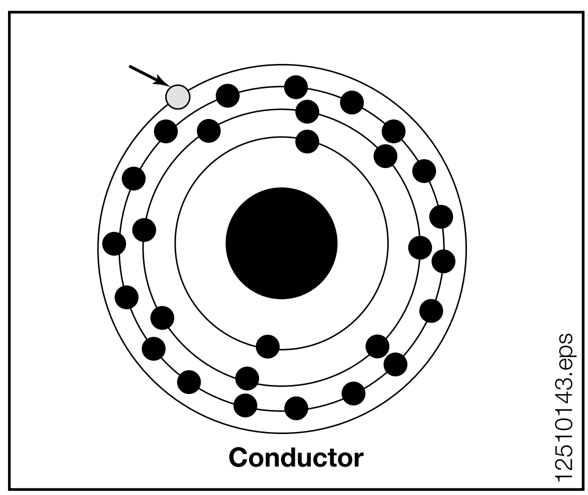
Conductors, Insulators and Semi-Conductors

Electrical properties of various materials are determined by the number of electrons in the outer ring of their atoms.

Conductors



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Materials with 1-3 electrons in the atoms outer ring make it easy for electrons to move from atom to atom. Remember that the definition of current flow is the movement of free electrons from one atom to another. The electrons in the outer ring of these conductors are loosely held and even a low EMF will cause the flow of free electrons.
Many metals are good conductors, especially gold, silver, copper, and aluminum. But not all conductors have the same amount of resistance to the flow of free electrons.

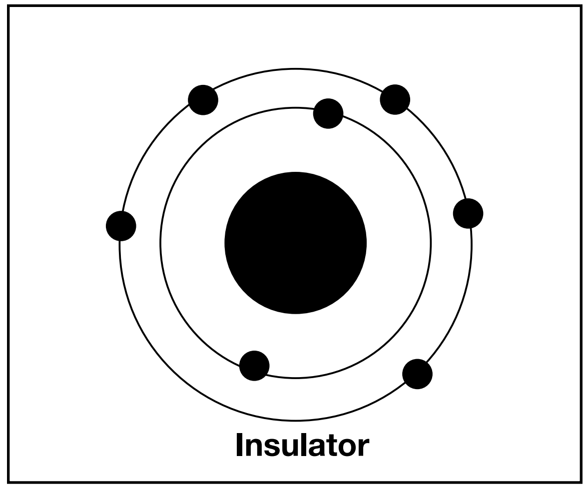
Insulators

Materials with 5-8 electrons in their outer ring have those electrons bound tightly. These materials are insulators (Poor conductors).

The electrons in the outer rings resist movement, the atoms don't give up the electrons easily or accept free electrons easily.

This effectively stops the flow of free electrons and thus any electrical current.
Rubber, glass, and certain plastics are examples of good insulators.

Insulators are used in circuits to insure that the flow of electrons stays in the conductor and can be directed to the proper place in the system.



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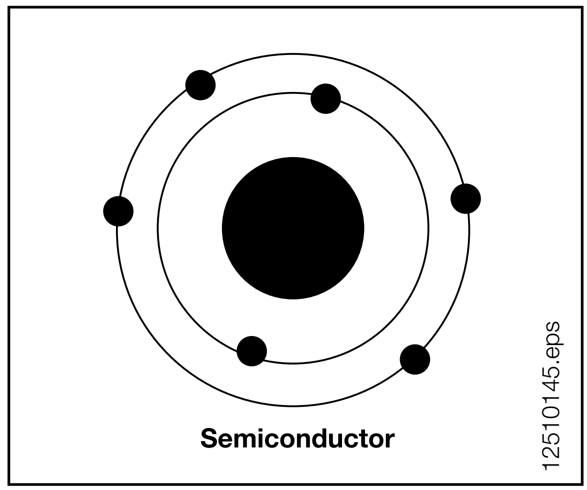
Semi-Conductors

Materials with exactly 4 electrons in the atoms outer ring are neither conductors nor insulators.

The 4 electrons in the outer ring cause special electrical properties which give them the name "Semi-Conductor".

Materials such as Germanium and Silicone are are two widely used semi-conductors.



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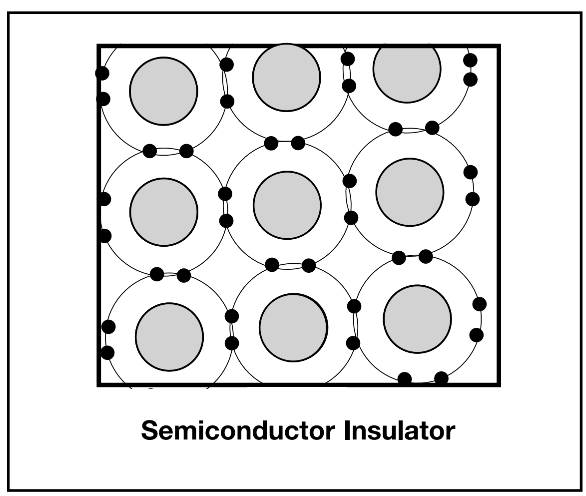
Semi-Conductor Doping

When semi-conductors are in the form of a crystal, the four electrons of the outer ring are shared with a neighboring atom.

This makes the crystal form of these materials an excellent insulator because there are no free electrons to carry a current flow.



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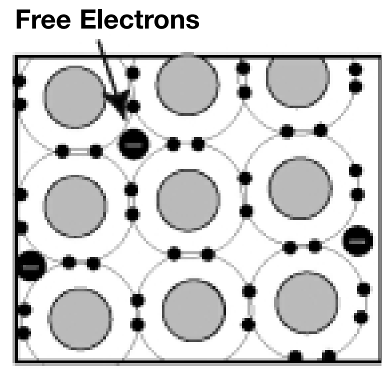
Other elements (Impurities) can be added to change the crystalline structure of the Germanium and Silicone.

This is called **Doping** of the semi-conductors.
Doping creates free electrons or holes enabling the semi-conductor to carry current.

N-Type Material

If the semi-conductor is doped with an element having 5 electrons in its outer ring there will not be enough space in the outer ring for the 9th electron (4 electrons in the semi-conductor and 5 in the impurity).

This type of doped material is called negative or N-material, because it already has excess electrons and will repel additional negative charges.



N - Material

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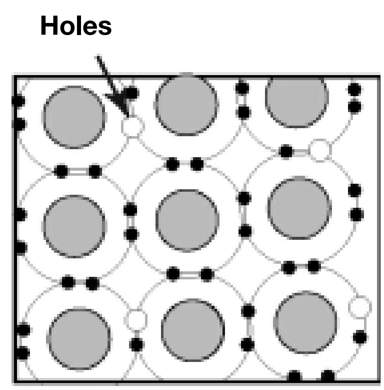
P-Type Material

If the semi-conductor is doped with an element having 3 electrons in its outer ring some of the atoms will only have 7 electrons in the outer ring. There will be a hole in some of the outer rings.
This type of doped material is called positive or P-material because it will attract free electrons



P-Material

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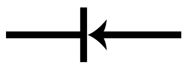
Junctions

Doping Germanium and Silicone cause them to behave in unusual but predictable ways when exposed to voltage, depending on which charge of the voltage is connected to which type of material (P or N).

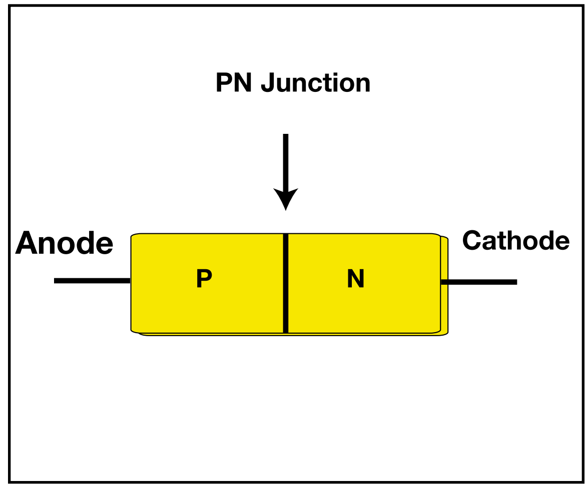
The line along which joined P and N material meet is called the **Junction.** A simple component consisting of P-material and N-material joined at a junction is called a diode. The application of voltage to the two doped semiconductor materials is called biasing.

A more complex material containing two PN junctions is called a **Transistor**.

Diode



When N and P-type semiconductor materials are joined together to form a single crystal a Diode is created. The diode allows electron flow in one direction only.



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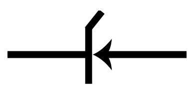
A diode has a **forward bias** when the Anode (P-material) is connected to B^+ and the Cathode (N-material) is connected to B^-.
Reversing the source voltage on the diode will result in current flow stoppage. This is called **reverse bias.**

Diodes are rated for specific voltage and current flow. The diode can not withstand unlimited forward bias and current flow.

Zener Diode

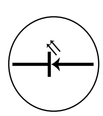


A diode which will allow a specified amount of reverse flow current is called a Zener Diode. If the breakdown voltage of the zener diode is 6 volts, at 6 volts and above the zener diode will allow reverse current flow with no damage to the diode.

Below the breakdown voltage the zener diode will function as a normal diode and allow current flow in only one direction.

Zener diodes are often used in charging systems to rectify or convert AC current to DC. Like the diode, zener diodes are rated for specific voltage, current and reverse current.

Light Emitting Diode



Light-Emitting Diodes (LED) emit visible light when forward biased. As current flows through the diode, electrical energy is converted into visible light that is radiated through the thin positive material layer in the diode.

Transistors

The Transistor is a diode with some additional semiconductor material. The transistor contains two PN junctions, compared to one in a diode.

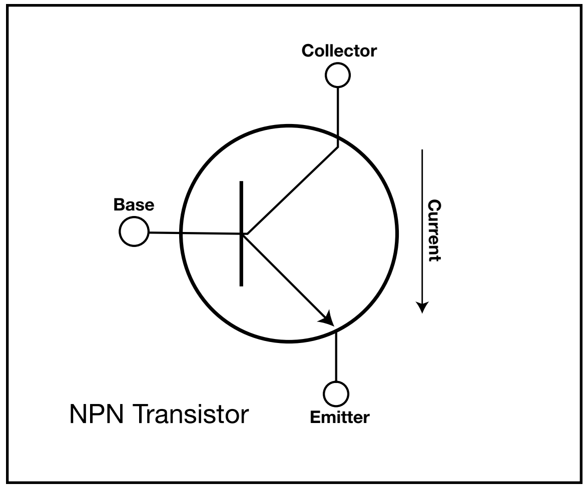
Transistors can be constructed in two ways: the P section can be sandwiched between two N sections forming a NPN transistor, or the N section sandwiched between two P sections forming a PNP transistor.

The three sections of the transistor are called the **Emitter**, the **Base** and the **Collector.**

Current applied to the base will flow through the transistor. Current flows through the NPN in one direction and through the PNP in the opposite direction.

Transistors are used to control current flow, act as a switch or as an amplifier to vary the current output dependent on base voltage variations.

A transistor allows control of large currents with small current signals.



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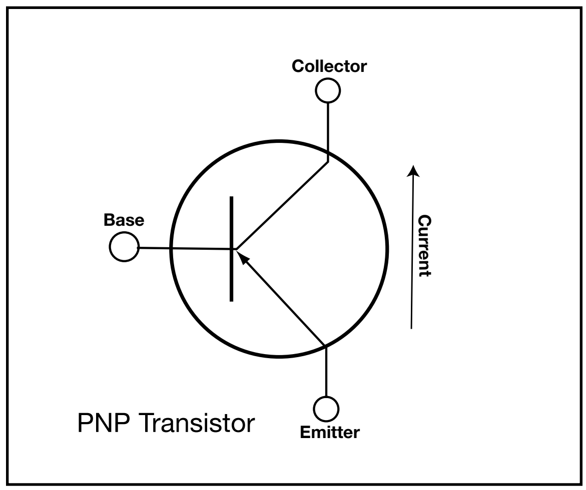

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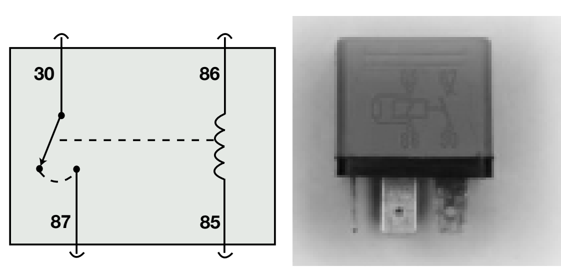
Relays

A Relay is a switch that uses electromagnetism to physically move the contacts.

A small of amount of current flow through a relay coil moves an armature and opens or closes a set of points.

The points control the flow of a larger amount of current through a separate circuit.



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Think of the two sides of a relay independently.

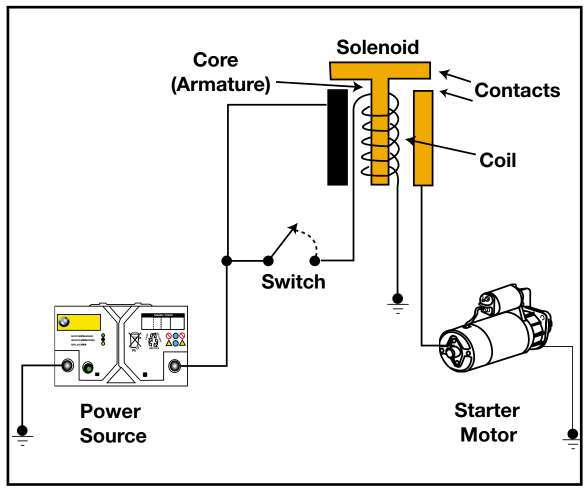
- **Control side:** Which includes the B^+(KL86) and B^-(KL85) for the coil that creates the magnetic force. If this side of the relay fails open the work side points will remain in their at rest position.
- **Work side:** Which includes the B^+ input power (KL30) and the Relay output (KL87). Failure of this side of the relay in the closed position (sticking points) will result in constant current flow.

BMW uses relays with various numbers of pins (3,4,5 pin) and pin configurations (normally open, normally closed and changeover type). Do not substitute relays. Always replace with the same type (e.g. DME Main Power Relay, Secondary Air Pump Relay and Rear Window Defroster Relay.). Refer to ETM 0140.

Solenoids

A Solenoid, like a relay, uses current flow and electromagnetism to produce mechanical movement. Solenoids consist of a coil winding around a spring loaded metallic plunger.

When current flows through the winding, the magnetic field attracts the movable plunger, pulling it against spring pressure into the center of the coil. When current flow stops, the magnetic field collapses and the plunger is moved out of the coil by spring pressure.



Solenoids are commonly used in starter motors, injectors and purge valves.

Switches

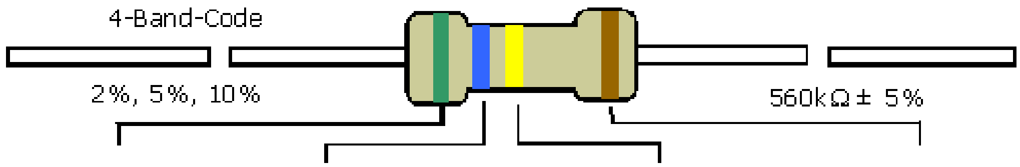
A Switch is a mechanical device used to start, stop or redirect current flow. A switch can be installed on the positive side of the circuit or the negative side of the circuit. A switch can be used to to control a load device directly or used to operate a relay which in turn can operate a higher current device. (e.g. Headlight switch, Horn button and Window switch.)

Resistors

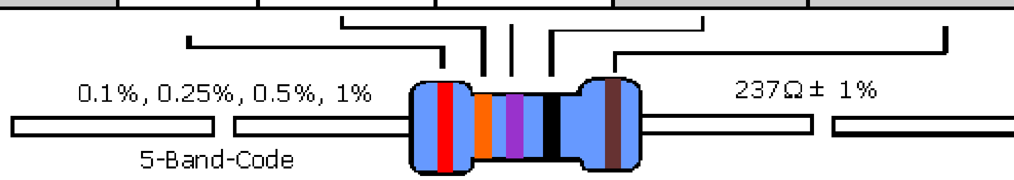
Resistors limit the current flow in a circuit. The resistor is used in a circuit to introduce a desired amount of resistance into the circuit.

Resistors are available in fixed resistance or variable resistance.
Fixed resistors are color coded to indicate their resistance.

Resistor color Code Guide



COLOR	1st BAND	2nd BAND	3rd BAND	MULTIPLIER	TOLERANCE
Black	0	0	0	1Ω	
Brown	1	1	1	10Ω	± 1% (F)
Red	2	2	2	100Ω	± 2% (G)
Orange	3	3	3	1KΩ	
Yellow	4	4	4	10KΩ	
Green	5	5	5	100KΩ	±0.5% (D)
Blue	6	6	6	1MΩ	±0.25% (C)
Violet	7	7	7	10MΩ	±0.10% (B)
Grey	8	8	8		±0.05%
White	9	9	9		
Gold				0.1	± 5% (J)
Silver				0.01	± 10% (K)



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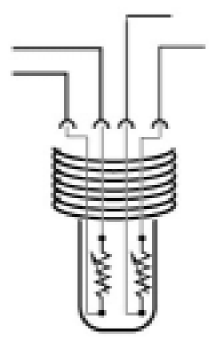
Variable Resistors

Thermistor

The resistance of materials can vary with changes in temperature; therefore, resistors can have a changing resistance value dependent on temperature.
A Thermistor is a resistor that can achieve large changes in resistance with small changes in temperature.
Thermistors are normally of the NTC (negative temperature coefficient) type. As the temperature increases the resistance decreases. BMW also uses PTC (positive temperature coefficient) type thermistors. In a PTC the resistance increases as the temperature increases.



Engine Temp Dual Thermistor

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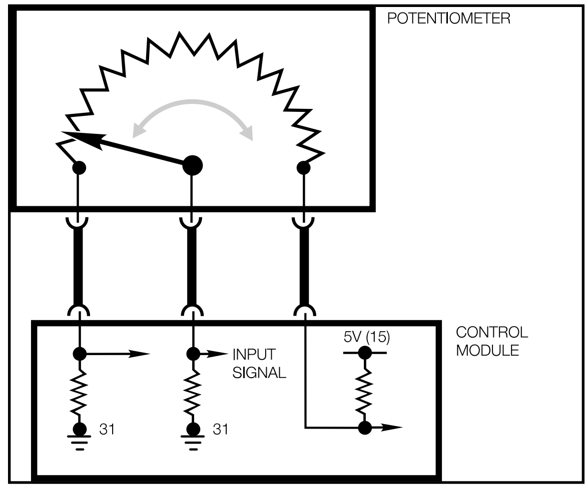
Potentiometer



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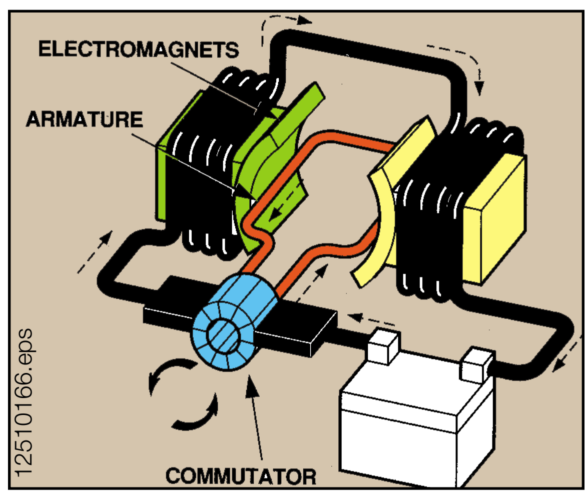
A Potentiometer (pot.) is a variable resistor capable of changing resistance values. Potentiometers have three terminals. One of the terminals is supply voltage, usually 5 volts. One of the terminals is the control module ground, and the third terminal is for the input signal into the control module. (Output from the Pot.) Potentiometers are used to measure mechanical movement. (e.g. Vane air flow meters, Throttle position sensors and Pedal position sensors.)

Rheostat

A Rheostat is similar in operation to a potentiometer except a Rheostat only has two connectors. This arrangement allows the resistance to be varied between those two connectors.

Electric Motors



DC motors are similar to DC generators. They may be described as generators run backwards. When current is passed through the armature of a DC motor, a torque is generated by magnetic reaction and the armature revolves.

Stepper Motors

Stepper Motors behave differently than standard DC motors. Unlike DC motors which spin freely when power is applied, stepper motors do as their name suggests, they step or rotate incrementally a little bit at a time. While DC motors need higher speeds to produce higher torque, stepper motors provide their highest torque at their slowest speeds. Stepper motors also have holding torque, the ability to resist movement by outside forces.
Steppers are driven by the interaction (attraction and repulsion) of magnetic fields. The driving magnetic field rotates as strategically placed coils are switched on and off. This pushes and pulls at permanent magnets arranged around the rotor that drive the output shaft.

Common Circuit Designations

NAME	CIRCUIT	
B+	Battery Positive	
B-	Battery Negative	
KL	Standardized Abbreviation for Clamp or Terminal Number	
KLO	Ignition Switch Off	
KLR	Voltage Ignition Switch in ACC, Run Start	Hot in Acc/ Run/ Start
KL15	Voltage Ignition Switch in Run and Start	Hot (12v) in Run/ Start
KL15U/15i	Voltage Ignition Switch in Run	Hot (12v) in Run
KL30	12v At All Times (Relay Work Power)	Hot (12v) All Times
KL30H	Starter Signal to ZKE	
KL50	Voltage Ignition Switch in Start	Hot (12v) in Start
KL58	Interior Lighting Dimmer Signal	
KL61	Ground with Alternator Output, 12v with KL15	
85	Relay Coil Ground (Signal) control side	
86	Relay Coil B+ Control Side	
87	Relay Output Work Side	
87a	Relay Output Work Side At Rest	

Review Questions

1. Electrons orbit around a nucleus of what materials? ______________________________

2. Why are some atoms referred to “Negative Ions” and where to do they collect?

____

3. Where do the “free” electrons come from and how are they freed? ______________________________

____

4. Describe the flow of electrons using the “Theory of Electron Flow” ______________________________

____

5. An increase in the number of negative ions collecting at the negative battery post will have what effect on the “potential of electrons” to flow? ______________________________

____

6. Name three things a complete circuit will contain? ______________________________

____

____

7. Describe how current flow will be affected by voltage and/or resistance. ______________________________

____

____

8. What affect will increasing current flow have on the magnetic field around a conductor?

____

9. Name the three forms of motion used to induce voltage in a conductor. ______________________________

____

____

10. What will happen to current, if a diode is installed in a forward bias? ______________________________

11. What happens to the resistance of an NTC type variable resistor if the temperature is decreased? ______________________________

12. What type of motor can be used to hold something still? ______________________________

13. What is Doping of semiconductors? ______________________________

14. Why can’t electrons move about freely in an insulator? ______________________________