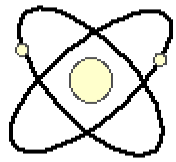
Theme 5: Electricity in the Home

Static Electricity

WHAT IS STATIC ELECTRICITY?

Everything we see is made up of tiny little parts called atoms. So what are atoms made of? In the middle of each atom is a "nucleus." The nucleus contains two kinds of tiny particles, called protons and neutrons. Orbiting around the nucleus are even smaller particles called electrons. The 115 kinds of atoms are different from each other because they have different numbers of protons, neutrons and electrons.



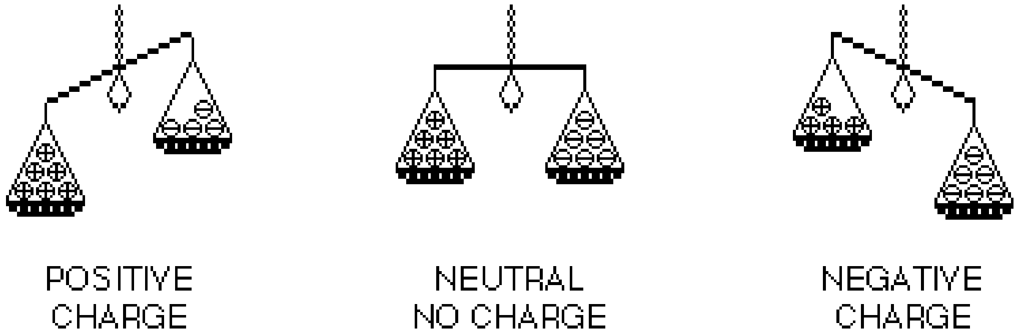
Protons, electrons and neutrons. These are very different from each other in many ways. One way they are different is their "charge." Protons have a positive (+) charge. Electrons have a negative (-) charge. Neutrons have no charge.

Usually, atoms have the same number of electrons and protons. Then the atom has no charge, it is "neutral." But if you rub things together, **electrons** can move from one atom to another. Some atoms get extra electrons. They have a negative charge. Other atoms lose electrons. They have a positive charge. When charges are separated like this, it is called static electricity.

ELECTRONS CAN MOVE

The protons and neutrons in the nucleus are held together very tightly. Normally the nucleus does not change. But some of the outer electrons are held very loosely. They can move from one atom to another.

An atom that looses electrons has more positive charges (protons) than negative charges (electrons). It is positively charged. An atom that gains electrons has more negative than positive particles. It has a negative charge. A charged atom is called an "ion."



Some materials hold their electrons very tightly. Electrons do not move through them very well. **These things are called insulators**. Plastic, cloth, glass and dry air are good insulators. Other materials have some loosely held electrons, which move through them very easily. **These are called conductors**. Most metals are good conductors.

Conductors and Insulators

•**Conductors** are materials in which the electrons can move rather freely (i.e. they readily conduct a flow of electrons).

•Examples of conductors are metals such as copper, silver, Aluminium plus salt water solutions (the human body falls into this category).

•**Non-conductors or Insulators** are materials in which the electrons are more tightly bound to the atoms and generally are not free to move.

•Examples of insulators are wood, plastic, and stone; in short, any non-metal.

•The earth acts as a large conductor and has a very large capacity to absorb charge concentrations from smaller conductors.

•So any charge on a conductor will be lost if there is a path to ground.

•Substances that fall between the metals and the insulators are called semiconductors.

•**Semiconductors** such as Silicon and Germanium are widely used in modern electronics since their properties may be radically altered by the addition of small amounts of impurity atoms.

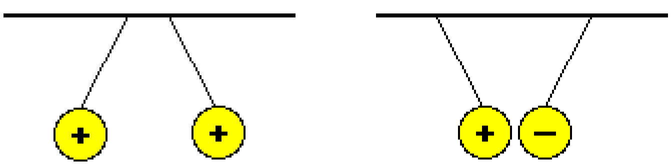
•**Superconductors** are perfect conductors in the sense that they offer no resistance to the flow of charges.

How can we move electrons from one place to another?

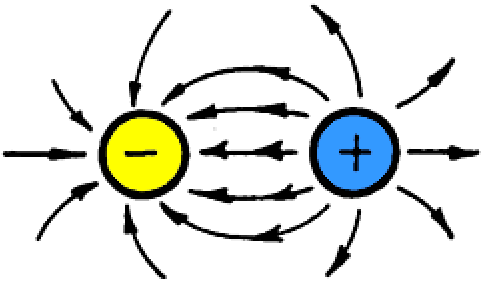
One very common way is to rub two objects together. If they are made of different materials, and are both insulators, electrons may be transferred (or moved) from one to the other. The more rubbing, the more electrons move, and the larger the charges built up. (Scientists believe that it is not the rubbing or friction that causes electrons to move. It is simply the contact between two different materials. Rubbing just increases the contact area between them.)

Static electricity is the imbalance of Positive and negative charges.

If two things have different charges, they attract, or pull towards each other. If two things have the same charge, they repel, or push away from each other.



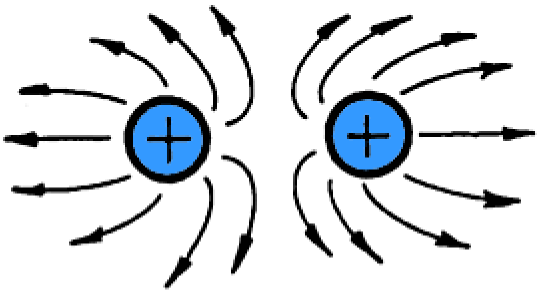
Unlike charges attract



When a positive charged particle (+) like a proton is near a negative charged particle (-) like an electron, the electrical field goes from one to the other.

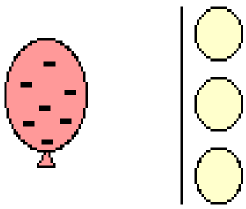
Like charges repel

When particles have the same charge, they repel each other.

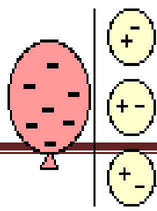


Like charges push away from each other

A charged object will also attract something that is neutral.



If you charge a balloon, it picks up extra electrons and has a negative charge. Holding it near a neutral object will make the charges in that object move. So there are more positive charges closer to the negative balloon. **Opposites attract.** The balloon sticks. (At least until the electrons on the balloon slowly leak off.)



It works the same way for neutral and positively charged objects.

So what does all this have to do with shocks? Or hair full of static? When you take off your wool hat, it rubs against your hair. Electrons move from your hair to the hat. Now each of the hairs has the same positive charge.

Remember, things with the same charge repel each other. So the hairs try to get as far from each other as possible. The farthest they can get is by standing up and away from the others.

As you walk across a carpet, electrons move from the rug to you. Now you have extra electrons. Touch a door knob and ZAP! The door knob is a conductor. The electrons move from you to the knob. You get a shock.

We usually only notice static electricity in the winter when the air is very dry. During the summer, the air is more humid. The water in the air helps electrons move off you more quickly, so you can not build up as big a charge.

In conclusion

Various materials have a tendency of either giving up electrons and becoming positive (+) in charge or attracting electrons and becoming negative (-) in charge.

Dry human skin, rabbit fur, cellulose acetate and **Perspex** have the greatest tendency to give up electrons when rubbed on something and become positively (+) charged.

Cling film, polyester, and **polythene** have the greatest tendency to become negatively charged (-) when rubbed.

CONSERVATION OF CHARGE

When we charge something with static electricity, no electrons are made or destroyed. No new protons appear or disappear. Electrons are just moved from one place to another. The net, or total, electric charge stays the same. This is called the **principle of conservation of charge.**

Coulomb's Law

(1) Charges may be either positive (like protons) or negative (like electrons).

(2) Like charges repel; unlike charges attract.

Charge is quantized

Charges on surface

Note that the charged atoms are on the surface of the material. If electrical charges build up on the outside of a metal, most of them will dissipate into the metal, similar to an electrical current.

Static electricity is formed much better when the air is dry or the humidity is low.

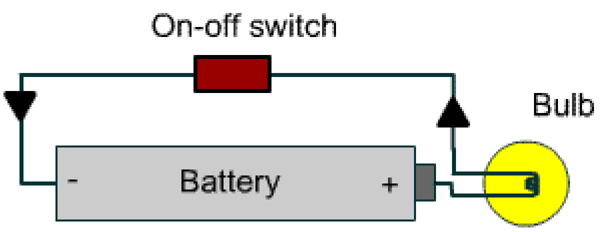
Electric currents

Static electricity sparks consist of the sudden movement of electrons from a negative to positive surface, **Direct current or DC** electricity is the **continuous** movement of the electrons through a wire.

A DC circuit is necessary to allow the current or steam of electrons to flow. Such a circuit consists of a source of electrical energy (such as a battery) and a conducting wire running from the positive end of the source to the negative terminal. Electrical devices may be included in the circuit.

Electrical circuit

An electrical circuit consisting of a source of DC power and a wire making a complete circuit is required for DC electricity to flow.



A flashlight is a good example of a DC circuit

*When the switch is closed we say that we have **a closed circuit.** When the switch is open , there is a break and the current stops flowing. We say that we have an **open circuit**. If a wire is connected across the switch or across bulb it will act as a bypass for the electric current as it will provide an easier path for it to flow. We say that we have a **short circuit.***

Voltage, current and resistance

The electricity moving through a wire or other conductor consists of its **voltage (V), current (I) and resistance (R).**

Electrical voltage

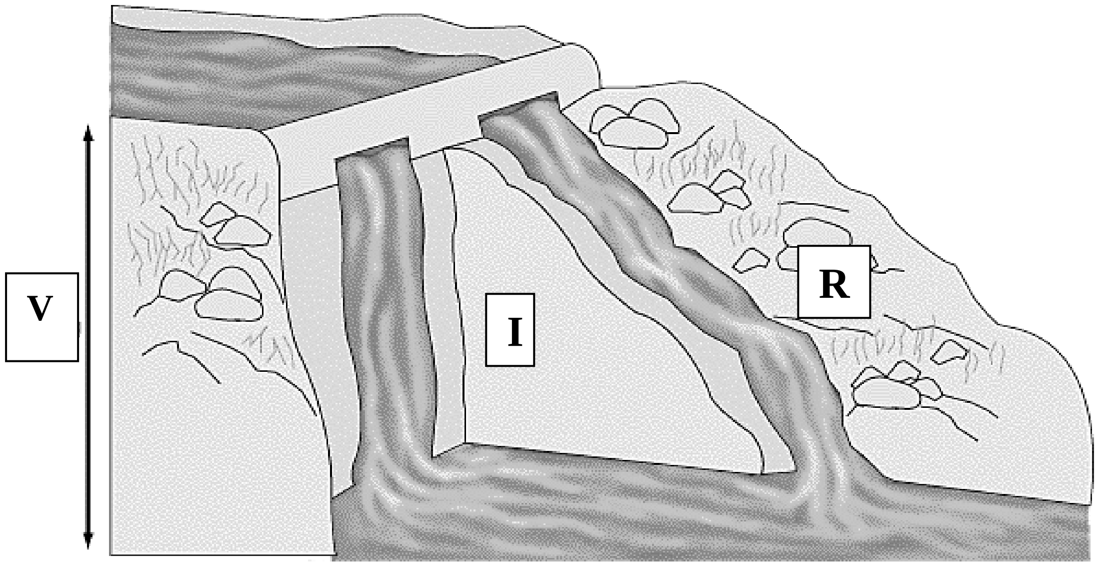
A potential or pressure builds up at one end of the wire, due to an excess of negatively charged electrons. It is like water pressure building up in a hose. The pressure causes the electrons to move through the wire to the area of positive charge. This potential energy is called Voltage, its unit of measurement is the Volt (V).

Electrical current

The number of electrons is called current and its unit of measurement is the Ampere or Amp (A). Electrical current is like the rate that water flows through a hose.

Resistance

An Ohm (Ω) is the unit of measurement of the electrical resistance. A conductor like a piece of metal has its atoms so arranged that electrons can readily pass around the atoms with little friction or resistance. In an insulator or poor conductor, the atoms are so arranged as to greatly resist or impede the travel of the electrons. This resistance is similar to the friction of the hose against the water moving through it.



Comparison with hose

The following chart compares water running in a hose and DC electricity flowing in a wire:

Water in a Hose	DC in a Wire	Electrical Units
pressure	potential (V)	Volts - - V
rate of flow	current (I)	Amps - A
friction	resistance (R)	Ohms - Ω

Creating DC electricity

Batteries and DC generators are used to create a continuous source of DC electricity . DC.Batteries rely on chemical reactions to create DC electricity.

The automobile battery consists of lead plates in a sulfuric acid solution. When the plates are given a change from the car's generator or alternator, they change chemically and hold the charge. That source of DC electricity can then be used to power the car's lights .

Current

As a physical quantity, **current** is the rate at which charges flow past a point in a circuit. As depicted in the diagram below, the current in a circuit can be determined if the quantity of charge Q passing by a cross section of a wire in a time t can be measured. The current is simply the ratio of the quantity of charge and time.

Charge is defined as the flow of current in a specific time.

$$Q = I * t$$

Electromotive Force (EMF)

Charge can flow in a material under the influence of an external electric field. To maintain a voltage (and flow of charge) requires an external energy source, ie. EMF (battery, power supply) . EMF is measured in volts.

EMF of a cell is equal to the energy (work done) per unit charge.

V = Work done/ charge

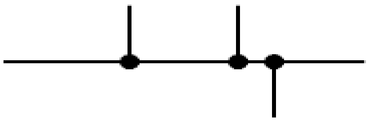
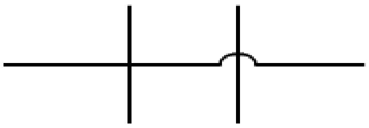
= W / Q or

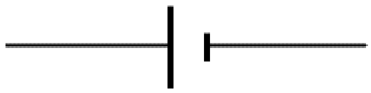
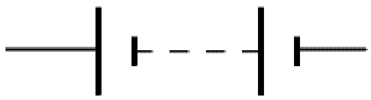
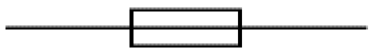
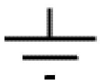
Work W = Q V

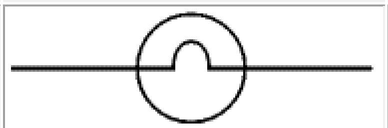
We can substitute Q = It in above and obtain

Work W = VIT

Circuit Symbols

Wires and connections		
Component	**Circuit Symbol**	**Function of Component**
Wire		To pass current very easily from one part of a circuit to another.
Wires joined		A 'blob' should be drawn where wires are connected (joined). Wires connected at 'crossroads' should be staggered slightly to form two T-junctions, as shown on the right.
Wires not joined		In complex diagrams it is often necessary to draw wires crossing even though they are not connected.

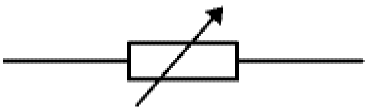
Power Supplies		
Component	**Circuit Symbol**	**Function of Component**
Cell		Supplies electrical energy. The larger terminal (on the left) is positive (+). A single cell is often called a battery, but strictly a battery is two or more cells joined together.
Battery		Supplies electrical energy. A battery is more than one cell.The larger terminal (on the left) is positive (+).
DC supply		Supplies electrical energy. DC = Direct Current, always flowing in one direction.
AC supply		Supplies electrical energy. AC = Alternating Current, continually changing direction.
Fuse		A safety device which will 'blow' (melt) if the current flowing through it exceeds a specified value.
Earth (Ground)		For many electronic circuits this is the 0V (zero volts) of the power supply, but for mains electricity and some radio circuits it really means the earth. It is also known as ground.

Output Devices: Lamps, Heater, Motor, etc.		
Component	**Circuit Symbol**	**Function of Component**
Lamp (lighting)		A transducer which converts electrical energy to light. This symbol is used for a lamp providing illumination, for example a car headlamp or torch bulb.
Heater		A transducer which converts electrical energy to heat.
Motor		A transducer which converts electrical energy to kinetic energy (motion).

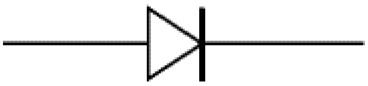
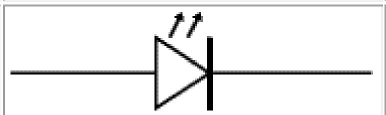
Switches

Component	Circuit Symbol	Function of Component
On-Off Switch (SPST)		SPST = Single Pole, Single Throw. An on-off switch allows current to flow only when it is in the closed (on) position.

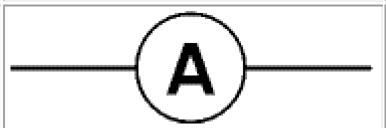
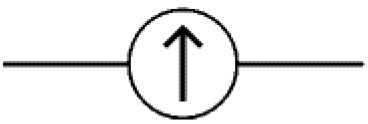
Resistors

Component	Circuit Symbol	Function of Component
Resistor		A resistor restricts the flow of current, for example to limit the current passing through an LED. A resistor is used with a capacitor in a timing circuit.
Variable Resistor (Rheostat)		This type of variable resistor with 2 contacts (a rheostat) is usually used to control current. Examples include: adjusting lamp brightness, adjusting motor speed, and adjusting the rate of flow of charge into a capacitor in a timing circuit.

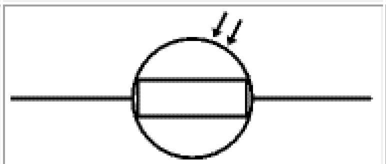
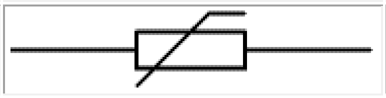
Diodes

Component	Circuit Symbol	Function of Component
Diode		A device which only allows current to flow in one direction.
LED Light Emitting Diode		A transducer which converts electrical energy to light.

Meters and Oscilloscope

Component	Circuit Symbol	Function of Component
Voltmeter		A voltmeter is used to measure voltage. The proper name for voltage is 'potential difference', but most people prefer to say voltage!
Ammeter		An ammeter is used to measure current.
Galvanometer		A galvanometer is a very sensitive meter which is used to measure tiny currents, usually 1mA or less.

Sensors (input devices)

Component	Circuit Symbol	Function of Component
LDR		A transducer which converts brightness (light) to resistance (an electrical property). LDR = Light Dependent Resistor
Thermistor		A transducer which converts temperature (heat) to resistance (an electrical property).

<u>Ohm's Law for Electrical Circuits</u>

The most fundamental equation in electrical circuits is called <u>Ohm's Law</u>. Ohm's Law is the equation

$$V = I * R$$

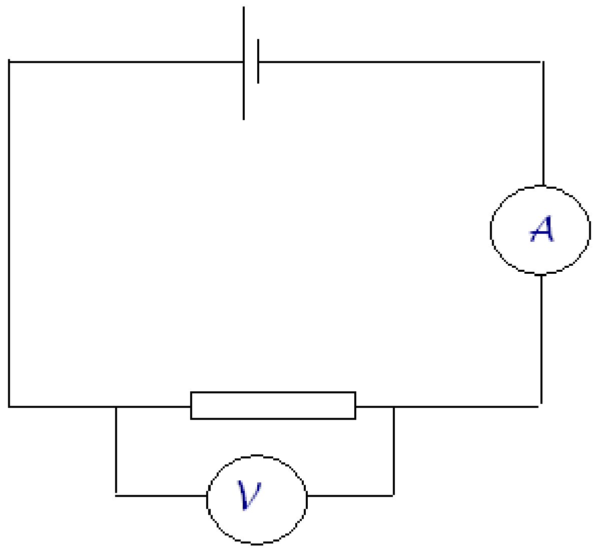
This is **Ohm's Law**, which states:

The current in a conductor is directly proportional to the potential difference between its ends provided that the temperature remains constant.

Since only metals have constant resistance as stipulated by Ohm's law, they are called ohmic conductors. All other materials which conduct current such as electrolytes and semiconductors etc. do have resistance. But they are known as non-ohmic conductors since their resistance is not constant. Hence for non-ohmic conductors the V-I graph is a curve.

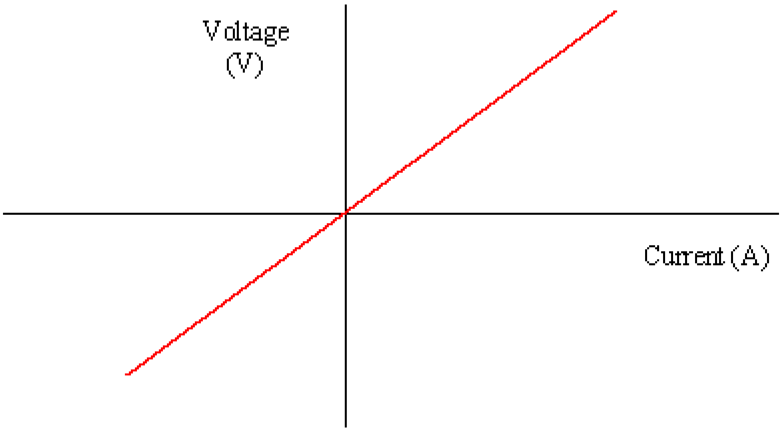
<u>Voltage Current Characteristics</u>

We can easily measure voltage and current, using the data to plot **voltage current graphs**. We use the following circuit.



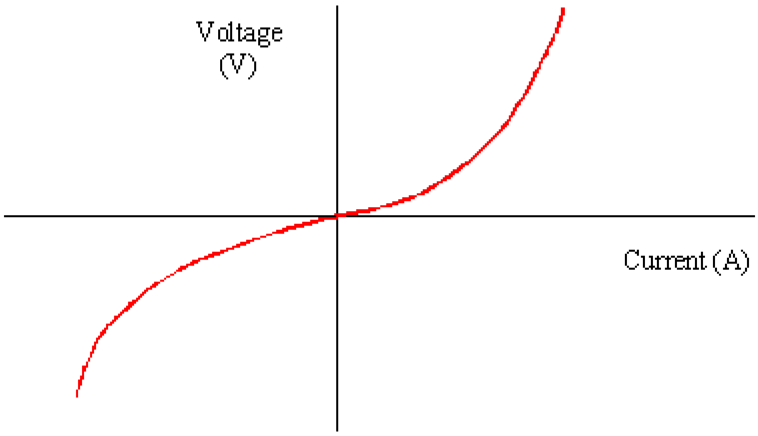
From this circuit we take readings of voltage and current plotting them as a graph called a **VI characteristic**.

We normally put the voltage on the y-axis and current on the x-axis. This allows us to determine the **resistance** from the **gradient**. **<u>This is a voltage current graph for an ohmic conductor:</u>**



The straight line shows a **constant ratio** between voltage and current, for both positive and negative values. So when the voltage is negative, the current is negative, i.e. flowing in the opposite direction. Ohm's Law is obeyed.

<u>For a filament lamp we see:</u>

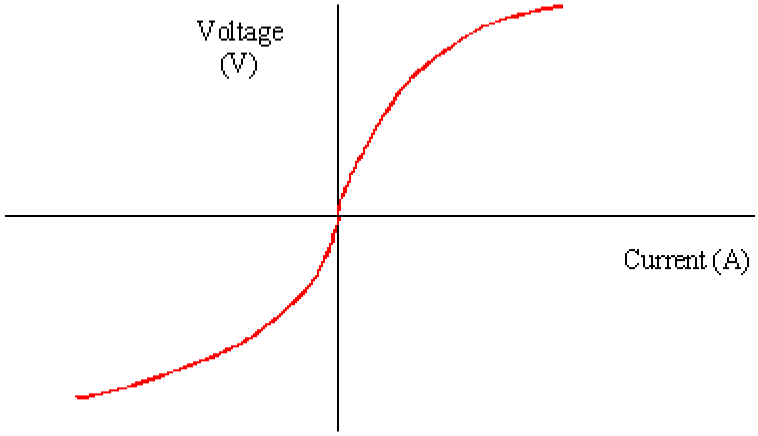


The resistance **rises** as the filament gets **hotter**, which is shown by the **gradient getting steeper**.

Can you explain why the shape of this graph suggests that a light bulb does not obey Ohm's Law?

A thermistor

(a heat sensitive resistor) behaves in the opposite way. Its resistance goes **down** as it gets **hotter**. This is because the material releases more electrons to be able to conduct.



Although it looks similar to the graph above, notice how the gradient is decreasing, indicating a lower resistance. There is, however, a health warning:

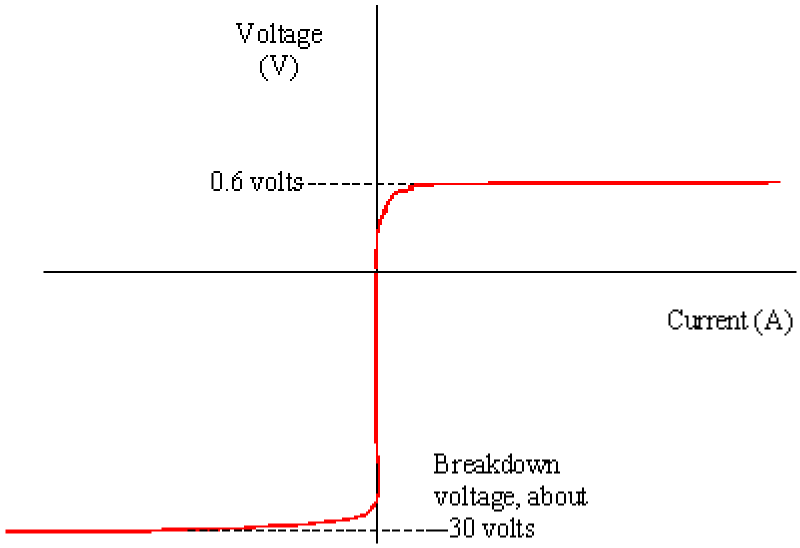
- As the current goes up, the thermistor gets hotter.
- As it gets hotter, it allows more current to flow;
- Therefore it gets hotter and so on.

This is called **thermal runaway**, and is a feature of many semi-conductor components. At the extreme the component will glow red-hot, then split apart. The thermistor is used wherever any electronic circuit detects temperature:Here we see a thermistor protecting a power supply from too high a temperature.

Why does a thermistor not obey Ohm's Law?

Diodes are semi-conductor devices that allow electric current to flow one way only.

The diode characteristic graph looks like this:



Note the way it is presented. However many text books show the graph with the voltage on the horizontal axis and current on the vertical. Watch out for this bear-trap in the exam.

Can you use the graph to explain why a diodes allows a current to flow one way only?

Resistivity

The resistance of a wire depends on three factors:

- the length; double the length, the resistance doubles.
- the area; double the area, the resistance halves.
- the material that the wire is made of.

Resistivity is a property of the material. It is defined as the **resistance of a wire of the material of unit area and unit length.**

First, the total length of the wires will effect the amount of resistance. The longer the wire, the more resistance that there will be. There is a direct relationship between the amount of resistance encountered by charge and the length of wire it must traverse. After all, if resistance occurs as the result of collisions between charge carriers and the atoms of the wire, then there is likely to be more collisions in a longer wire. More collisions means more resistance.

Second, the cross-sectional area of the wires will effect the amount of resistance. Wider wires have a greater cross-sectional area. This can be attributed to the lower amount of resistance which is present in the wider pipe. In the same manner, the wider the wire, the less resistance that there will be to the flow of electric charge. When all other variables are the same, charge will flow at higher rates through wider wires with greater cross-sectional areas than through thinner wires.

A third variable which is known to effect the resistance to charge flow is the material that a wire is made of. Not all materials are created equal in terms of their conductive ability. Some materials are better conductors than others and offer less resistance to the flow of charge. Silver is one of the best conductors, but is never used in wires of household circuits due to its cost. Copper and aluminum are among the least expensive materials with suitable conducting ability to permit their use in wires of household circuits. The conducting ability of a material is often indicated by its **resistivity**. The resistivity of a material is dependent upon the material's electronic structure and its temperature. For most (but not all) materials, resistivity increases with increasing temperature.

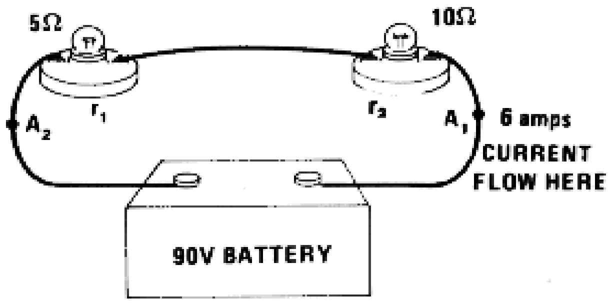
SERIES AND PARALLEL CIRCUITS

What are "series" and "parallel" circuits?

There are two basic ways in which to connect more than two circuit components: *series* and *parallel*. First, an example of a series circuit:

Series DC circuit

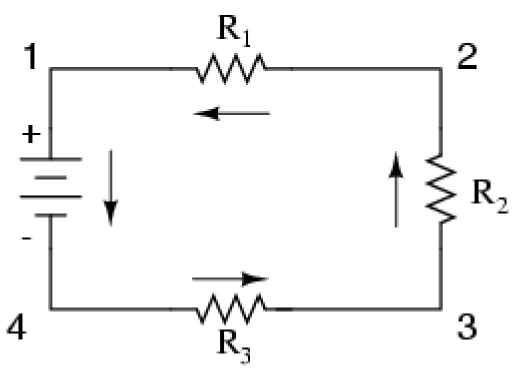
In an electrical circuit, several electrical devices such as light bulbs can be placed in a line or in series in the circuit between the positive and negative poles of the battery. This is called a series circuit.



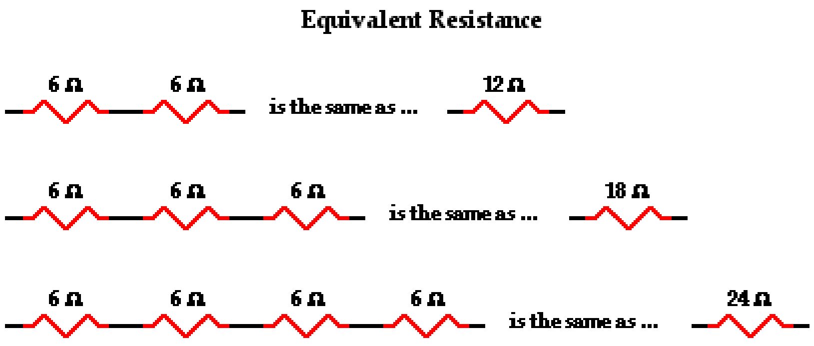
Two light bulbs in a series circuit with a battery

One problem with such an arrangement is if one light bulb burns out, then it acts like a switch and turns off the whole circuit.

Here, we have three resistors (labeled R_1, R_2, and R_3), connected in a long chain from one terminal of the battery to the other. The defining characteristic of a series circuit is that there is only one path for electrons to flow.



Charge flows together through the external circuit at a rate which is everywhere the same. The current is no greater at one location as it is at another location. There is a clear relationship between the resistance of the individual resistors and the overall resistance of the collection of resistors.



Total Resistance of a circuit is the amount of resistance which a single resistor would need in order to equal the overall effect of the collection of resistors which are present in the circuit.

$$R_T = R_1 + R_2 + R_3 + \ldots$$

where R_1, R_2, and R_3 are the resistance values of the individual resistors which are connected in series.

1. **The current in a series circuit is everywhere the same.**
2. **Charge does NOT accumulate at any given location.**
3. **Charge does NOT become used up by resistors.**

Current - the rate at which charge flows - is everywhere the same. It is the same at the first resistor as it is at the last resistor as it is in the battery. Mathematically, one might write

$$I_{battery} = I_1 = I_2 = I_3 = \ldots$$

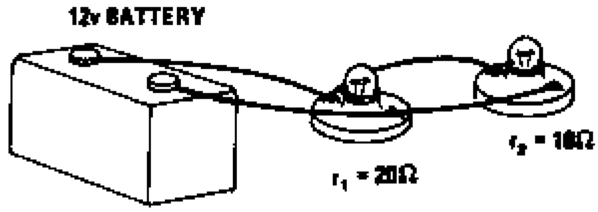
where I_1, I_2, and I_3 are the current values at the individual resistor locations.

In series circuits, the resistor with the greatest resistance has the greatest voltage drop.

Since the current is everywhere the same within a series circuit, the I value of V = I • R is the same in each of the resistors of a series circuit. So the voltage drop (V) will vary with varying resistance. Wherever the resistance is greatest, the voltage drop will be greatest about that resistor.

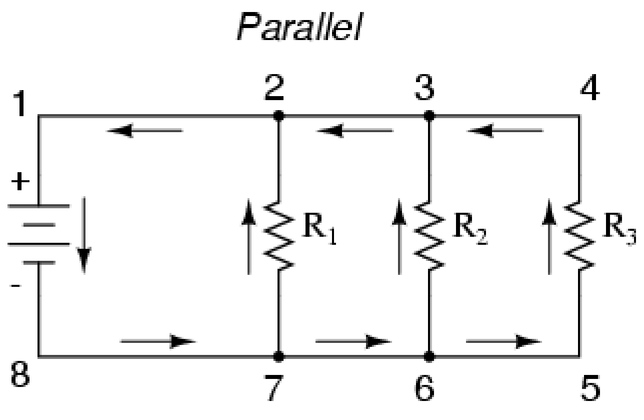
$$\mathbf{V_1 = I \bullet R_1 \quad V_2 = I \bullet R_2 \quad V_3 = I \bullet R_3}$$

<u>Parallel DC circuit</u>



Devices can also arranged in a parallel configuration, such that if any bulbs go out, the circuit is still intact. Not only is a parallel circuit useful for holiday lighting, the electrical wiring in homes is also in parallel. In this way lights and appliances can be turned on and off at will.

<u>Two light bulbs in a parallel circuit</u>



If either light bulb would go out, the other would still shine. You could add other bulbs or even appliances such as electric motors in parallel to this circuit, and they would remain independent of each other.

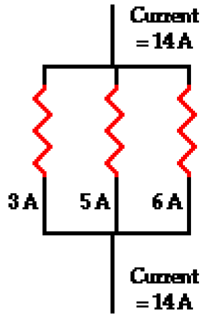
Again, we have three resistors, but this time they form more than one continuous path for electrons to flow. Each individual path (through R_1, R_2, and R_3) is called a *branch*.

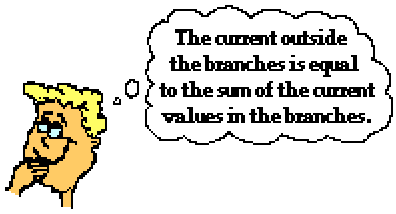
The defining characteristic of a parallel circuit is that all components are connected between the same set of electrically common points.

In a parallel circuit, charge *divides* up into separate branches . Nonetheless, when taken as a whole, the total amount of current in all the branches when added together is the same as the amount of current at locations outside the branches. The current outside the branches is the same as the sum of the current in the individual branches.

In equation form, this principle can be written as

$$I_{total} = I_1 + I_2 + I_3 + \ldots$$

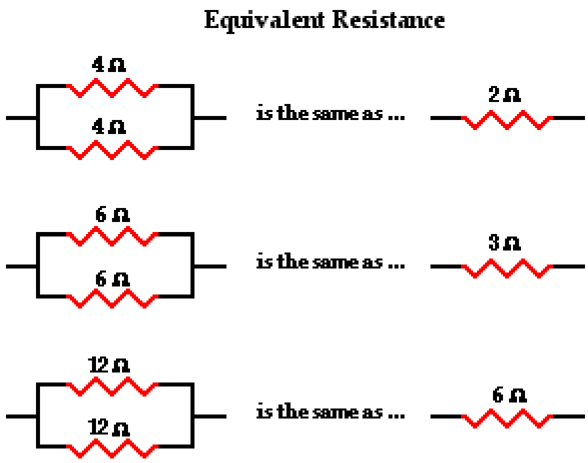




where I_{total} is the total amount of current outside the branches (and through the battery) and I_1, I_2, and I_3 represent the current in the individual branches of the circuit.

Total Resistance

There is a clear relationship between the resistance of the individual resistors and the overall resistance of the collection of resistors.



This method is consistent with the formula

$$1 / R_T = 1 / R_1 + 1 / R_2 + 1 / R_3 + \ldots$$

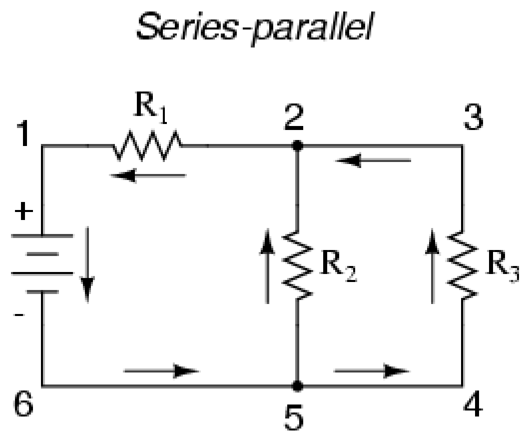
Voltage Drops for Parallel Branches

In a parallel circuit, a charge does not pass through every resistor; rather, it passes through a single resistor. Thus, the entire voltage drop across that resistor must match the battery voltage. It matters not whether the charge passes through resistor 1, resistor 2, or resistor 3, the voltage drop across the resistor which it *chooses* to pass through must equal the voltage of the battery. Put in equation form, this principle would be expressed as

$$\mathbf{V_{battery} = V_1 = V_2 = V_3 = \ldots}$$

If three resistors are placed in parallel branches and powered by a 12-volt battery, then the voltage drop across each one of the three resistors is 12 volts. A charge flowing through the circuit would only encounter one of these three resistors and thus encounter a single voltage drop of 12 volts.

Combination circuits



In this configuration, we'd say that R_2 and R_3 are in parallel with each other, while R_1 is in series with the parallel combination of R_2 and R_3. By applying the total resistance of parallel branches to a combination circuit, the combination circuit can be transformed into a series circuit. Then an understanding of the equivalent resistance of a series circuit can be used to determine the total resistance of the circuit.

Series and parallel resistor configurations have very different electrical properties.

- In a **series circuit**, all components are connected end-to-end, forming a single path for electrons to flow. Current **I** is the same in all resistors while voltage is different across each resistor.(depends on the resistance)

- In a **parallel circuit**, all components are connected across each other, forming exactly two sets of electrically common points. The voltage drop is the same across all resistors while the current is different in each resistor (depends on resistance)

- A "branch" in a parallel circuit is a path for electric current formed by one of the load components (such as a resistor).