## Electricity Basics.

## Fundamental Terms

Electricity is caused by a property of matter known as CHARGE.
Charge is measured in COULOMBS. (C) and is usually given the symbol Q .
The smallest amount of charge that can occur is that carried by an ELECTRON.
For historical reasons, the charge carried by an electron is said to be negative and is equal to $-1.6 \times 10^{-19} \mathrm{C}$.

All of electricity can be explained in terms of the behaviour of electrons.
It is helpful to have a mental image of an electron. This can be anything you like!
E.g.


When electrons move, an electric current is produced which is measured in AMPs by an AMMETER.
Electric current is given the symbol I (Intensite du courant).
Electric current can be thought of as the number of electrons per second moving past a point.
Electric current is defined as the charge moved divided by the time taken (in seconds).

$$
\text { Current }=\frac{\text { Charg e }}{\text { time }} \quad \Rightarrow \mathrm{I}=\frac{\mathrm{Q}}{\mathrm{t}} \quad \Rightarrow \text { So } 1 \mathrm{Amp}=1 \text { Coulomb per second }
$$

(Current is the rate of change of charge. $I=\Delta Q / \Delta t$.).
To measure a current the ammeter has to be connected so that the current has to flow THROUGH the ammeter, as if to count the electrons.
It has to be connected in SERIES.
Energy is measured in JOULES and is given the symbol W.
Electrons will only move when they can lose (or gain) energy.
Therefore electrons can only move when there is an energy difference to where they are moving.
I.E, there is a POTENTIAL DIFFERENCE (PD) in their energy.

PD is measured in VOLTS and is often called VOLTAGE.
It is given the symbol V.
PD is measured by a VOLTMETER and is connected ACROSS the circuit so as to measure the energy each electron has.
It has to be connected in PARALLEL.

PD is defined as the energy lost divided by the charge that has moved.

$$
\mathrm{PD}=\frac{\text { Energy }}{\mathrm{Ch} \text { arge }} \quad \Rightarrow \mathrm{V}=\frac{\mathrm{W}}{\mathrm{Q}} \quad \Rightarrow \text { So } 1 \text { Volt }=1 \text { Joule per Coulomb }
$$

(The energy that each electron has!)
( PD is the energy change per unit charge $\mathrm{V}=\Delta \mathrm{W} / \Delta \mathrm{Q}$ ).
An electric current can ONLY flow around a circuit when the electrons have energy, i.e., when there is a potential difference.

Electrons are NEVER LOST in a circuit. All of the electrons that start to flow around a circuit from a battery end up entering the other side of the battery. Charge is always conserved.
(This is sometimes called Kirchhoff's first Law)
Electrons do lose (gain) energy by the work that they do in going through the various parts of the circuit. The total energy lost cannot be greater than the energy they start with. Energy is always conserved. (This is sometimes called Kirchhoff's second law.)

Any part of the circuit that causes electrons to lose energy is said to have RESISTANCE.

## Circuit Symbols

Electrical components have many different shapes and sizes. To simplify drawing circuit diagrams, each component is given a circuit symbol.
Some common ones are shown below.
(If the circuit symbol is not known, then a rectangular labelled box is used)


## Basic circuits

Many of the rules for basic circuits were developed in the early part of the 19th century (1800 1850). It was realised that 'something' moved in an electric circuit and it was defined that this 'something' moved from POSITIVE to NEGATIVE.
It was not until 1897 that the 'something' was discovered to be electrons and that, having a negative charge, actually moved from negative to positive!
To save rewriting all of the rules, it was decided to keep CONVENTIONAL CURRENT as moving from POSITIVE to NEGATIVE, and modern electric and electronic circuits still retain this convention. Conventional current is usually just referred to as CURRENT.

An electric circuit must enable the electrons to have a complete path to move from the source of energy and return to the energy source, e.g. a lamp connected to a battery.


To measure the current in the circuit, an ammeter must be placed so that all of the electrons pass THROUGH the AMMETER. Since electrons are not lost in the circuit, an ammeter placed after the lamp will have exactly the same reading.


BEWARE. An ammeter has a very small resistance so that the electrons lose little energy when passing through. If an ammeter is connected across the lamp, then a very large current may pass, damaging the ammeter, the battery ((and possibly you!)

To measure the energy lost by electrons (the PD) across part of the circuit, a voltmeter must be placed across that part.


A voltmeter has a very large resistance so that only a few electrons are needed to measure the energy available.

If a voltmeter is connected into the circuit like an ammeter, then the voltmeter will give an incorrect reading and the circuit will not work.

## Series and Parallel

## Series circuits

In a series circuit, all of the electrons pass through each of the components.


Therefore the current is the same in each component.
An ammeter connected anywhere in the circuit will read the same value.


However, the electrons use some of their energy in each component.
Therefore the PD available from the battery is shared by the components.


Voltmeter V will show a value that is equal to sum of the values shown by voltmeter 1 and voltmeter 2.

$$
\Rightarrow V=V_{1}+V_{2}
$$

## Parallel circuits

In a parallel circuit, some of the electrons pass through one of the components while other electrons pass through the others.
Therefore the current in each component can be different.
Each lamp is effectively connected directly to the battery.
Therefore the electrons use the same energy in each component.
Therefore the PD across each component is the same.


Ammeter A shows a value that is equal to sum of the values shown by ammeter 1 and ammeter 2 .


$$
\Rightarrow A=A_{1}+A_{2}
$$

In the following circuits, all of the lamps are identical.
A single lamp connected to the battery lights with full brightness.
Describe the brightness of each lamp in the following circuits.
1).

3).

2).

4).


## Resistance

Any part of the circuit that causes electrons to lose energy is said to have RESISTANCE.
In 1827, Georg Ohm investigated how the current through a thin wire varied with the potential difference (PD) across the wire.
He found that, so long as the temperature of the wire was constant then

$$
\frac{\mathrm{PD}}{\mathrm{current}}=\text { cons } \tan \mathrm{t}=\text { RESISTANCE } \quad \Rightarrow \frac{\mathrm{V}}{\mathrm{I}}=\mathrm{R}
$$

## This is known as Ohm's Law

Resistance is measured in OHMS which have the symbol $\Omega$

$$
1 \mathrm{ohm}=1 \text { volt per amp }
$$

Ohm's Law is the main rule in electricity and electronics. It is a very simple rule, but is often incorrectly used.
It is essential that the resistance of a component (or circuit) is calculated by using the PD ACROSS the component or circuit divided by the current THROUGH the component.

$$
\mathrm{R}=\frac{\mathrm{V}}{\mathrm{I}} \Rightarrow \mathrm{I}=\frac{\mathrm{V}}{\mathrm{R}} \Rightarrow \mathrm{~V}=\mathrm{IR}
$$

## Resistors

Resistors are components that have a specified resistance and are available in values from less than $1 \mathrm{~m} \Omega$ up to more than $100 \mathrm{M} \Omega$. The symbol for a resistor is:


Resistors are made from a variety of materials including wire, carbon and metal oxides. They are designed to have only a very small change in value with changes in temperature.

## Resistors in series



The battery PD is V. The PD across $\mathrm{R}_{1}$ is $\mathrm{V}_{1}$, PD across $\mathrm{R}_{2}$ is $\mathrm{V}_{2}$ and $P D$ across $\mathrm{R}_{3}$ is $\mathrm{V}_{3}$. Since energy is always conserved

$$
\Rightarrow \mathrm{V}=\mathrm{V}_{1}+\mathrm{V}_{2}+\mathrm{V}_{3}
$$

The same current, I, passes through each resistor.
If the total resistance of the circuit is $\mathrm{R}_{\mathrm{T}}$, then using Ohm's Law

$$
\Rightarrow \mathrm{IR}_{\mathrm{T}}=\mathrm{IR}_{1}+\mathrm{IR}_{2}+\mathrm{IR}_{3}
$$

Dividing by I

$$
\Rightarrow \mathbf{R}_{\mathbf{T}}=\mathbf{R}_{\mathbf{1}}+\mathbf{R}_{\mathbf{2}}+\mathbf{R}_{\mathbf{3}}
$$

For resistors in series, the total resistance is ALWAYS greater than any individual resistance.
So for resistors in series, the total resistance is the sum of the individual resistances.

## Resistors in parallel



The battery PD is V. This is the PD across each resistor.
The current through $R_{1}$ is $I_{1}$, current through $R_{2}$ is $I_{2}$ and the current $R_{3}$ is $I_{3}$.
Since charge is always conserved

$$
\Rightarrow \mathrm{I}_{\mathrm{T}}=\mathrm{I}_{1}+\mathrm{I}_{2}+\mathrm{I}_{3}
$$

If the total resistance of the circuit is $\mathrm{R}_{\mathrm{T}}$, then using Ohm's Law

$$
\frac{\mathrm{V}}{\mathrm{R}_{\mathrm{T}}}=\frac{\mathrm{V}}{\mathrm{R}_{1}}+\frac{\mathrm{V}}{\mathrm{R}_{2}}+\frac{\mathrm{V}}{\mathrm{R}_{3}}
$$

Dividing by V

$$
\frac{1}{\mathrm{R}_{\mathrm{T}}}=\frac{1}{\mathrm{R}_{1}}+\frac{1}{\mathrm{R}_{2}}+\frac{1}{\mathrm{R}_{3}}
$$

For resistors in parallel, the total resistance is ALWAYS less than any individual resistance. While this looks a complicated formula it is relatively easy to use with the $1 / x$ button on a calculator.
The usual error made is to forget to find the final reciprocal!

## Real circuits

Seldom are real circuits all series or all parallel. They are usually a mixture! Consider this circuit.


Examining the circuit reveals that $\mathrm{R}_{1}$ and $\mathrm{R}_{2}$ are directly in parallel, and so the parallel resistor formula can be used to find their total resistance, $\mathrm{R}_{\mathrm{P}}$.
The circuit can then be redrawn as


The circuit is now just a series circuit and the total resistance can be found using the series resistor formula.

Consider the following circuits:
how would you calculate the total resistance of the circuit?
1).

2).

$3)$.

4).

5).


## Electrical energy and power.

Consider a battery connected to a lamp.


When electrons move through the lamp, they lose energy, and the energy is converted to light and heat.
The total energy lost by the electrons is equal to
the energy lost by each electron $\times$ the number of electrons

$$
\begin{gathered}
=>\text { Energy lost }=\mathrm{PD} \times \text { electrical charge } \\
=>\mathbf{W}=\mathbf{V} \mathbf{Q}
\end{gathered}
$$

Measuring electric charge is difficult, but charge $=$ current $\times$ time

$$
Q=I t
$$

=> W = V I t
where W is in Joules, V is in volts, I is in amps and t is in seconds
Power, P , is defined as energy change per second or the rate of energy change.
So Power $=$ Energy change $/$ time $\Rightarrow P=W / t \quad \Rightarrow P=V I$

$$
\text { => Electric power, } \mathrm{P}=\mathrm{V} \mathrm{I}
$$

where P is in watts, V is in volts, I is in amps.
Since electrical power, $\mathrm{P}=\mathrm{V}$ I, electrical energy, $\mathrm{W}=\mathrm{V}$ It can be written as $\mathrm{W}=\mathrm{Pt}$.
This is useful for the commercial unit of electrical energy, the kilowatt hour (kWh)
A kilowatt of electricity costs approximately 20 p for domestic users.
The kilowatt hour is defined as a 1000 watts for 1 hour

$$
\begin{gathered}
=>1 \mathrm{kWh}=1000 \times 3600=3,600,000 \mathrm{~J}=3.6 \mathrm{MJ} \\
=>\mathbf{1 k W h}=\mathbf{3 . 6 M J}
\end{gathered}
$$

