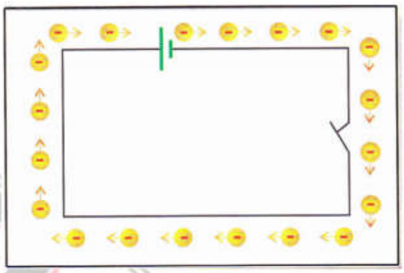
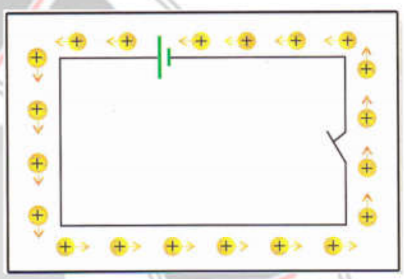
Unit (1): Dynamic electricity & Electromagnetism

Chapter 1: Electric Current & Ohm's Law

- **Introduction:**





- **The electron current direction:** The electric current through a conductor has been described as **the movement of electrons from its negative terminal to its positive terminal.**

- **The conventional (traditional) current direction:** The electric current was assumed to be composed of positive charges that the movement from the positive to the negative terminal of a conductor, It is opposite to the direction of motion of electrons.

- ***Some Basic Concepts of electricity***

➢ ***Definition***

The electric current intensity (I):

It is the quantity of charges passed through a given cross section in one second.

$$\boxed{I = \frac{Q}{t}}$$ (Coulomb/Second or Ampere)

Calculating number of charges (electrons):

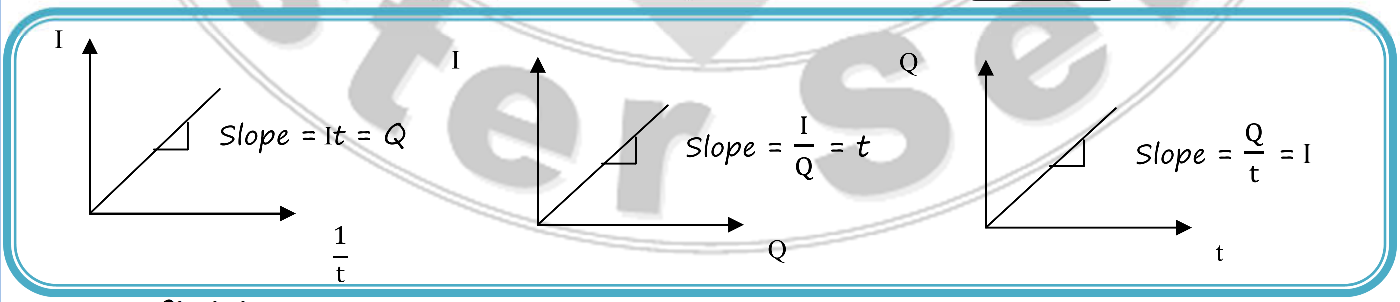
$$\boxed{Q = n \times e^-}$$

Where: Q: is quantity of charges.

n: is the number of charges (electrons).

e^-: is electron charge (1.6×10^{-19} C).

$$\boxed{n = \frac{Q}{e^-}}$$



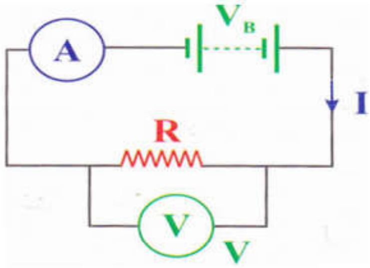
➢ ***Definition***

- The potential difference (V):

It is the work done to transfer unit of charge between two terminals of a conductor.

$$\boxed{V = \frac{W}{Q}}$$ (Joule/Coulomb or Volt)

➢ Definition



– The electromotive force of a source (e.m.f):

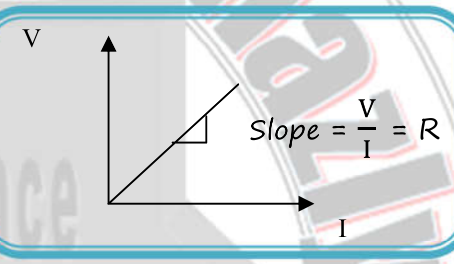
It is the total work done to transfer unit of charge throughout the whole electric circuit outside and inside the source.

➢ Definition

– Ohm's Law:

The current intensity in a conductor is directly proportional to the potential difference across its terminals at a constant temperature.

$\boxed{V = IR}$ Constant Temperature.



➢ Definition

– Resistance of material (R):

It is opposition to the flow of the electric current.

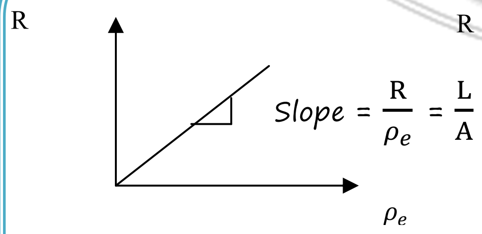
$\boxed{R = \frac{V}{I}}$ (Volt/Ampere or Ohm or Ω)

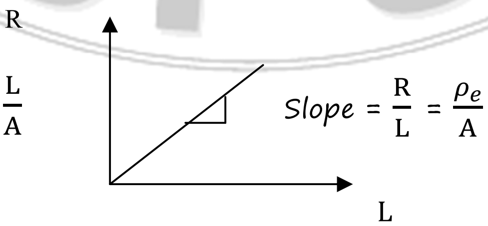
- **Factors affecting on resistance (R) at constant temperature:**

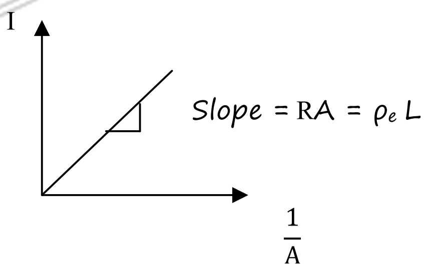
1. Resistivity of material ($R \propto \rho_e$).
2. Length of conductor ($R \propto L$).
3. Cross-sectional area ($R \propto \frac{1}{A}$).

$\boxed{R = \rho_e \frac{L}{A}}$ $\boxed{\rho_e = R \frac{A}{L}}$ (Ω.m)

$\boxed{R = \rho_e \rho \frac{L^2}{m}}$







Definition

- Resistivity of a material (ρ_e):

It is numerically equal to the resistance of a piece of material of length one meter and cross-sectional area 1 m^2.

Definition

- Conductivity of a material: (σ)

It is the reciprocal of the resistivity.

$$\boxed{\sigma = \frac{1}{\rho_e}}$$

($\Omega^{-1}.m^{-1}$ or Simon)

- G.R.F.: When the length of a wire increases its resistance also increases.

$R = \rho_e \frac{L}{A}$, resistance of wire is directly proportional with its length.

- G.R.F.: The electrical conductivity of copper is high.

Because $\sigma = \frac{1}{\rho_e}$, the resistivity of copper material is very low.

✓ Connecting resistors

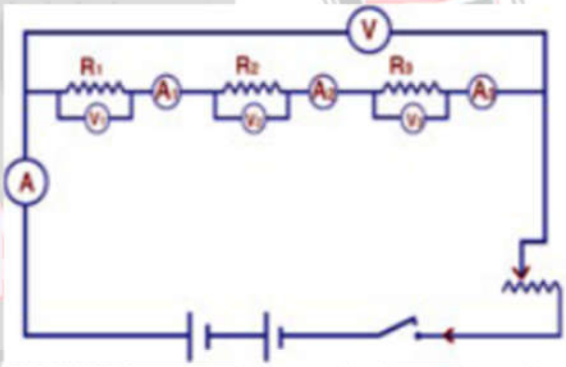
Firstly: series connection

Resistors are connected in series **to obtain a higher resistance**. The equivalent resistance of a group of resistors connected in series can be obtained in connecting these resistors in an electric circuit comprising a battery, an ammeter, a rheostat (variable resistor) and a switch. The circuit is closed and the rheostat is adjusted so that an appropriate current I is passed. The voltage difference across each resistor is measured (V_1 across R_1, V_2 across R_2, V_3 across R_3).

➢ **Definition**

- **Kirchhoff's law:** The total voltage (V_T), which is equal to the sum of the voltage differences across the resistors in the series circuit.

- **Proof**



$V_T = V_1 + V_2 + V_3$ $I_T = I_1 = I_2 = I_3$

But ... $V = IR$

$V_1 = IR_1$

$V_2 = IR_2$

$V_3 = IR_3$

$IR_T = IR_1 + IR_2 + IR_3$

$$\boxed{R_T = R_1 + R_2 + R_3}$$

Thus, the equivalent resistance R_T of a group of resistors connected in series equals the sum of these resistances. It is to be noted that the largest resistance in the combination determines the total resistance in a series connection. If N resistances are connected in series each equal r then:

$$\boxed{R = Nr}$$

We conclude that if we want a large resistance out of a bunch of small resistances, we simply connect them in series.

- **G.R.F.: We connect resistors in series connection in an electric circuit.**

To obtain a large resistance out of a bunch of small resistances.

Ex.: If three resistors are connected in series, their values are $R_1 = 2\ \Omega$, $R_2 = 3\ \Omega$, $R_3 = 6\ \Omega$. Calculate the total resistance.

$R_T = R_1 + R_2 + R_3$ $R_T = 2 + 3 + 6$ $R_T = 11\ \Omega$.

✓ Secondly: Parallel connection

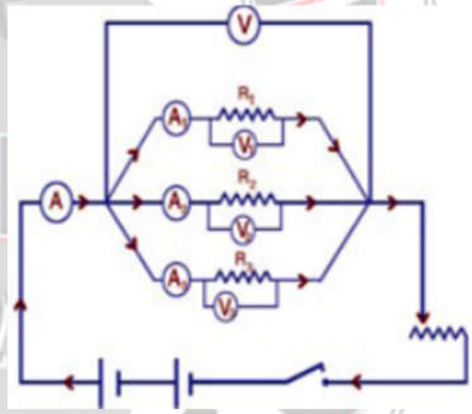
The purpose of connecting resistors in parallel is **to obtain a small resistance out of a bunch of large resistances.** To obtain the equivalent resistance for a parallel connection, the combination is included in an electric circuit comprising a battery, an ammeter and a rheostat all connected.

We close the circuit and adjust the rheostat to obtain an appropriate current in the main circuit of intensity I, which can be measured by the ammeter. The total voltage difference can be measured across the terminals of the resistances by a voltmeter (V). The current in each branch is measured (I_1 in R_1, I_2 in R_2, and I_3 in R_3).

In a parallel connection, the total current is determined by the smallest resistance. This case is similar to the flow of water in pipes.

The smallest pipe (the highest resistance) determines the flow rate in a series connection, while the widest pipe (the least resistance) determines the rate of flow in a parallel connection, since it draws most of the water current.

- **Proof**



$V = V_1 = V_2 = V_3$

$I_T = I_1 + I_2 + I_3$

$I_T = \frac{V}{R_T}, \quad I_1 = \frac{V}{R_1}, \quad I_2 = \frac{V}{R_2}, \quad I_3 = \frac{V}{R_3}$

$$\frac{V}{R_T} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

$$\boxed{\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}}$$

When N resistances are connected in parallel each equal to r.

$$\frac{1}{R_T} = \frac{N}{R_1}$$

$$\boxed{R_T = \frac{r}{N}}$$

Therefore, if we wish to obtain a small resistance out of a bunch of resistors, we simply connect them in parallel.

➢ **Note:**

In the case of two resistors in parallel, the equivalent resistance (R_T) is given by:

$$\boxed{R_T = \frac{R_1 x R_2}{R_1 + R_2}}$$

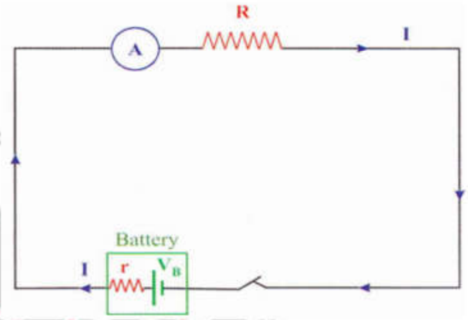
- G.R.F.: We connect resistors in parallel connection in an electric circuit.

To obtain a small resistance out of a bunch of large resistances.

✓ Ohm's Law for a closed circuit

We know that the e.m.f of an electric cell (battery – source) is the total work done inside and outside the cell to transfer an electric charge of 1C in the electric circuit.

If we denote the e.m.f of a battery by V_B, the total current in the circuit by I, the external resistance by R and the internal resistance of the cell by r, then:



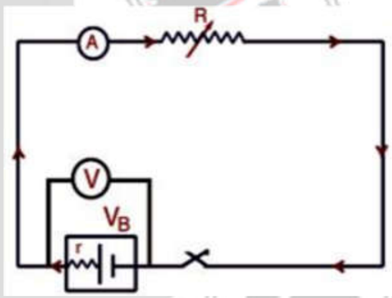
$V_B = IR + Ir$

$V_B = I(R + r)$

$$\boxed{I = \frac{V_B}{R+r}}$$

This is known as Ohm's law for a closed circuit, from which we find that the current intensity in a closed circuit is the e.m.f of the total source divided by the total (external plus internal) resistance of the circuit.

- **Relation between e.m.f and voltage across a source:**



$V = V_B - Ir$

From this relation, we see that as I is decreased gradually in the circuit, by increasing the external resistance R, the voltage difference across the source increases.

When the current vanishes, the voltage difference across the source becomes equal to the e.m.f of the source. Hence, we may define the e.m.f of a source as the voltage difference across it when the current ceases to flow in the circuit.

➢ **Note:**

- Terminal voltage of a battery equals e.m.f of a battery ($V = V_B$) when:

1) r = 0 (If internal resistance equal zero).

2) I = 0 (If no current flows in circuit or open circuit).

- In series connection, to know an unknown potential difference at one resistor:

$V_1 = \frac{R_1}{(R_1+R_2)} \times V_T$ $\qquad$ $V_2 = \frac{R_2}{(R_1+R_2)} \times V_T$

- In parallel connection, to know an unknown current intensity at one resistor:

$I_1 = \frac{R_2}{(R_1+R_2)} \times I_T$ $\qquad$ $I_2 = \frac{R_1}{(R_1+R_2)} \times I_T$

- G.R.F.: If the electric circuit is switched off, the potential difference between the two poles of electric source equals its e.m.f.

$V = V_B - Ir$, when circuit is switched off $I = 0$, so $V = V_B$.

- G.R.F.: Efficiency of the battery increases by decrease of its internal resistance.

$V = V_B - Ir$, as we decrease the internal source (r), the voltage difference across the source (V) a broach to the e.m.f of the source (V_B).

✓ Electric Power (P_w) and Electric energy(W)

$$\boxed{P_w = VI = I^2R = \frac{V^2}{R}}$$ (Watt).

$$\boxed{W = P_w \times t}$$ (Watt.Sec. or Joule).

K.Watt. h = 3.6×10^6 J.

- G.R.F.: The home electrical devices are not connected in series.

Because when connected in parallel, the current is divided on them, so when current is cut off in on device, the other devices are still working, and do not be affected. Also parallel connection decreases the total resistance.

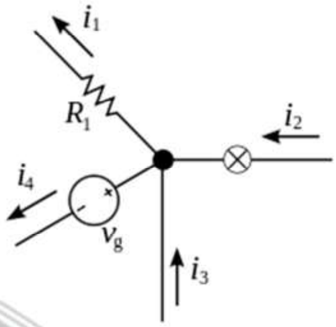
- G.R.F.: If the filament of a lamp in the house is cut off, the other lamps still lighten.

Because the lamps in the house are connected in parallel so the current flowing in each is different and if one of them is cutoff the others will be working.

G.R.F.: When the total power of the electrical instruments used in houses exceeds a certain value the electric current intensity flowing through the fuse increases.

Because the power ($P_w = IV$) and since the voltage of the electrical instruments in houses are constant so the total power is directly proportional to the current intensity.

- ## Kirchhoff's first law Or Kirchhoff's current law (KCL):



-The current entering any junction is equal to the current leaving that junction. $i_2 + i_3 = i_1 + i_4$

This law is also called Kirchhoff's first law, Kirchhoff's point rule, or Kirchhoff's junction rule (or nodal rule).

-The principle of conservation of electric charge states that:

At any node (junction) in an electrical circuit, the sum of currents flowing into that node is equal to the sum of currents flowing out of that node.

Or

The algebraic sum of currents at a point in closed circuit is zero.

That means: $i_2 + i_3 + i_1 + i_4 =$ **zero**, $\Sigma I =$ **zero.**

- ## Kirchhoff's second law Kirchhoff's voltage law (KVL):

-The sum of all the voltages around the loop is equal to zero.

$V_2 + V_3 + V_1 + V_4 =$ **zero**, $V = IR$.

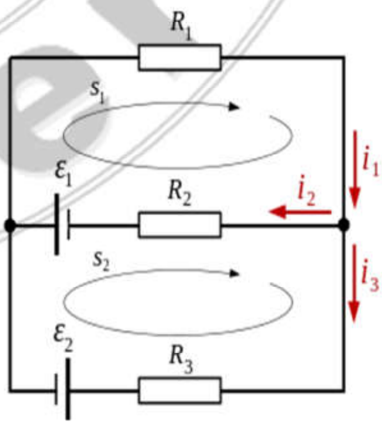
This law is also called Kirchhoff's second law, Kirchhoff's loop (or mesh) rule.

-The principle of conservation of energy states that:

The directed sum of the electrical potential differences (voltage) around any closed network is zero.

Or

The algebraic sum of electromotive force in closed circuit equal to the algebraic sum of potential difference in circuit.



Example:

According to the first law we have

. $I_1 - I_2 - I_3 = 0$

The second law applied to the closed circuit (1) gives

. $R_2I_2 + \varepsilon_1 - R_1I_1 = 0$

The second law applied to the closed circuit (2) gives

. $R_3I_3 - \varepsilon_2 - \varepsilon_1 + R_2I_2 = 0$