Chapter: Electricity

- **Electricity** → Its simply related to the study of charges in two forms (i) Static Electricity.
  (ii) Current Electricity.

(i) Static electricity: when we study charges at rest, sometimes it is also called as electrostatics.

(ii) Current Electricity: Study of charges when they are in motion.

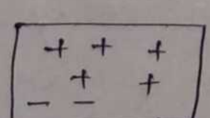
* Basics of electric charge

- Electric charge is the property of particle because of which it attract other charge particles and the force by which these particles attracts or repels called as force of electricity or simply electric force.

- Charges is of two types → (+) Positive charge (eg. protons).
  (−) Negative charge (eg. electrons).

- Properties of charges
  - likes charges repels each other eg F ←⊕ ⊕→ F
  - ~~Unlike~~ Unlike charges attract each other. ⊖→ ←⊕
  - To calculate net amount of charge on a body we apply algebraic addition of charges, this net amount of charge also defines whether the body is +ve, −ve, neutral in nature.

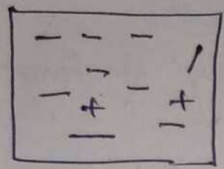
eg. Find the nature of the following bodies.

(i) 

$\Rightarrow (+5q) + (-2q) \Rightarrow +3q$ → body is +ve.

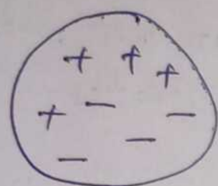
let $+q$ signifies ⇒ +ve charge and $-q$ = −ve charge.

(ii)



$\Rightarrow (-8q) + (+2q) \Rightarrow -6q$ → hence −ve ∴ body is negative in nature

(iii)



$\Rightarrow (+4q) + (-4q) = 0 \Rightarrow$ Neutral body.

Note: ① if body is +ve → means → +ve charge dominates.

② if body is −ve → means → −ve charge dominates.

③ if body neutral → means → body has EQUAL no of +ve and −ve charges.

- S.I unit of charge ⇒ Coulomb (C)
- Smallest possible charge ⇒ $+1.6 \times 10^{-19}$ C (for proton).
  -1.6×10^{-19} C (for electron).

Note: For any charge q (let) indicating total charge on a body it must be

$$\boxed{q = ne}$$

- q → Total charges
- n → integral multiple (1, 2, 3, - - -)
- e → (charge on each electron)

Note: Protons are well seated inside the nucleus of an atom. They cannot be easily removed from or added to the nucleus of an atom.

we only deal with electrons for getting a negative as well as positive ions. The excess electrons makes an object negative and deficit of electrons make it positive.

Q= How many electrons will be there in one coulomb of charge?

Sol: charge on one electron, $e = 1.6 \times 10^{-19}$ C [No need to write -ve sign]

$\because q = ne \Rightarrow n = \frac{q}{e}$

$\therefore n = \frac{1}{1.6 \times 10^{-19}} \Rightarrow \frac{1 \times 10^{19}}{1.6} = \frac{1 \times \cancel{100}^{25} \times \cancel{100}^{25} \times 10 \times 10^{15}}{\cancel{16}_{4}}$

$n = 625 \times 10 \times 10^{15}$

$\boxed{n = 6.25 \times 10^{18}}$ electrons

Note: Practical units of charge

micro → $1 \mu C = 10^{-6}$ C

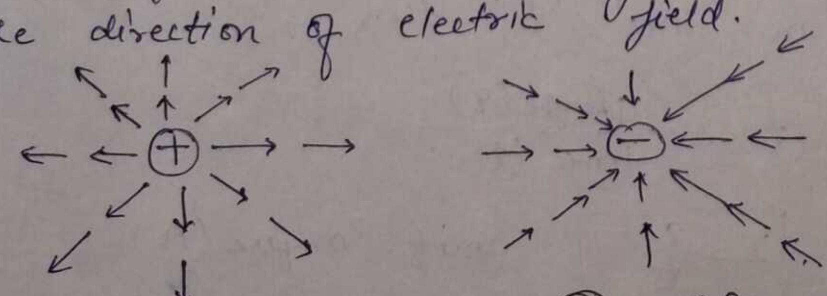
nano → $1 nC = 10^{-9}$ C

pico → $1 pC = 10^{-12}$ C

* Concept of Electric field:

- Electric field is a region created by a charge around it, in which other charge experiences electric force.
- Electric field is represented by lines and arrowheads indicating the direction of electric field.

eg:



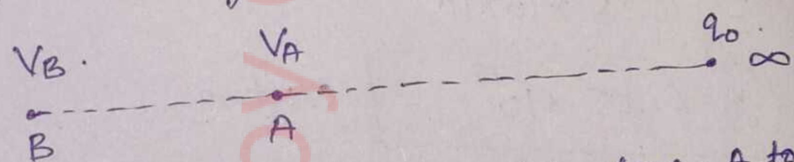
for +ve charge (for -ve charge)

* **Electric Potential** ⇒ It is the work done per unit charge in bringing the charge from infinity to that point against electrostatic force.

$$V = \frac{W}{Q}$$

where,
V = Electric potential (Volt).
W = work done (joule).
Q = charge (coulomb).

* **Electric Potential difference**: It is defined as the amount of work done to carrying a unit charge from one point to another in an electric field. It is also called as Voltage.



$$V = V_B - V_A = \frac{W}{q_0}$$

W → Work done. A to B.
q_0 → +ve charge (unit charge).
V_B → Electric potential at (B)
V_A → Electric potential at (A)

Q = Define 1 Volt (do yourself).

* **Electric current** The rate of flow of charge is known as electric current. It is denoted by I.

if 'q' is net charge passing through any cross-section of a conductor in time 't' then

$$\text{Current } (I) = \frac{\text{charge } (q)}{\text{time } (t)}$$

$$I = \frac{q}{t}$$ unit: ampere (A)

Q= Define one Ampere (Do by yourself).

* Conductors: Those substances which conduct electricity easily are called conductors

(OR)

Those material which has plenty number of free electrons which can participate in the flow of current can be considered as conductors.

eg. All metals, silver, gold etc.

* Insulators: Those substances which do not conducts electricity are called insulators.

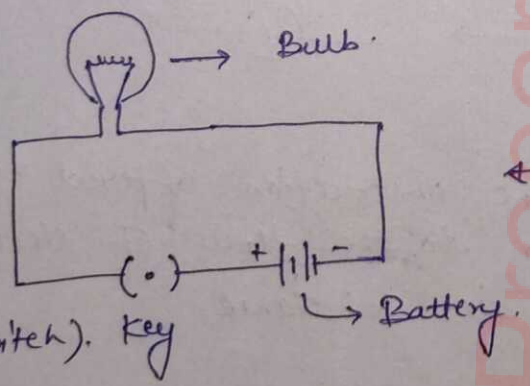
(OR)

Material having negligible amount of free electrons.

eg. wood, paper, mica etc.

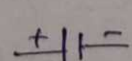
* Electric circuit ⇒ A circuit is a close electrical path in which current can flow.

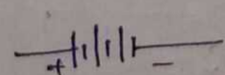
*eg

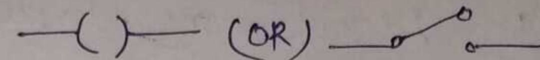


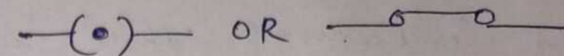
← example of electrical circuit.

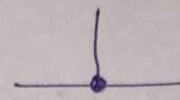
Symbol of some commonly used components in circuit diagrams.

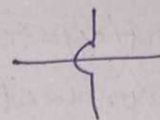
(1.) An electric cell 

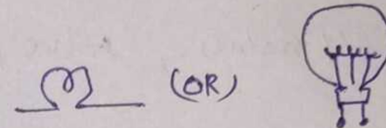
(2) A battery 

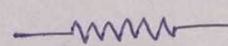
(3) Plug key or Switch (open) OFF condition → 

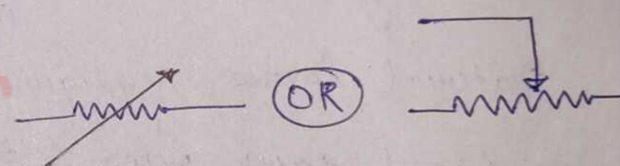
(4) Plug key or switch (closed) ONN condition → 

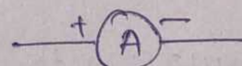
(5) A wire joint → 

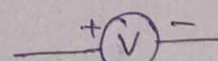
(6) Wires crossing without joining → 

(7) Electric Bulb → 

(8) A resistor of Resistance R → 

(9) Variable resistance or Rheostat → 

(10) Ammeter → 

(11.) Voltmeter → 

* Electrical Resistance: The obstruction offered by a conductor to the flow of electric current (flow of electrons) is called its resistance.

unit: ohm Ω

* Electrical Conductance: It is a measure of ease with which a charge can flow in a conductor.

$$G = \frac{1}{R}$$ unit ohm^{-1} or siemen.

R → Resistance (Ω).

* **Electrical Conductivity (σ)** The reciprocal of resistivity is called conductivity.

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

unit ⇒ mho/metre
(OR)
siemen/metre.

σ = electrical conductivity
ρ = Resistivity

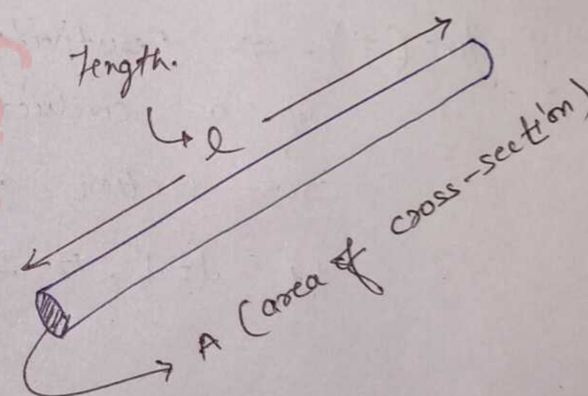
* **Factors affecting electrical Resistance (R)**

① Resistance of a conductor is directly proportional to its length.

$$R \propto l$$

② Resistance of a conductor is inversely proportional to its area of cross-section

$$R \propto \frac{1}{A}$$



Combining ① and ②

$$R \propto \frac{l}{A}$$

$$\boxed{R = \frac{\rho l}{A}}$$

where,
R = Resistance of conductor Ω
ρ = Resistivity
l = length (m)
A = cross-sectional area (m^2)

* Specific Resistance of a conductor or Resistivity (ρ)

we have seen $R = \frac{\rho l}{A}$ ($\rho \rightarrow$ pronounced as Rho)

$$\therefore \rho = \frac{RA}{l}.$$

here, constant ρ is called specific resistance or resistivity of a given material (conductor). like copper, alluminium etc.

- ρ is the characteristic property of conducting material
- ρ is independent of the size and shape of conductor. (but mathematically it is observed that it depend upon R, A and l but its not true).

Define (ρ). ⇒ Resistivity can be defined as the resistance of a conducting material having unit area of cross-section and unit length.

let $l = 1$, $A = 1$ $\therefore \rho = \frac{R(1)}{(1)}$

$$\boxed{\rho = R}$$

unit:

$$\rho = \frac{(\text{unit of } R) \times (\text{unit of } A)}{(\text{unit of } l)}$$

$$= \frac{\text{ohm} \times (\text{metre})^2}{(\text{metre})}$$

$$\rho = (\text{ohm})(\text{metre})$$

$$\rho = \Omega\text{-}m.$$

*. **OHM's Law** ⇒ It states that, the potential difference (V) applied between the ends of a conductor bears a constant ratio with the electric current (I) flowing through it, provided that physical condition of conductor remains same (area, length, temp etc)

Derivation:-

according to ohm's law

$$I \propto V$$

or, $\frac{V}{I}$ = constant → (This constant is Resistance of conductor (R))

$$\frac{V}{I} = R$$

$\therefore$ $\boxed{V = IR}$

- V → Voltage (V) (Volts)
- I → current (I) (amperes, A)
- R → Resistance R (in Ω).

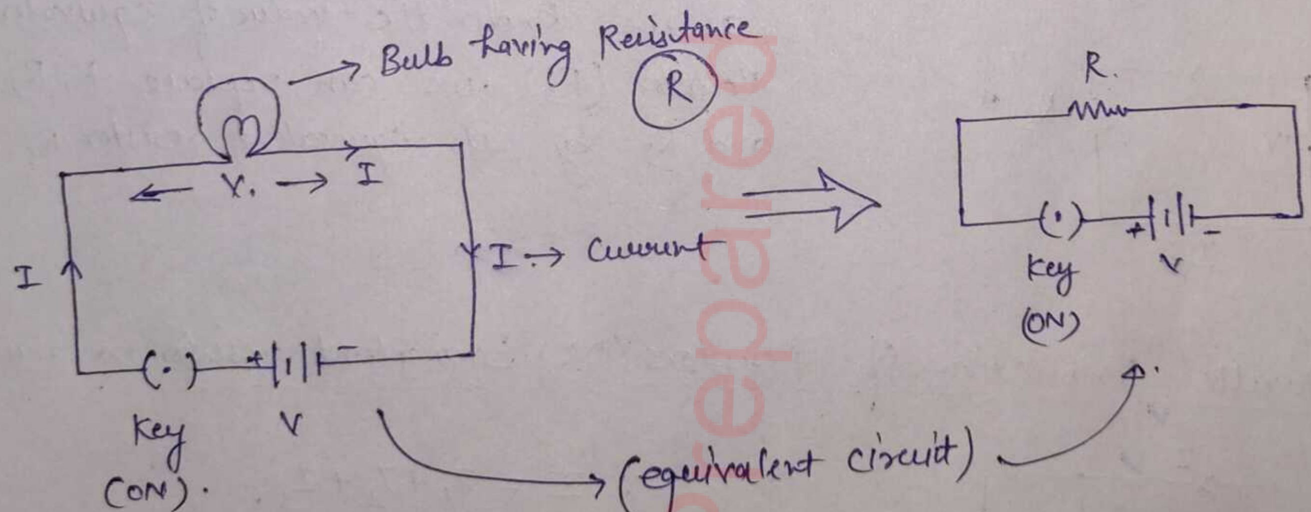
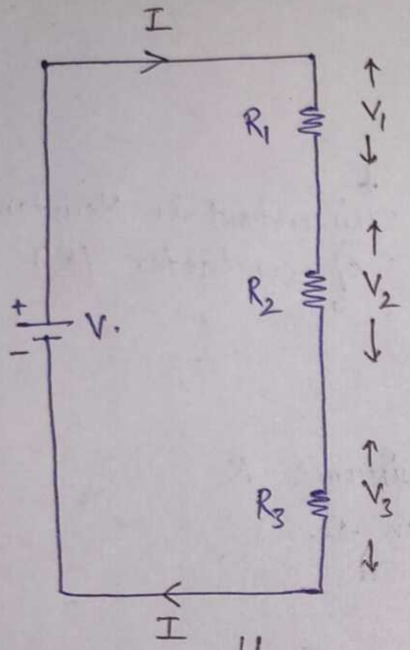


Fig: showing flow of current in circuit following ohm's law.

* Resistance of a system of "Resistors"

(a) Series connection. (b) parallel connection.

(a) Series connection of Resistors (OR) Equivalent resistor in series.



$\because \quad V = V_1 + V_2 + V_3$

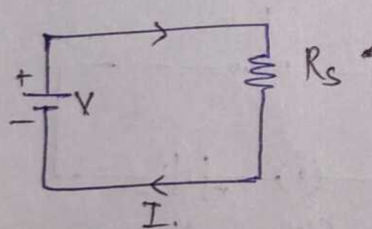
$V = IR_1 + IR_2 + IR_3.$

$\cancel{I} R_s = \cancel{I}(R_1 + R_2 + R_3)$

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

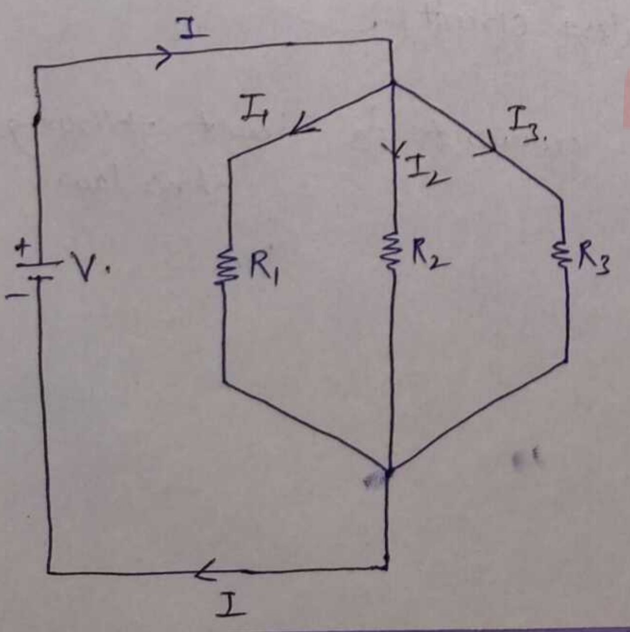
Equivalent Resistance.

⇓



as we know the value of equivalent Resistor (R_s) we can replace R_1, R_2 and R_3 by its equivalent resistor R_s.

(b) Parallel connection of Resistors (OR) Equivalent resistor in parallel



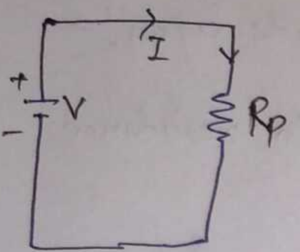
$\therefore \quad I = I_1 + I_2 + I_3.$

$\frac{V}{R_p} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}.$

$\frac{\cancel{V}}{R_p} = \cancel{V}\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right)$

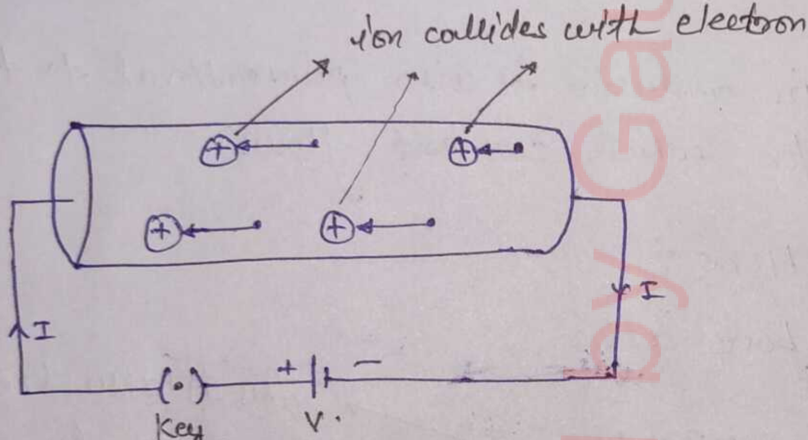
$$\boxed{\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}}$$

Now by knowing the value our circuit will have:-



$R_p \rightarrow$ equivalent Resistor for R_1, R_2 and R_3.

* Heating effect of electric current



- When a potential-difference (voltage) is applied between the ends of a conductor, current flows resulting in the flow of large number of free electrons.
- These free-electrons constantly keep on colliding with positive ions of the conductors
- Hence ions gains energy on collision and begins to vibrate more vigorously about their mean positions
- This results in a rise in the temprature of the conductor and we say conductor has been heated.
- Thus the flow of current has a heating effect on conductor.

* Expression for calculation of Heating effect of conductor

The heat produced in conductor depends upon:-

① Heat produced directly proportional to resistance

$$H \propto R.$$

② Heat produced directly proportional to square of the current flowing in conductor.

$$H \propto I^2$$

③ Heat produced in conductor is also proportional to the time duration for which current flows.

$$H \propto t$$

Combining above all

$$H \propto I^2 R t$$ → This is also known as Joule's law of heating.

$$\boxed{H = I^2 R t} \text{ joule.}$$

* Practical applications of heating effect of electric current

① Electric bulb

- The electric heating is also used to produce light as in an electric bulb.
- As the current flows through filament of bulb its get very hot and emit light.
- Filament of bulb is made up of tungsten (melting point = 3380 °C).

(2) Electric fuse:

- Fuse used in electric circuit works on Joule's law of heating.
- It protects from
  - → overloading
  - → short circuit
  - → fluctuation in power supply.
- If a (larger) current flows than the specified value through the circuit, the temprature of fuse wire increases. This melts the fuse wire and breaks the circuit.
- Fuse (its wire) made up of alloys consisting
  - → iron
  - → copper
  - → aluminium
  - → lead
  - etc.

(or) Sometime fuse is also made up of a metal.

- We connect fuse in series with the device.

* **Electric Power** → It is defined as the amount of electric work done in one second.

$$P = \frac{W}{t}$$

power ← P; W → work done (joule) (electric work done); t → time (seconds)

Unit ⇒ Watt (J/s).

Derivation for electric power

$$\because V = \frac{W}{q}$$

$$\therefore W = Vq$$

as $q = It$

$$W = VIt \quad \text{——} (1)$$

we know that

$P = \frac{W}{t}$ putting W from (1)

$P = \frac{VIt}{t}$ watt

$\boxed{P = VI}$ * → 1st Relation.

using ohm's law
$V = IR$.

$P = (IR)I$

$\boxed{P = I^2R}$ * Watt

↓

2nd Relation of Power

using ohm's law
$V = IR$.
or $I = V/R$.

$P = V(V/R)$

$\boxed{P = \frac{V^2}{R}}$ * Watt

↓

3rd Relation of Power

- we will use all these (3) (2) & (1) relation in numericals.

* <u>Commercial unit of electrical Energy.</u>

∵ $P = \frac{W}{t}$ → here this electric work (W) = Electric energy (E)

∴ $W = E$

$P = \frac{E}{t}$

or $E = Pt$.

↓

In this expression $\underset{\text{(electric Energy)}}{E} = \underset{\text{(Power)}}{P} \times \underset{\text{(time)}}{t}$ —— (1)

electric Energy ↓ joule; Power ↓ watt; time ↓ s.

• The eqn (1) defines electrical energy in small units. i.e. in watt and seconds.

• For commercial purposes we have to use big units.

Watt → becomes → Kilowatt

Seconds → becomes → 1 hour.

$\therefore \quad E = (1\,kW)\cdot(1\,hour)$

$= (1000\,W)\,(60\times 60\,s)$

$= 1000\times 60\times 60 \quad J.$

$= 3.6\times 10^6\ J \qquad \because (10^6 = 1\,Mega)$

$E = 3.6\ MJ$ (mega joule)

↓

this 3.6×10^6 or $3.6\ MJ$ is termed as 1 kWh or 1 unit of power in commercial sense.

$\therefore \boxed{1\,kWh = 3.6\,MJ.}$

(OR)

1 unit of electrical power ⇒ means ⇒ 3.6×10^6 joules has been consumed by appliances.

(OR)

1000 watt runs for 1 hours ⇒ consumes ⇒ 3.6×10^6 joules of electrical energy.