ELECTRICITY

Charge: The internal property of the body which is responsible for the electrical & magnetic phenomenas associated with the body is called charge.

Charges are of two types : (1) Positive (2) Negative

It is a scalar quantity. S.I. unit coulomb (C) & c.g.s. unit stat-coulomb.

Electric Current: An electric current is defined as the amount of charge flowing through any cross-section of a conductor in unit time.

$$\text{Electric Current } (I) = \frac{\text{charge } (Q)}{\text{time } (t)} \quad \text{or} \quad \boxed{I = \frac{Q}{t}}$$

Electric current is a scalar quantity. S.I. unit ampere (A)

Definition of 1 ampere: We know, $I = \frac{Q}{t}$

$$\therefore \quad 1 \text{ ampere (A)} = \frac{1 \text{ coulomb (C)}}{1 \text{ second (s)}} = 1\, C s^{-1}$$

Electric current through a conductor is said to be one ampere if one coulomb charge flows through any cross-section of the conductor in one second.

NOTE: Smaller units of current are also used:

1 milli-ampere $(mA) = 10^{-3} A$

1 micro-ampere $(\mu A) = 10^{-6} A$

Electric Current in terms of number of electrons:

Let 'n' be the no. of electrons flowing through any cross-section of the conductor in time 't'.

Charge on 1 electron, $e = 1.6 \times 10^{-19} C$

$\therefore$ Total charge, $Q = ne$

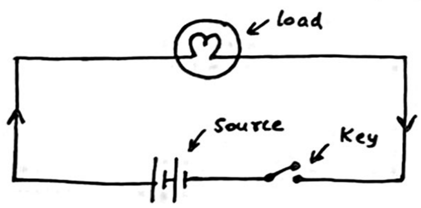
$$\therefore \text{ Electric Current, } I = \frac{Q}{t}$$

$$\text{or} \quad \boxed{I = \frac{ne}{t}}$$

Direction Of Current: The conventional direction of electric current is from positive to negative electrode. However, the direction of electronic current (current due to flow of electrons) is from negative to the positive electrode of the battery.

Ammeter: Ammeter is a device used to measure electric current. In a circuit an ammeter is shown by −(A)+ .
An ammeter has a very low resistance so that it does not effect the actual resistance of the circuit when used.
The resistance of an ideal ammeter is zero. It is always connected in series in an electric circuit to avoid changes in current.

Electric Circuit: An electric circuit is a closed conducting path containing a source of electric energy and a device or load utilizing the electric energy.



Electric circuit can be of two types:
1. Open circuit: An electric circuit through which no electric current flows is known as open electric circuit.
2. Closed circuit: An electric circuit through which electric current flows continously is known as closed circuit.

Electric Potential:

Electric potential is defined as the electric potential energy or work done on charges per unit charge.

OR

Electric potential is defined as the amount of work done in bringing a unit positive charge from infinity to that point.
Electric potential is a scalar quantity. S.I. unit volt (V)

$$\text{Electric Potential } (V) = \frac{\text{Work done } (W)}{\text{Charge } (q)}$$

or

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

Definition of 1 volt:

We know $V = \frac{W}{q}$

$$\therefore \quad 1\,V = \frac{1\,J}{1\,C} = 1\,JC^{-1}$$

Thus, the electric potential is said to be 1 volt if 1 joule work is done in moving 1 coulomb charge.

NOTE: Smaller units of electric potential are also used:

1 milli-volt (mV) = 10^{-3} V 1 micro-volt (μV) = 10^{-6} V

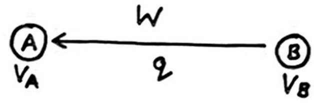
Larger units of electric potential:

1 kilo volt (kV) = 10^{3} V 1 mega volt (MV) = 10^{6} V

Electric Potential Difference:

Electric potential difference between two points A and B is defined as the work done per unit charge in moving a unit positive charge from point B to point A.

$$\Delta V = V_A - V_B = \frac{W}{q}$$



It is a scalar quantity. S.I. unit volt (V). It is denoted by V. It is also called voltage.

$$V = \frac{W}{q} \quad , \text{ But } \quad I = \frac{q}{t} \quad \text{or} \quad q = I \times t$$

$$\therefore \boxed{V = \frac{W}{q} = \frac{W}{I \times t}}$$

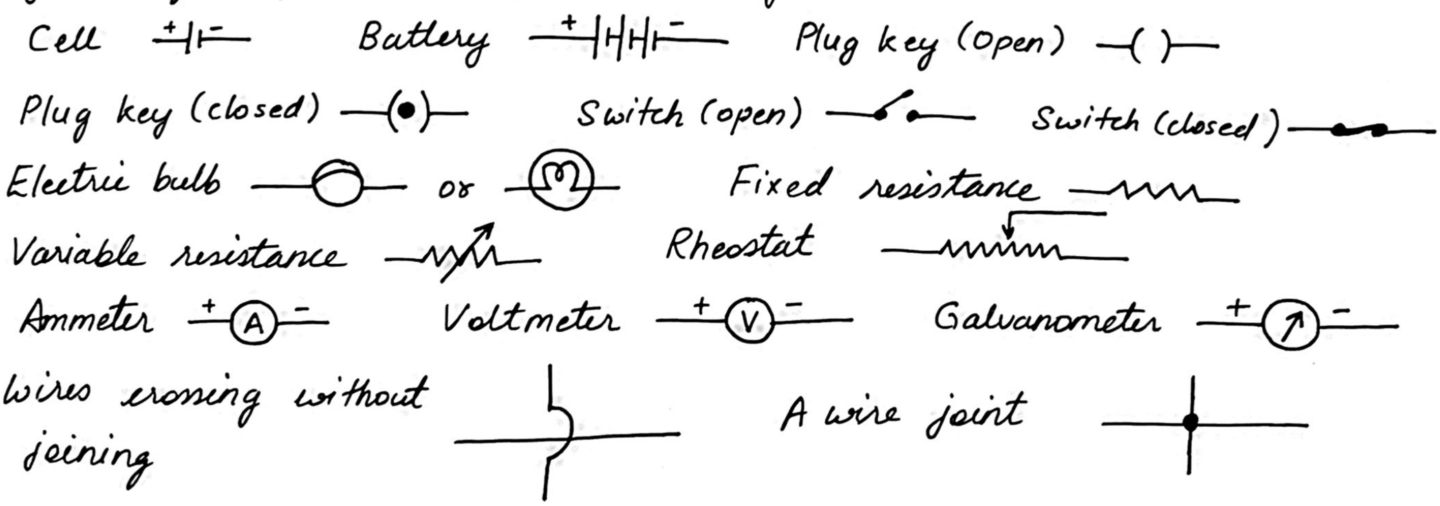
NOTE: Electric current only flows through a conductor if the ends of the conductor are maintained at different electric potentials.

Voltmeter: Voltmeter is a device which is used to measure potential difference. In a circuit it is shown as: 

A volt meter is always connected in parallel to avoid any changes in the actual potential of the circuit.

Circuit Diagram: A diagram showing the arrangement of various components in an electric circuit with the help of their symbols is known as circuit diagram.

Symbols of Components in a Circuit diagram.



Ohm's Law: It states that - " the electric current flowing in a conductor is directly proportional to the potential difference across the ends of the conductor, provided the temperature and other physical conditions remain the same."

Ohm's law establishes a relation between electric current & potential diff.

Mathematically this law can be stated as:

Electric current (I) ∝ Potential difference (V)

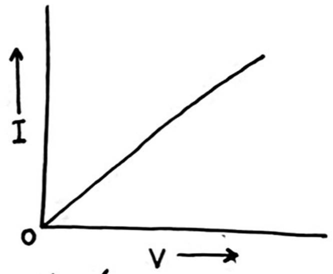
or $I \propto V$ or $V \propto I$

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

Here $R \text{ (constant)} = \frac{V}{I}$ is known as resistance of conductor.

The ratio of potential difference across the ends of a conductor to the current flowing through it remains constant, if temperature and other physical conditions of the conductor remains the same.

The graph between V and I is a straight line passing through the origin as shown in the figure alongside.



Resistance (R):

Resistance of a conductor is the property of a conductor to oppose the flow of charge through it.

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

Thus, resistance of a conductor is defined as the ratio of the potential difference across the ends of the conductor to the current flowing through the conductor.

Resistance is a scalar quantity. Its S.I. unit is ohm (Ω).

Definition Of 1 Ohm:

We know: $1 \text{ ohm} = \frac{1 \text{ Volt}}{1 \text{ amper}}$ $\left(\because R = \frac{V}{I}\right)$

$$\therefore \quad 1\Omega = 1 V A^{-1}$$

Resistance of a conductor is said to be 1 ohm if a potential difference of 1 volt across the ends of the conductor makes a current of 1 ampere to flow through it.

The resistance of the conductor can be measured by finding the slope of the V-I graph.

Resistor: A component in an electric circuit which offers resistance to the flow of electrons consisting electric current is known as a resistor. eg. a metallic wire or a conductor used in an electric circuit.

Variable Resistance: In an electric circuit, sometimes current has to be increased or decreased. A component used in an electric circuit to change the current without changing the potential difference across the circuit is called variable resistance.

Rheostat: It is a device used in an electric circuit to change the resistance and hence current in the circuit. Hence, rheostat acts as a variable resistance of unknown value in the circuit.

Good Conductor: A conductor or a material which offers low resistance to the flow of electrons or electric current in an electric circuit is known as a good conductor.
example - silver, copper, aluminium etc

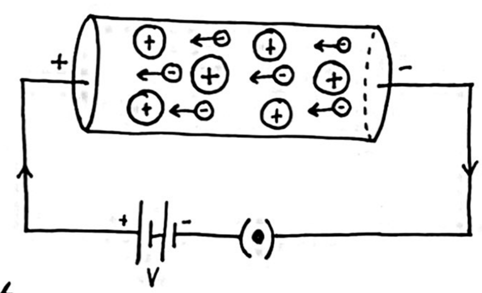
Poor Conductor: A conductor or a material which offers higher resistance to the flow of electrons or electric current in an electric circuit is known as a poor conductor.
e.g- iron.

Insulator: A material which offers a very high resistance to the flow of elections or electric current in an electric circuit is known as an insulator.
e.g. rubber, dry wood.

Ohmic Material: A material, which obeys Ohm's law is known as ohmic material. e.g. copper, aluminium.

Non-Ohmic materail: A material which does not obey Ohm's law is known as non-ohmic material. e.g. electrolyte

Cause Of Resistance:



A conductor has a large no. of free electrons which move randomly in all directions. When a potential difference is maintained across the ends of the conductor, the free elections drift from one end to the other end of the conductor. During their movement, they collide with each other and with the atoms (ions) of the conductor. These collisions oppose the flow of free elections from one end to the other end of the conductor. This opposition to the flow of free electrons due to the collisions is known as resistance of the conductor. More the collisions suffered by electrons in a condultor, more is the resistance of the conductor.

Factors affecting Resistance:

1. Length of the conductor - The resistance of the conductor is directly proportional to its length.
   i.e. $R \propto l$ ---(1)
2. Area of cross-section - The resistance of the conductor is inversely proportional to it area of cross-section.
   i.e. $R \propto \frac{1}{A}$ ----(2)
3. Nature of material - The resistance of the conductor depends on the nature of its material. Metals are good conductors so their resistance is low.
4. Temperature of material - The resistance of a conductor depends upon its temperature. The resistance of metals increases with rise in temperature, however, the resistance of semi-conductors decreases with increase in temperature.

Formula For Resistance:

From above eqns. (1) & (2)

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

or

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

ρ = specific resistance or resistivity of conductor

Definition of Resistivity:

We know, $R = \rho \frac{l}{A}$

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

If $A = 1$ and $l = 1$, we have, $\rho = R$

Thus, Resistivity of a conductor is defined as the resistance of the conductor of unit length & unit area of cross-section.

Unit of Resistivity:

S.I unit = ohm-m (Ω-m)
c.g.s unit = ohm-cm (Ω-cm)

NOTE:
1. Resitivity of a substance is a characteristic property of that substance and hence is independent of the dimension (l, b, h) of the substance.
2. The resistivity of metals is very low, however that of insulators is very high.
3. The value of resistivity of alloys lies in between that of metals & insulators.

Combination Of Resistances:

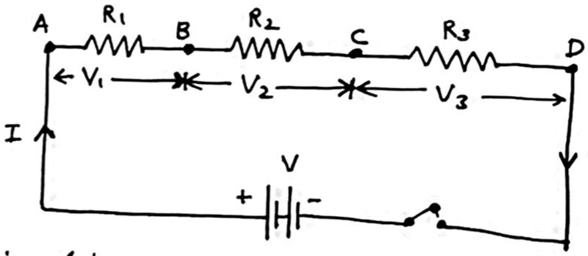
Conductors or resistors can be connected with one another in three ways:

(i) Series combination (ii) Parallel Combination (iii) Mixed or series-parallel Combination

Series Combination:

Two or more conductors are said to be connected in series if they are connected one after the other such that the same current flows through each conductor when some potential difference is applied across the combination.

Equivalent Resistance in series:



Consider three conductors R_1, R_2 & R_3 connected in series across a cell. Let current I be flowing through each resistance and V be the potential difference across the combination of the resistances. If V_1, V_2 & V_3 be the potential difference across resistances R_1, R_2 & R_3 respectively, then potential difference across AD = Potential difference across R_1 + Potential difference across R_2 + Potential difference across R_3.

i.e. $V = V_1 + V_2 + V_3$

According to Ohm's law:

$$V_1 = IR_1$$

$$V_2 = IR_2$$

$$V_3 = IR_3$$

If R_s be the effective resistance of series combination of R_1, R_2 & R_3 then $V = IR_s$

Hence $IR_s = IR_1 + IR_2 + IR_3$

or $IR_s = I(R_1 + R_2 + R_3)$

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

If n resistors are connected in series, then effective resistance,

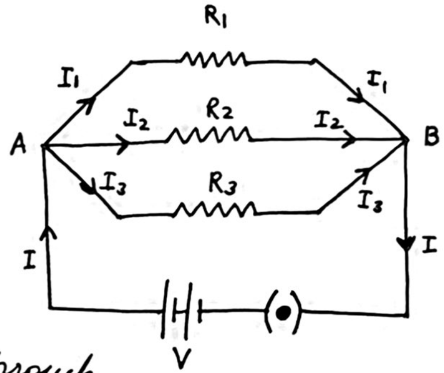
$$\boxed{R_s = R_1 + R_2 + R_3 + R_4 + \cdots + R_n}$$

i.e. effective resistance of a series combination of resistors is the sum of individual resistances of the resistors in the combination.

Parallel Combination:

Two or more resistors are said to be connected in parallel if one end of each resistor is connected at one common point and the other end of each resistor is connected at other common point such that the potential difference across each resistor is equal to the applied potential diff. across the combination of resistors.

Equivalent Resistance in Parallel:



Let us consider three resistors R_1, R_2 & R_3 connected in parallel across a cell having potential diff. V applied across A & B. The current I drawn from the cell divides into three parts I_1, I_2 & I_3 at point A. Current I_1 flows through R_1, I_2 through R_2 & I_3 flows through R_3.

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

According to Ohm's law:

$$I_1 = \frac{V}{R_1}$$

$$I_2 = \frac{V}{R_2}$$

$$I_3 = \frac{V}{R_3}$$

If R_p is the equivalent resistance of parallel combination, then, $I = \frac{V}{R_p}$

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

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

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

If n resistors are connected: $\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + --- + \frac{1}{R_n}$

i.e. the reciprocal of net or equivalent resistance is equal to the sum of reciprocals of resistances of the individual resistances of the combination.

NOTE: 1. In series combination potential divides but current is same.
2. In parallel combination current divides but potential is same.

Heating effect of electric current:

We know that pot. diff. is the work done per unit charge in carrying a charge from one point to another.

If W is the work done to carry the charge q, then:

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

or $W = V \times q$

If I is the current flowing in time t, then

$$q = I \times t$$

$\therefore$ $W = VIt$

This work done is equal to the heat produced in joules in the conductor

i.e. $$\boxed{H = VIt}$$

Other forms of the above relation:

$$V = IR$$

$\therefore$ $H = (IR)It$

or $$\boxed{H = I^2Rt}$$

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

$\therefore$ $H = V\left(\frac{V}{R}\right)t$

or $$\boxed{H = \frac{V^2 t}{R}}$$

Joule's Law Of Heating:

It states that - "the amount of heat produced in a conductor is directly proportional to the square of electric current flowing through it, directly proportional to the resistance of the conductor and directly proportional to the time for which electric current flows through the conductor."

i.e. $H \propto I^2$

$H \propto R$

$H \propto t$

or $H = k\, I^2 R t$

Here $K = 1$

$\therefore$ $$\boxed{H = I^2 Rt}$$

Electric Energy:

The work done by a source of electricity to maintain a current in an electrical circuit is known as electrical energy.

We know, $W = Vq$

& $q = It$

$\therefore \quad W = VIt$

$W = E$ (Electric energy)

$\therefore \quad \boxed{E = VIt}$ or $\boxed{E = I^2Rt}$ or $\boxed{E = \frac{V^2t}{R}}$ (see page 9)

Electric Power:

Electric power is defined as the amount of electric energy consumed in a circuit per unit time.

If W is the amount of electric energy consumed in a circuit in t seconds, then the electric power,

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

But $W = VIt$

$$\therefore \quad P = \frac{VIt}{t}$$

or $\boxed{P = VI}$

Thus, electric power is defined as the product of potential difference applied across the circuit and current flowing through it.

Other forms:

$P = \frac{W}{t}$, But $W = I^2Rt$

$\therefore \quad P = \frac{I^2Rt}{t}$ or $\boxed{P = I^2R}$

Also $P = \frac{W}{t}$, But $W = \frac{V^2t}{R}$

$\therefore \quad P = \frac{V^2t}{R \times t}$ or $\boxed{P = \frac{V^2}{R}}$

Unit of Power: SI unit = watt (W)

Bigger units, 1 kilowatt = 10^3 W or 1 kW = 10^3 W

1 mega watt = 10^6 W or 1 MW = 10^6 W

1 gigawatt = 10^9 W or 1 GW = 10^9 W

Definition of 1 Watt:

$$P = VI$$

$$\therefore \quad 1W = 1V \times 1A$$

or $$1W = 1VA$$

Thus, electric power is said to be 1 watt if 1 ampere current flows through a circuit having 1 volt potential difference.

Practical unit: horse power (h.p.)

$$1 \text{ h.p.} = 746 \text{ W}$$

Relation between electric energy & electric power:

electric energy = VIt

electric power = VI

$\therefore$ Electric energy = Electric Power × Time

or $$\boxed{E = P \times t}$$

Commercial unit of electric energy – kilowatt-hour:

$$E = P \times t$$

$$\therefore \quad 1 \text{ kWh} = 1 \text{ kW} \times 1 \text{ h}$$

Thus, A kilowatt-hour is the amount of electric energy used by 1000 Watt electric appliance when it operates for one hour.

NOTE: 1 unit = 1 kWh

Relation between kWh and joule:

$$1 \text{ kWh} = 1000 \text{ W} \times 1 \text{ h}$$

$$= 1000 \frac{J}{s} \times 3600 \text{ s} \qquad (\because 1W = 1Js^{-1} \text{ \& } 1h = 60 \times 60 s)$$

$$\therefore \quad 1 \text{ kWh} = (1000 \times 3600) \frac{J}{s} \times s$$

or $$1 \text{ kWh} = 3600000 \text{ J}$$

or $$\boxed{1 \text{ kWh} = 3.6 \times 10^6 \text{ J}}$$

Super conductors: The substances whose resistance becomes zero at very low temperature (critical temperature) are called superconductors.