ELECTRICITY AND MAGNETISM

Electric current

"Rate of flow of electric charge through any point of the circuit is called electric current" current is denoted by I.

If a charge 'q' flows through the circuit for time 't', then $I = \frac{q}{t}$.

If a charge 'dq' flows through the circuit for time 'dt', then $I = \frac{dq}{dt}$

Current is a scalar quantity and its unit is ampere

$$1 \text{ ampere} = \frac{1 \text{ coulomb}}{1 \text{ sec}} = \text{flow of } 6.25 \times 10^{18} \text{ electrons/sec.}$$

Electromotive Force (e.m.f.) : That external force which makes the current carriers (free electrons) to move in a definite direction, is called as electromotive force or e.m.f.

e.m.f. of a cell is the maximum potential difference between its two terminals when no current is drawn. Its SI unit is volt (V).

Ohm's law : According to Ohm's law, current flowing through a conductor is directly proportional to the potential difference across its two ends provided physical conditions of the conductor (like) temperature, mechanical strain, etc.) remain unchanged. i.e.,

$$I \propto V$$

or $$V \propto I$$

or $$V = IR$$

where R is a constant of proportionality and is called as the resistance of the conductor. Hence

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

Resistance :

$$\text{Resistance} = \frac{\text{potential difference}}{\text{current}}.$$

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

Resistance of a conductor is the obstruction offered by the conductor to the flow of charge through it. It is mechanically defined as the ratio of potential difference applied across the two ends of the conductor to the current flowing through it. Its SI unit is ohm, represented by Ω.

Ohm :

$$1 \text{ ohm} = \frac{1 \text{ volt}}{1 \text{ ampere}}$$

or $$1\Omega = \frac{1\text{ V}}{1\text{ A}}$$

If an applying a potential difference of one volt across the two ends of a conductor, a current of one ampere flows through it, then the resistance of the conductor is said to be one ohm :

Specific resistance (or resistivity) : Resistivity of the material of the conductor is defined as the resistance of unit length and unit area of cross-section of that conductor. Hence specific resistance or resistivity is given as

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

Where,

R = resistance of the conductor

A = area of cross-section of the conductor

l = length of the conductor

Its SI unit is ohm-metre (Ωm)

Temperature coefficient of resistance : It is defined as the increase in resistance per unit original resistance per unit increase in temperature. It is denoted by α. Hence,

$$\alpha = \frac{\text{Increase in resistance}}{\text{Original resistance} \times \text{increase in temp.}}$$

$$= \frac{R_t - R_0}{R_0 \times t}$$

Its unit is $°C^{-1}$ or K^{-1}.

Variation of resistance with temperature : The resistance of a metal conductor varies with temperature as per the following relation.

$$R_t = R_0 (1 + \alpha t + \beta t^2)$$

where, R_0 = resistance of the conductor at 0°C

R_t = resistance of the conductor at t°C.

α and β = temperature coefficients of resistance

Since the value of β is very small, we generally have

$$R_t = R_0 (1 + \alpha t)$$

Combination of resistances

(i) *Series combination* : Equivalent resistance R of a number of resistances R_1, R_2, R_3, ... in series is given by.

$$R = R_1 + R_2 + R_3 + \ ...$$

(ii) *Parallel combination* : Equivalent resistance R of a number of resistances R_1, R_2, R_3, ... in parallel is given by,

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + ...$$

Conductance : The reciprocal of the resistance of a conductor is called its conductance. It is denoted by G.

Hence, $$G = \frac{1}{R}$$

Its SI unit is mho or ohm^{-1} (Ω^{-1})

Conductivity : The reciprocal of the resistivity of the material of a conductor is called its conductivity. It is denoted by σ.

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

Its SI unit is ohm^{-1} metre^{-1} ($\Omega^{-1}m^{-1}$).

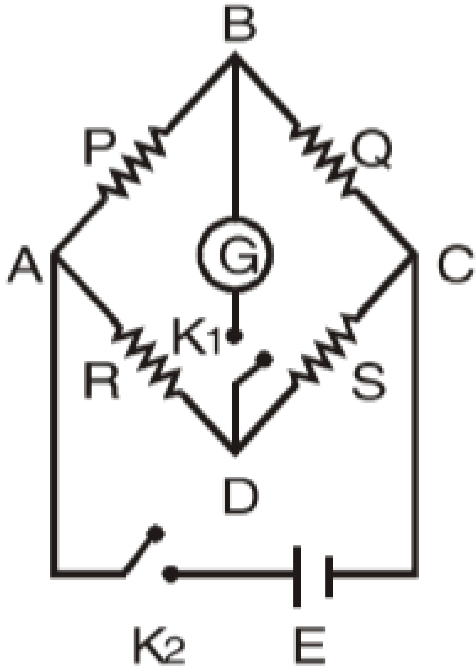
Drift velocity : It is defined as the average velocity with which the free electrons in a conductor get drifted under the influence of an external field. This velocity is in addition to normal random motion of the electrons and its value is of the order of 10^{-5} ms^{-1}.

Kirchhoff's laws : *First law* "Algebraic sum of all the currents meeting at a point or junction in an electrical circuit is always zero, i.e., $\sum i = 0$.

Second law, " In any closed loop of an electrical circuit, the algebraic sum of the e.m.fs. is equal to the algebraic sum of the product of the resistances and the currents flowing through them, i.e., $\sum E = \sum(iR)$.

Wheatstone's Bridge: According to the principle of Wheatstone's bridge, when four resistances P, Q, R and S are arranged (as shown in figure), and galvanometer G shows no deflection (i.e., the bridge is balanced), then

$$\frac{P}{Q} = \frac{R}{S}$$



Wheat stones bridge

Here P, Q are called ratio arms, R is known resistance arm and S is unknown resistance arm.

Potentiometer : According to the principle of potentiometer, when a constant current is passed through a wire of uniform area across-section, then fall of potential V across any portion of the wire is directly proportional to the length l of that portion, i.e.,

$$V \propto l$$

or $V = kl$

where k is called potential gradient.

Terminal potential difference of a cell : It is the potential difference between two terminals of a cell when current is being drawn from the cell. It is represented by V. Terminal potential difference V of a cell is always less than the e.m.f. E of the cell. Also,

$$E - V = Ir$$

When I is the current flowing through the circuit. If R be the external resistance in the circuit, then

$$I = \frac{E}{R + r}$$

Grouping of Cells :

(i) ***Cells in series*** **:** Current through the external resistance R is given by

$$I = \frac{nE}{R + nr}$$

where, n = number of cells

E = e.m.f. of each cell

r = internal resistance of each cell

(ii) ***Cells in parallel*** **:** Current through the external resistance R is given by,

$$I = \frac{mE}{mR + r}$$

where, m = number of cells

E = e.m.f. of each cell

r = internal resistance of each cell.

(iii) ***Cells in mixed grouping*** **:** Current through the external resistance R is given by,

$$I = \frac{mnE}{mR + nR}$$

where, m = number of rows of cells in parallel

n = number of cells in series in each row

E = e.m.f. of each cell

r = internal resistance of each cell

Magnetic length : The distance between the positions of two magnetic poles of a dipole or a bar magnet is called its magnetic length. It is represented by '$2l$'.

Magnetic dipole : Magnetic dipole consists of two unlike poles of equal strength separated by a small distance.

Magnetic dipole moment : The product of magnetic pole strength and magnetic length of the dipole is called its magnetic dipole moment, i.e.,

$$M = m \times 2l$$

And SI unit is ampere metre^2 (A m^2)

Geographic meridian : A vertical plane passing through the axis of rotation of the earth is called the geographic meridian.

Magnetic meridian : A vertical plane passing through the axis of a freely suspended magnet is called the magnetic meridian.

Magnetic declination : The angle between geographic meridian and magnetic meridian at a place is called as the magnetic declination at that place.

Magnetic inclination : The angle between the direction of total intensity of earth's magnetic field and the horizontal direction at any place is called as the magnetic inclination or dip at that place. It is represented by δ.

Horizontal component of earth's magnetic field : It is the component of total intensity of earth's magnetic field in the horizontal direction. It is represented by H and also

$$\tan \delta = \frac{V}{H}$$

where V is the vertical component of earth's magnetic field.

Diamagnetic Substances : These substances, when placed in a magnetic field, get feebly magnetised in a direction opposite to the direction of the magnetising field.

Paramagnetic substances : These substances, when placed in a magnetic field, get feebly magnetised in the direction of the magnetising field.

Ferromagnetic substance : These substances, when placed in a magnetic field, get strongly magnetised in the direction of the magnetising field.

Curie's law : According to this law, the magnetic susceptibility of a paramagnetic material is inversely proportional to its absolute temperature, i.e.,

$$\chi_m \propto \frac{1}{T}$$

or $$\chi_m = \frac{C}{T}$$

where C is the constant of proportionality called as Curie's constant.

Magnetic field due to a bar magnet :

(i) At a point on axial line of the bar magnet :

$$B = \frac{\mu_0}{4\pi} \cdot \frac{2Md}{\left(d^2 - l^2\right)^2}$$

where, μ_0 = permeability of free space

M = magnetic moment

d = distance of the point from the centre of the magnet

$2l$ = magnetic length of the magnet

For a short magnet $l^2 << d^2$, then

$$B = \frac{\mu_0}{4\pi} \cdot \frac{2M}{d^3}$$

(ii) At a point on equatorial line of the bar magnet :

$$B = \frac{\mu_0}{4\pi} \cdot \frac{M}{\left(d^2 + l^2\right)^{3/2}}$$

where notations have their usual meanings.

For a short magnet, $l^2 << d^2$, then

$$B = \frac{\mu_0}{4\pi} \cdot \frac{M}{d^3}$$

Torque on a bar magnet in a magnetic field : Torque τ on a bar magnet of magnetic moment M in a magnetic field B is given by,

$$\tau = MB \sin\theta.$$

where θ = angle between magnetic length and direction of magnetic field.

Potential energy of a bar magnet placed in a magnetic field : When a magnetic dipole is rotated from its initial position $\theta = \theta_1$, to final position $\theta = \theta_2$, then potential energy stored in it is given by,

$$\tau = MB \sin\theta$$

where θ = angle between magnetic length and direction of magnetic field.

Vibration magnetometer : The time period of vibration of a freely suspended magnet in earth's magnetic field H is given by,

$$T = 2\pi\sqrt{\frac{I}{MH}}$$

where, I = moment of inertia of the magnet about the axis of rotation

M = magnetic moment of the magnet

H = horizontal component of earth's magnetic field.

Intensity of Magnetisation : Intensity of magnetisation of a magnetic material is defined as the magnetic moment per unit volume of the specimen or pole strength per unit area of cross--section of the specimen. It is represented by I. Hence,

$$I = \frac{\text{Magnetic moment}}{\text{Volume}} = \frac{M}{V}$$

$$\text{But } M = m \times 2l \text{ and } V = a \times 2l$$

$$\text{Therefore, } I = \frac{m \times 2l}{a \times 2l} = \frac{m}{a}$$

$$= \frac{\text{pole strength}}{\text{area of cross section}}$$

And SI unit of I is ampere metre^{-1} (A m^{-1}).