

## Chapter - 19

## Electric Charge

Electrostatics:-

Branch of physics that deals with the study of charge particle and its behaviour when it is at rest is called electrostatics.

Current: Alignment of electrons.

Types of Charge:

i) Positive charge: The kind of charge in which atoms lose electron is known as positive charge.  
example: glass rod, fur, etc.

ii) Negative charge: The kind of charge in which atoms gain extra electron is known as negative charge.

$$M_e = 9.3 \times 10^{-31} \text{ kg}$$

$$M_p \approx M_n = 1.67 \times 10^{-27} \text{ kg}$$

Properties of electric charge

(i) Same charges repel each other and opposite charge attract each other. Therefore, the concept of repulsive and attractive force is originated.

(ii) Quantization of charge:

The charge of atom is always available in discrete form if atom has n number of electron with electronic charge e then total amount of charge of atom is  $Q = ne$ .

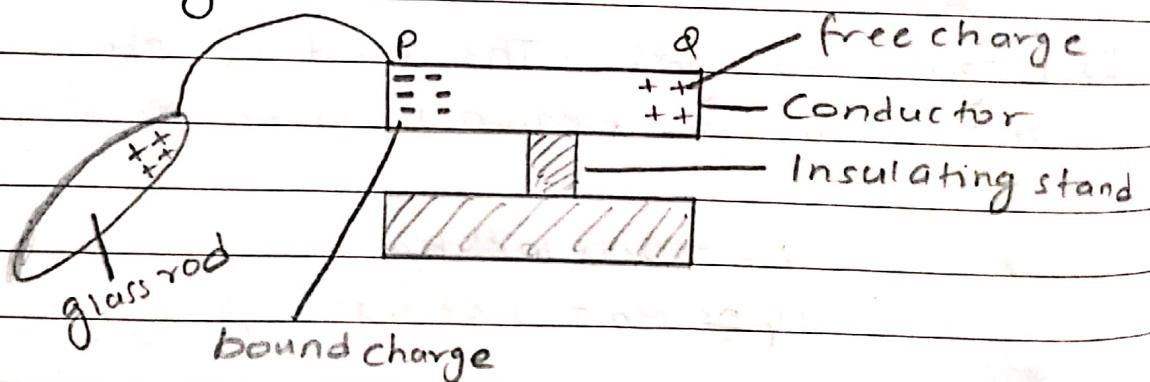
(iii) Charge always follows principle of conservation of charge.

- iv) Magnitude of charge is not affected by speed of the body.
- v) Charge is scalar quantity. It is because it doesn't obey vector algebra.

### Electrostatic's Induction

The temporary electrification of electric conductor when it comes close to any charge particle is known as electrostatic induction. For eg: when silk is kept near to glass and rod then there is electric charge setup in rod and becomes chargeless when we remove silk.

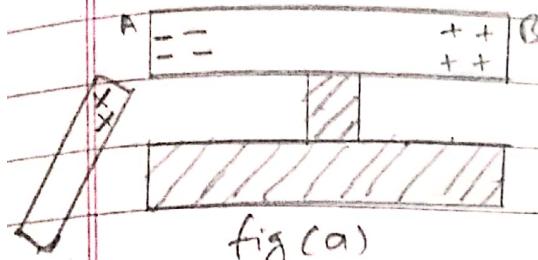
### Induced Charge



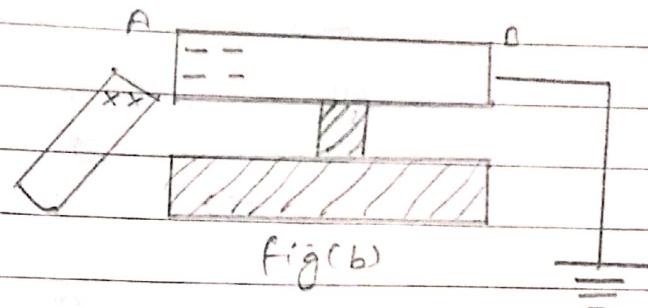
The amount of charge setup in conductor due to process of electrostatic induction is known as Induced charge.

In given experiment, the charge developed in close end (1<sup>st</sup> end) of conductor is said to be bound charge & the same charge is developed at far end (2<sup>nd</sup> end) is called free charge.

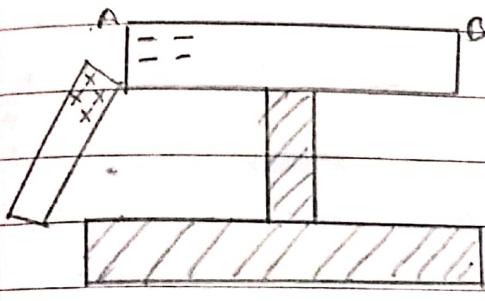
## Charging by negatively induction



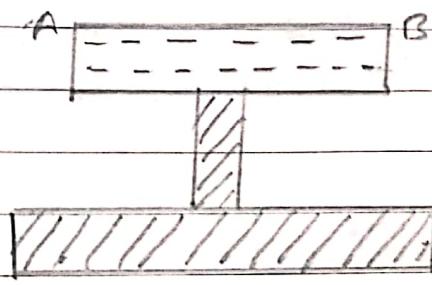
fig(a)



fig(b)



fig(c)



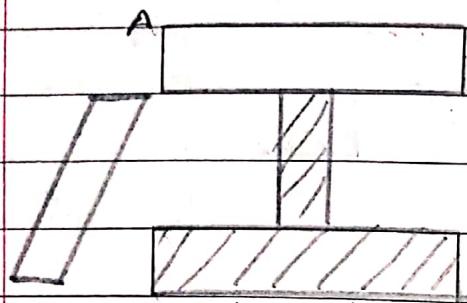
fig(d)

- Step 1: At first, A glass rod is rubbed with silk and placed close to conductor A : B as shown in fig (a). It is clearly seen that bound charge and free charge is setup at two end of conductor.
- Step 2: The phenomena of grounding is applied from B such that positive charge are grounded.
- Step 3: As shown in fig (c) we removed the effect of grounding.
- Step 4: At last when we remove glass rod there is no effect of induced phenomena such that conductor becomes negative.

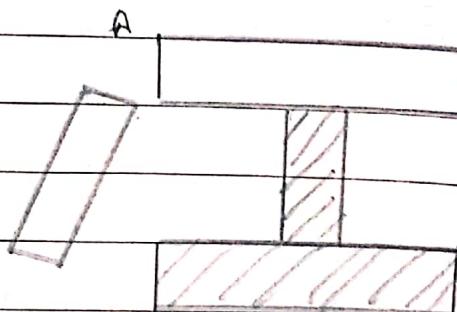
### Linear charge Density

The amount of charge per unit length of any conductor is known as linear charge density. It is denoted by ' $\lambda$ ' i.e.  $\lambda = \frac{q}{l}$

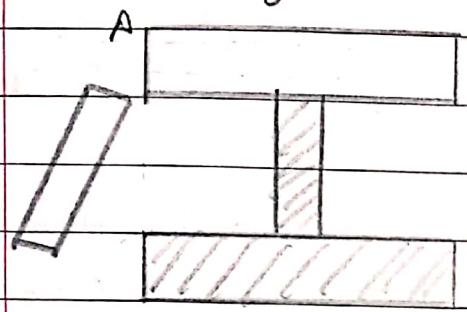
its unit is  $\text{cm}^{-1}$ .



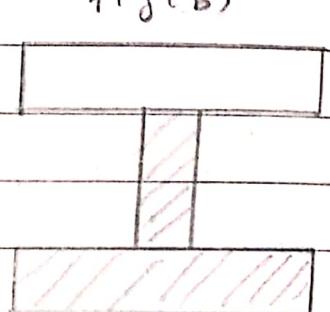
fig(a)



fig(b)



fig(c)



fig(d)

Step: 1 At first the ebonite rod is rubbed with fur and placed close to conductor AB as shown in the figure (a). It is clearly seen that the bound charge and free charge is set up at two end of conductor.

Step: 2 The phenomena of grounding is applied from second (b) end such that negative charge are grounded.

Step: 3 As shown in fig(c) we remove the effect of grounding.

Step: 4 At last when we remove ebonite and there is no effect of Induced phenomena such that the conductor become negative.

### The Surface Charge density ( $\sigma$ )

The distribution of the charge particle along the any particular cross section area A is known as surface charge density.

Mathematically,

Surface Charge Density =  $\frac{\text{Total charge along cross section}}{\text{Area of cross section}}$

$$= \frac{Q}{A}$$

It is denoted by  $\sigma$ .

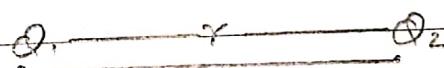
It's unit is  $\text{Cm}^{-2}$ .

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### Coulomb's Law

In 1875, the french scientist experimented verified the force of attraction and force of repulsion between two charge particle when it is placed at a certain distance so called Coulomb's law which states that:

The force of attraction & repulsion between two charges  $Q_1$  and  $Q_2$  at distance ( $r$ ) is inversely proportional to square of the distance between them.  
i.e.



$$F \propto Q_1 Q_2 \quad \textcircled{a}$$

$$\& F \propto \frac{1}{r^2} \quad \textcircled{b}$$

Combining  $\textcircled{a}$  and  $\textcircled{b}$  we get;

$$F \propto \frac{Q_1 Q_2}{r^2}$$

$$F = k \frac{Q_1 Q_2}{r^2} \quad \textcircled{c}$$

Where,  $k$  is proportionality constant which represent the state of medium used. In vacuum or free space (air)

the value of  $k$  in S.I. unit is  $k = \frac{1}{4\pi\epsilon_0}$

Where,  $\epsilon_0 = 8.85 \times 10^{-12} \text{ C}^2 \text{N}^{-1} \text{m}^{-2}$  is called  
permittivity of vacuum.

Then eq.③ becomes,

$$F = \frac{1}{4\pi\epsilon_0} \frac{Q_1 Q_2}{r^2}$$

which is required expression for Coulomb's force.

But in case of CGS units,  $k=1$  then  $F = \frac{Q_1 Q_2}{r^2}$   
is required Coulomb's force.

$$\vec{F}_{12} = \frac{1}{4\pi\epsilon_0} \frac{Q_1 Q_2}{r_{12}^2} \hat{r}_{12} = \frac{1}{4\pi\epsilon_0} \frac{Q_1 Q_2}{r_{12}^2} \vec{r}_{12}$$

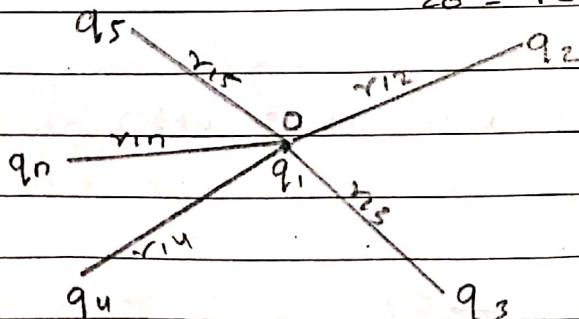
$$\hat{a} = \frac{\vec{a}}{|a|}$$

### Relative Permittivity

Relative permittivity of any medium is defined as  
the ratio of permittivity of medium to permittivity of  
vacuum.

It is also called dielectric constant ( $k$ ).

i.e.  $k = \frac{\epsilon}{\epsilon_0}$  where,  $\epsilon$  = Permittivity of medium  
 $\epsilon_0$  = Permittivity of vacuum



Let us suppose point charge  $q_1$  is at point  $O$  such  
that it experience multiple force  $F_1, F_2, F_3, \dots, F_n$   
due to presence of multiple charge.

$q_1, q_2, q_3, \dots, q_n$  separated distance of  $r_1, r_2, r_3, \dots, r_n$  respectively. Then the total force exerted by point charge  $q$  is calculated by using principle of superposition. i.e. net force is equal to vector sum of individual force.

i.e.

$$\vec{F} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 + \vec{F}_4 + \dots + \vec{F}_n$$

## Chapter 20

## Electric Field.

### Electric Lines of Force.

The imaginary line due to any point charge (either +ve or -ve) from where if we draw tangent gives the direction for electric field is known as electric line of force.

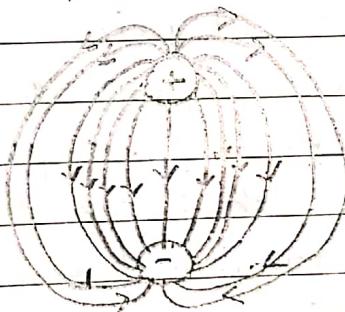


fig:- electric line of force

### Properties:

- ↳ It is imaginary line of force due charge
- ↳ It never intersect with each other.
- ↳ It starts from positive and end on negative charge.

### Electric Field

The force experienced by unit point charge when it is placed inside the electric line of force is called

Electric field. It is denoted by  $E$ . Point of charge  $q_0$  is placed inside line of force  $F$  then electric field is defined as:

$$E = \frac{\text{Force due to charge}}{\text{charge}}$$

$$E = \frac{F}{q_0}$$

It's SI unit is  $\text{N}\text{e}^{-1}$ .

V.V.T

Electric field due to point charge ( $q_0$ )



Let us fig:- Electric field due to point charge

Let us consider any charge particle having magnitude  $q$  is placed at point  $O$ . Another point charge  $q_0$  is placed at point  $P$ , at a distance of  $r$  from  $O$ . From point charge  $q_0$  there are multiple line of force that can be drawn from where if we draw tangent we can assure the direction of electric field  $E$ .

The force exerted by point charge  $q_0$  and charge  $q$  is given by Coulomb's law as

$$F = \frac{1}{4\pi\epsilon_0} \frac{qq_0}{r^2}$$

Due to force  $F$ , there is certain value of electric field is generated which is  $E = \frac{F}{q_0}$

$$E = \frac{1}{4\pi\epsilon_0} \frac{qq_0}{r^2} \times \frac{1}{q_0}$$

$$E = \frac{1}{4\pi\epsilon_0} \frac{q}{r^2}$$

which is required Expression for Electric Field due to point charge.

If point charge is placed at any medium having permittivity  $\epsilon$  then.

$$E = \frac{1}{4\pi\epsilon} \frac{q}{r^2} \quad (k = \frac{\epsilon}{\epsilon_0} \text{ or } \epsilon = k\epsilon_0)$$

$$E = \frac{1}{4\pi k\epsilon_0} \frac{q}{r^2}$$

There are multiple charges  $Q_1, Q_2, Q_3, \dots, Q_n$  are present at a distance  $r_{12}, r_{13}, r_{14}, \dots, r_n$  then the respective value of electric field is given by superposition principle i.e.

$$\vec{E} = \vec{E}_1 + \vec{E}_2 + \vec{E}_3 + \dots + \vec{E}_n$$

### Electric Flux.

The total number of electric line of force passing through the surface Area when it is held perpendicular to lines of force is known as electric flux.

It is denoted by  $\phi$ .

It indicate the magnitude of electric field. It means that more the electric flux more will electric field and vice-versa.

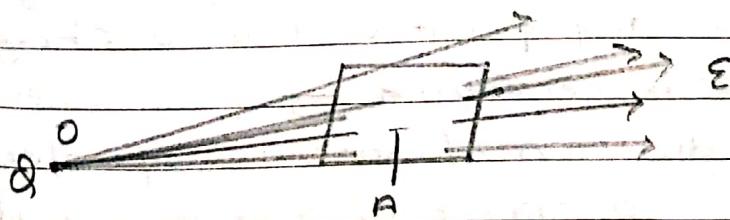


fig.: Electric flux

Let us consider point charge  $Q_0$  is at point O which generate electric lines of force and allows to pass on Surface area A perpendicularly then value of electric

field will be.

$$E = \frac{\phi}{A}$$

$$\text{i.e. } \phi = E \times A$$

The unit of Electric Flux is  $\text{N} \cdot \text{C}^{-1} \cdot \text{m}^2$

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### Gauss's Theorem

It states that total electric flux at any closed surface is equal to  $\frac{1}{\epsilon_0}$  times amount of charge present at that closed surface.

$$\text{i.e. } \phi_C = \frac{1}{\epsilon_0} \times Q$$

$$\therefore \phi = \frac{Q}{\epsilon_0}$$

Proof: (Electric flux due to point charge)

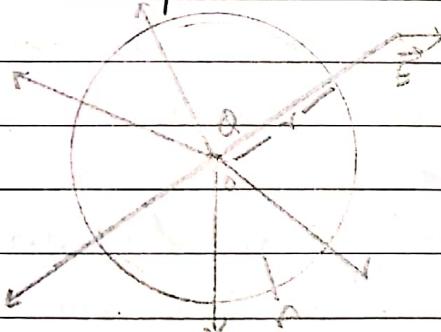


fig: Electric flux due to point charge.

Let us consider a point charge having charge  $Q$  placed at any point  $O$ . Due to charge electric lines of force is generated by from where we can predict the direction of intensity of electric field. Let us suppose a sphere of radius  $r$  is drawn from point  $O$  such that Electric flux is measured in surface area  $A$ .

Then, electric flux  $\phi$  is given by,

$$\phi = \epsilon \times A - \text{I}$$

The total surface Area of sphere.

$$A = 4\pi r^2 \quad \text{(ii)}$$

& intensity of electric field due to point charge  $Q$

$$E = \frac{1}{4\pi\epsilon_0} \frac{Q}{r^2} \quad \text{(iii)}$$

Using (ii) and (iii) in Eq.(i).

$$\phi = E \times A$$

$$= \frac{1}{4\pi\epsilon_0} \frac{Q}{r^2} \times 4\pi r^2$$

$$\therefore \phi = \frac{Q}{\epsilon_0}$$

Electric field due to charged sphere.

i) When point lies outside sphere.

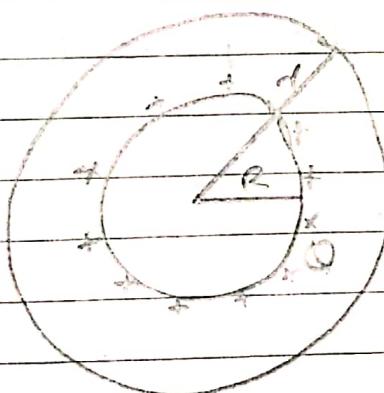


fig:- field when point is outside the sphere.

Let us consider a charged sphere of radius  $R$  where total charge  $Q$  is distributed uniformly. Consider any point  $P$  outside the charged sphere with concentric radius ' $r$ ' from center  $O$ . The surface area covered by radius ' $r$ ' is considered as Gaussian sphere where total electric flux is distributed due to charge  $Q$  of charged sphere of  $R$ .

$$\phi = E \times A \quad \text{--- (i)}$$

where,

$$A = 4\pi r^2$$

Acc. to gauss's theorem the total electric flux is given by;

$$\phi = \frac{Q}{\epsilon_0} \quad \text{--- (ii)}$$

Equations (i) and (ii)

$$\phi = \phi$$

$$E \times 4\pi r^2 = \frac{Q}{\epsilon_0}$$

$$E = \frac{1}{4\pi r^2 \epsilon_0}$$

which is req'd Exp'n for electric field due to charged sphere when point lies outside sphere.

ii) When point lies at the sphere ( $r = R$ )

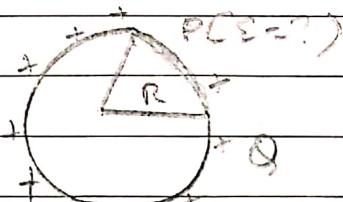


fig.: field when point is at the sphere.

Let us consider a charged ~~per~~ sphere of radius  $R$  where total charge  $Q$  is distributed uniformly.

Consider any point  $P$  at charged surface sphere. The surface area covered by the radius  $r$  is considered as Gaussian sphere where total electric flux  $\phi$  is distributed due to charge  $Q$  of charge sphere of  $R$ .

$$\Phi = EA - \textcircled{1}$$

Where,

$$A = 4\pi R^2$$

Acc. to gauss's theorem the total electric flux is given by:

$$\Phi = \frac{Q}{\epsilon_0} - \textcircled{2}$$

Equating eq. \textcircled{1} and \textcircled{2}

$$\Phi = \Phi$$

$$EA = \frac{Q}{\epsilon_0}$$

$$E = \frac{1}{4\pi R^2 \epsilon_0} Q$$

which is required expr for electric field due to charged ~~surface~~ sphere when point lies at the sphere.

iii) When point lies inside the sphere ( $r < R$ )

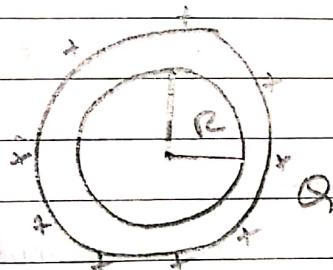


fig: field when point is inside the sphere.

let us consider a charged sphere of radius  $R$  where total charge  $Q$  is distributed uniformly. Consider any Point  $P$  inside the charge sphere with concentric radius ' $r$ '. The area covered by small sphere (radius  $r$ ) with area ( $A = 4\pi r^2$ ) is considered as Gaussian sphere. Since Gaussian surface doesn't enclosed any charge particle as shown in figure, then

$$\phi = E \times A \quad \text{--- (i)}$$

$$\text{where, } A = 4\pi r^2$$

According to Gauss theorem the total Electric flux is given by:

$$\phi = \frac{Q}{\epsilon_0}$$

Equating (i) and (ii)

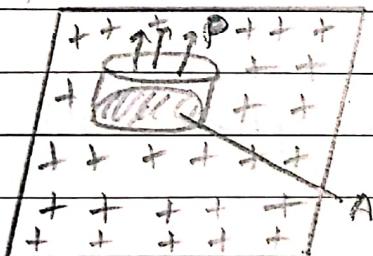
$$\phi = \phi$$

$$E \times 4\pi r^2 = \frac{Q}{\epsilon_0} \quad [Q=0]$$

$$E \times 4\pi r^2 = 0$$

$$\therefore E = 0$$

Electric field due to plane charged conductor.



Surface charge density

$$\sigma = \frac{Q}{A}$$

$$Q = \sigma \times A$$

fig: field due to plane conductor

Let us suppose plane charge conductor having charge  $Q$  in its upper surface. If  $P$  be any point outside the surface where Electric Field is to be determine.

For that let us assume two cylindrical outside the plane conductor which is perpendicular to plane and lower cylindrical surface is parallel to curve surface area. Let  $\sigma$  be surface charged density for cylindrical A therefore total amount of

charge  $Q$  is  $C = \frac{Q}{A}$

$$\therefore Q = C \times A - \text{I}$$

If  $E$  be the electric field in the cylindrical area  $A$  then total flux in the plane conductor outside the surface is

$$\Phi = E \times A - \text{II}$$

Then,

From Gauss's Theorem

$$\Phi = \frac{Q}{\epsilon_0}$$

$$\text{on } E \times A = \frac{C \times A}{\epsilon_0}$$

$$\therefore E = \frac{C}{\epsilon_0}$$

which is required expression for electric field due to plane charged conductor.

### Electric field due Linear charge conductor

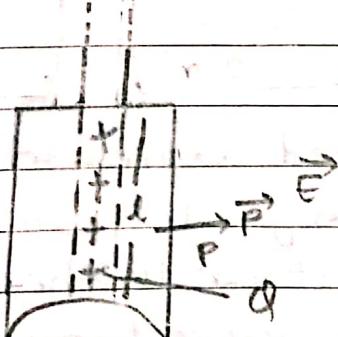


fig: field due to line charge.

Let us consider an infinitely long charge conductor as shown in figure. Our task is to calculate the electric field at any point  $P$  outside the conductor.

for the length ( $l$ ).

Let us draw a cylindrical surface at radius ( $r$ ) where linear charge creates the field; we consider these areas as gaussian surface.

If  $Q$  be total amount of charge over length ' $l$ ' then linear charge density ' $\lambda$ ' is given by:-

$$\lambda = \frac{Q}{l}$$

$$Q = \lambda \times l \quad \text{--- (i)}$$

Since, curved surface area of cylinder is the Gaussian surface where electric lines of force passes normally then; total number of flux is given by:

$$\phi = E \times A$$

$$\phi = E \times 2\pi r l \quad \text{--- (ii)}$$

Using Gauss's theorem

$$\phi = \frac{Q}{\epsilon_0} \quad [\text{using (i) \& (ii)}]$$

$$E \times 2\pi r l = \frac{Q \times l}{\epsilon_0}$$

which is  $E = \cancel{\frac{Q}{2\pi r \epsilon_0}}$

$$E = \frac{Q}{2\pi r \epsilon_0}$$

which is required expression for electric field due to linear charge. It seems that electric field is inversely proportional to the radius of gauss's surface & directly proportional to the amount of charge for given length.



## Electric Potential)

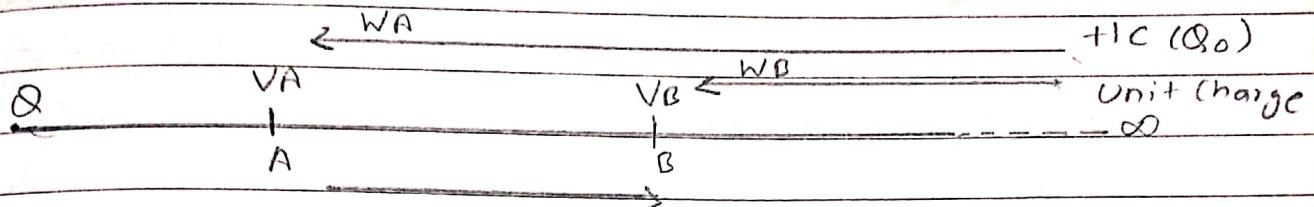


fig:- Electric potential

The amount of work done required to bring unit charge (test charge) in the region of electric field due to point charge  $Q$  from infinity is called Electric Potential. Let  $W_A$  and  $W_B$  be the amount of work done due to unit charge when we bring it from infinity to point  $A$  and point  $B$  - then respective potential due to point charge  $Q$  is given by  $V_A$  and  $V_B$  i.e.

$$\text{Potential at point } A = \frac{W_A}{Q_0}$$

$$\text{Potential at point } B = \frac{W_B}{Q_0}$$

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# Electric Potential at point due to point charge.

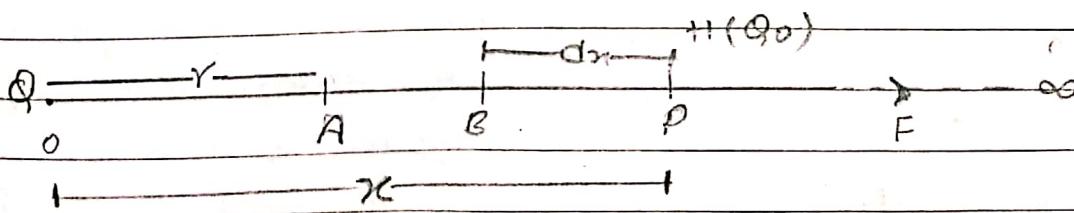


fig:- Electric Potential at point due to point charge.

Let us consider a point charge  $Q$  lies at point  $O$  which generate the electric field upto infinity. Consider a point  $P$  at distance ' $r$ ' where electric potential is to

be determined. For that consider two different points A and B. Test charge (unit charge) at a distance of  $r$  from point charge Q. Also consider another point B at very small distance  $dr$ . If  $W_{QA}$  be the amount of work done when we bring Q from infinity point A. The coulomb's force due to charge Q and Q is given by:

$$F = \frac{1}{4\pi\epsilon_0} \cdot \frac{Q \cdot 1}{r^2} \quad \text{--- (i)}$$

Since force cover small distance  $dr$  then small work done is given by.

$$dW = -F \times dr$$

Where, -ve sign indicates that work done is done against electrostatic force.

Total workdone from infinity to point A i.e. (at r)

$$W = \int_{\infty}^r dw$$

$$= \int_{\infty}^r -fdn = \int_{\infty}^r -\frac{1}{4\pi\epsilon_0} \cdot \frac{Q}{r^2} \cdot dn$$

$$= -\frac{Q}{4\pi\epsilon_0} \int_{\infty}^r \frac{1}{n^2} dn$$

$$W = \frac{Q}{4\pi\epsilon_0} \left[ \frac{n^{-2+1}}{-2+1} \right]_{\infty}^r$$

$$= \frac{Q}{4\pi\epsilon_0} \left( \frac{1}{n} \right)_{\infty}^r$$

$$= \frac{Q}{4\pi\epsilon_0} \left( \frac{1}{r} - \frac{1}{\infty} \right)$$

$$W_{QA} = \frac{Q}{4\pi\epsilon_0 r} \quad \text{--- (ii)}$$

But from the definition Electrical Potential is equal to workdone ( $\infty$ -point)

$$V_A = W_{\text{QA}}$$

$$\therefore V_A = \frac{Q}{4\pi\epsilon_0 r}$$

$\therefore$  This ~~the~~ is the required <sup>expression</sup> equation for the electric potential at point due to point charge.

\* Potential difference bet<sup>n</sup> two points.

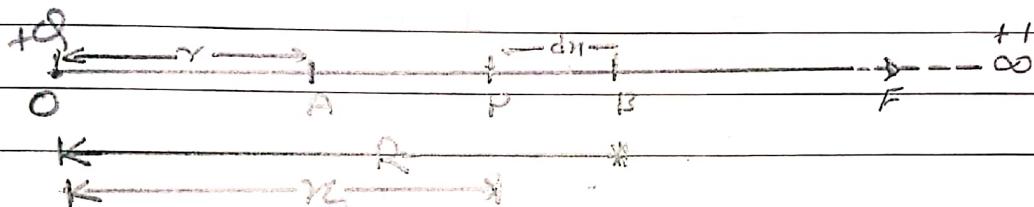


fig: Electric potential due to two points.

Let us suppose point charge  $Q$  is at point  $O$  which generate the electric line of force where Coulomb's force are active upto infinity. Let us consider two points  $A$  and  $B$  at a distance of  $r$  and  $R$  from point charge  $Q$ . The potential difference bet<sup>n</sup> point  $A$  and  $B$  is equal to the amount of work done on bringing test charge (unit charge) from infinity & given by  $V_A$  &  $V_B$ .

i.e.  $V_A - V_B = W_{BA} \quad \text{--- (i)}$

Let us consider small distance  $d_n$  from point  $B$  to point  $P$ . Then small amount of workdone is given by  $dW$  i.e.

$$dW = -f d_n \quad \text{--- (ii)}$$

Where, -ve sign indicate that work is done against electrostatic force. Total workdone due to test charge when we bring it from infinity to two different point

at distance  $r$  and  $R$  is.

$$W_{BA} = \int_R^r dw$$

$$= \int_R^r -fdn \quad (\text{using (ii)})$$

$$= \int_R^r -\frac{1}{4\pi\epsilon_0} \frac{Q}{n^2} dn$$

$$= -\frac{Q}{4\pi\epsilon_0} \int_R^r \frac{1}{n^2} dn$$

$$= -\frac{Q}{4\pi\epsilon_0} \frac{n^{-2+1}}{-2+1} \Big|_R^r$$

$$\therefore W_{BA} = \frac{Q}{4\pi\epsilon_0} \frac{1}{n} \Big|_R^r$$

$$W_{BA} = \frac{Q}{4\pi\epsilon_0} \left( \frac{1}{r} - \frac{1}{R} \right) \quad \text{--- (iii)}$$

from Eq. (i) and (iii)

$$V_A - V_B = W_{BA}$$

$$V_A - V_B = \frac{Q}{4\pi\epsilon_0} \left( \frac{1}{r} - \frac{1}{R} \right)$$

which is req<sup>n</sup>. Exp<sup>n</sup> for pd. for two pt. A & B.

### \* Potential gradients:

The differential value of potential difference with respect to distance (say) is known as potential gradient. i.e.

$$\text{Potential gradient} = \frac{dv}{dn} / \frac{dv}{dy} / \frac{dv}{dz}$$

Its unit is volt per meter ( $V m^{-1}$ )

$$1 \text{ J} = 10^7 \text{ erg}$$

$$1 \text{ coulomb} = 3 \times 10^9 \text{ stat coulomb}$$

Date \_\_\_\_\_  
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\* Unit of potential difference

from the definition of potential difference

Potential difference =  $\frac{\text{Work done}}{\text{charge}}$

$$\text{i.e. } V = \frac{W}{q}$$

Since unit of  $W$  is Joule and unit of charge is coulombs. Then

$$V = \frac{\text{Joule}}{\text{coulomb}} - \text{volts.}$$

for exam  
S.Q.

# Define one Volts

Since from definition of potential;

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

if  $W = 1 \text{ J}$  and  $C = 1 \text{ C}$ . then  $V = 1 \text{ volt}$ .

Therefore, amount of energy generated due to bringing of 1 coulomb charge using 1 Joule (work done) is known as 1 volts.

\* Relation between Volts and stat Volts.

Since,

$$1V = \frac{1 \text{ J}}{1 \text{ coulomb}}$$

$$(1 \text{ coulomb} = 3 \times 10^9 \text{ stat coulomb})$$
$$1 \text{ J} = 10^7 \text{ erg}$$

$$1V = \frac{10^7 \text{ erg}}{3 \times 10^9 \text{ stat coulomb}}$$

$$1V = \frac{10^7 \text{ erg}}{300 \times 10^9 \text{ stat coulomb}}$$

$$1V = \frac{1}{300} \text{ stat volt.}$$

V.V.I  
2mark

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\* Relation betw. Electric field and potential gradients.

The potential difference due to charge  $q$  at a distance  $r$  from test charge / unit charge is given by

$$V = \frac{1}{4\pi\epsilon_0} \frac{q}{r} \quad \text{--- i)}$$

It implies that potential difference is inversely proportional to distance.

The rate of change of potential w.r.t  $r$  is given by;

$$\frac{dv}{dr} = \frac{d}{dr} \left[ \frac{1}{4\pi\epsilon_0} \frac{q}{r} \right]$$

$$\frac{dv}{dr} = \frac{q}{4\pi\epsilon_0} \frac{dr^{-1}}{dr}$$

$$\frac{dv}{dr} = \frac{q}{4\pi\epsilon_0} (-1r^{-1-1}) \quad \left[ \frac{dn^n}{dn} = n n^{n-1} \right]$$

$$\frac{dv}{dr} = - \left( \frac{1}{4\pi\epsilon_0} \frac{q}{r^2} \right)$$

$$-\frac{dv}{dr} = E \quad \text{--- ii)}$$

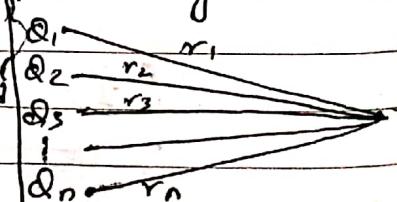
where,  $E = \frac{1}{4\pi\epsilon_0} \frac{q}{r^2}$  is the amount of electric field

at a point  $r$ .

Then from eq<sup>n</sup> ii) it is clearly seen that electric field is equal to negative gradient of potential.

\* Electric Potential due to multiple charges.

Consider a point 'P' where the multiple potential is developed due to charges  $Q_1, Q_2, Q_3, \dots, Q_n$  at a distance of  $r_1, r_2, r_3, \dots, r_n$ .



{Ily → similarly}

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from P. If  $V_1, V_2, \dots, V_n$  be the amount of potential developed at point P due to multiple charges then resultant potential  $V$  is given by the superposition principle which states that total / resultant potential is equal to the vector sum of individual potential i.e.

$$\vec{V} = \vec{V}_1 + \vec{V}_2 + \vec{V}_3 + \dots + \vec{V}_n$$

$$\vec{V} = \frac{1}{4\pi\epsilon_0} \frac{Q_1}{r_1} + \frac{1}{4\pi\epsilon_0} \frac{Q_2}{r_2} + \dots + \frac{1}{4\pi\epsilon_0} \frac{Q_n}{r_n}$$

$$\vec{V} = \frac{1}{4\pi\epsilon_0} \left[ \frac{Q_1}{\vec{r}_1} + \frac{Q_2}{\vec{r}_2} + \dots + \frac{Q_n}{\vec{r}_n} \right]$$

which is required potential due to  $Q_1, Q_2, \dots, Q_n$ .

### \* Equipotential Surface

The surface where the value of potential is equal everywhere throughout the surface is known as Equipotential surface. Meaning that if we assume two point A and B on the Equipotential surface then from the definition;

$$V_A = V_B \quad \text{--- a)}$$

If any test charge is brought from point B to point A with the application of workdone  $W_{BA}$  (force due to charge  $Q$ ) then amount of potential setup is.

$$V_{AB} = V_B - V_A \quad \text{--- i)}$$

Ily,  $V_{AB} = W_{BA} \quad \text{--- ii)}$

$$W_{BA} = V_B - V_A$$

$$W_{BA} = V_B - V_B \quad [V_A = V_B]$$

$$W_{BA} = 0$$

Hence throughout the Equipotential surface workdone is zero.

## Capacitor

Every physical quantity in the nature possess some characteristics that tends to capture the charge in their body according as their nature, shape & size and distance between insulating medium. Such property of matter which try to store the charge in their body is called capacitance. The device used to store the charge is called capacitor. Capacitor consists of two plate separated by insulating medium like <sup>mica</sup> ~~mica~~ or air as below:

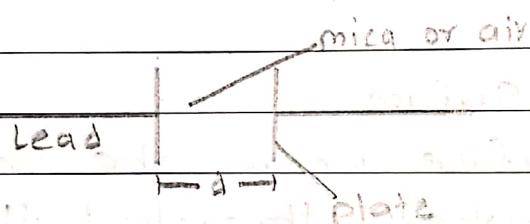


fig: capacitory/symbol

The horizontal line connected on either side of plate is called lead which is used to provide external voltage source.

### \* Capacitances of any capacitor.

Let us assume any capacitor of capacitance  $C$  is connected to the battery of potential difference ' $V$ ' then.

Experimentally it is found that the charge stored in capacitor over time ' $t$ ' is directly proportional to the amount of potential difference used i.e.

$$Q \propto V$$

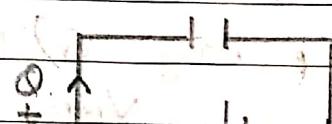


fig: Capacitances of capacitor

$$Q = CV \quad Q = CV - i$$

where,  $C$  is proportionality constant so called capacitance of capacitor depend upon medium, shape & size and distance bet' insulating medium. From Eq. i)

$$Q = CV$$

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

i.e. capacitance of any capacitor is mathematically equal to the ratio of charged store per unit volt.

### \* Unit of Capacitor.

Since the capacitance is ratio of charge stored to the applied potential difference then,

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

Since,  $Q$  is measured in Coulomb and P.D is in Volts, the SI unit of  $C$  is  $CV^{-1}$ . It is also called farad (F). Since, farad is extremely large unit of capacitor. In practical purpose, we use micro farad ( $\mu F = 10^{-6} F$ )

$$1 \mu F = 10^{-6} F$$

$$\begin{aligned} 1 \mu \mu F &= 10^{-6} \times 10^{-6} F \\ &= 10^{-12} F \\ &= 1 PF \end{aligned}$$

$$\text{since, } C = Q/V$$

Capacitance of the capacitor in which capacitor store 1 coulomb of charge using 1 volt is called 1 farad.  
i.e.  $C = \frac{1 C}{1 V} = 1 F$

### \* Capacitance bet' two parallel plate.

Let us consider two <sup>identical</sup> metallic parallel plate  $X$  and  $Y$  each having area  $A$ , with charge density  $\sigma$ . The metallic

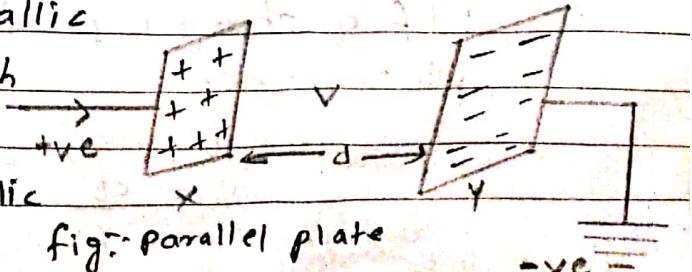


fig: Parallel plate

plate Y is grounded whereas plate X is charged with positive source such that throughout the surface of X positive charges flows. As we know that whenever positive charges flows on neighbouring plate then there is induction of negative charge on plate Y such that there is V potential is setup between plate separated by distance of d. The amount of electric field E due to potential V is:  $E = \frac{V}{d}$  — i)

The Electric Field in plane conductor (x) using Gauss's theorems is given by

$$E = \frac{\sigma}{\epsilon_0} — ii)$$

where,  $\epsilon_0$  is the permittivity of vacuum.

Since the relation betw of  $\sigma$ , q and A is

$$\sigma = \frac{q}{A} — iii)$$

Then, from Eq. i), ii) & iii)

$$E = \frac{\sigma}{\epsilon_0}$$

$$\text{or, } E = \frac{q}{A\epsilon_0}$$

$$\text{or, } \frac{V}{d} = \frac{q}{A\epsilon_0}$$

$$\therefore V = \frac{qd}{A\epsilon_0} — iv)$$

If q charges produces V potential on parallel plate then,

$$q = CV$$

$$\therefore C = \frac{q}{\frac{ad}{A\epsilon_0}}$$

$$\boxed{\therefore C = \frac{A\epsilon_0}{d}} \rightarrow v)$$

which is required capacitance of parallel plate.  
from eq: v) it can be infer that capacitance increase when

- i) Area of plate increase
- ii) increase with  $\epsilon_0$ , i.e. depends on medium.
- iii) With decrease the distance betw. plate.

### Uses of Capacitor

- i) Capacitor is mostly used in research purposes.
- ii) It is mostly used in telecommunication for transmission and reception.
- iii) It is used in electronic filter circuit.
- iv) It is used in alternating current (AC) circuit.

### Types of Capacitor:

- i) Cylindrical Plate Capacitor
- ii) Spherical Plate Capacitor
- iii) Parallel Plate Capacitor

### # Elactance

The reciprocal of capacitance is called elactance.  
It is denoted by 'S' i.e.

$$\text{elactance (S)} = \frac{1}{\text{Capacitance (C)}}$$

→ Its unit is  $f^{-1}$ .

V.V.I

## # Combination of Capacitor

The arrangement of any capacitor by parallel or series means for desirable value of capacitance is known as combination of capacitor.

There are two types of combinations:-

① Series combination

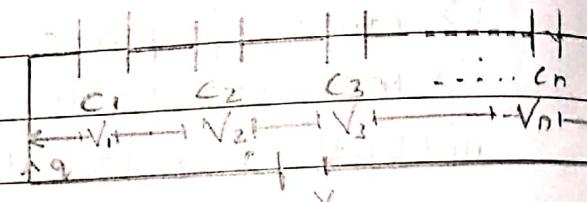
② Parallel Combination

V.V.I

## ① Series Combination

The combinations of capacitor in which 2nd terminal of first capacitor is connected to 1st terminal

of 2nd capacitor and so on is known as series combinations. Such that the connection is end to end. In such condition the same amount of charge is stored in all capacitor.



Let us consider different capacitor of capacitance  $C_1, C_2, \dots, C_n$  is connected in series with battery source of potential difference  $V$ , such that  $q$  amount of charge flows through all capacitor. But in this case potential is drop along each capacitor by  $V_1, V_2, \dots, V_n$  as shown in figure.

Then, total amount of potential in series combination is

$$V = V_1 + V_2 + V_3 + \dots + V_n \quad \text{--- (i)}$$

Since the value of:

$$V_1 = \frac{q}{C_1}$$

$$V_2 = \frac{q}{C_2} \quad [\text{since } Q = CV]$$

$$V_n = \frac{q}{C_n}$$

If total capacitance of combination is given by  $C$  then total potential is reduced at  $V = \frac{q}{C}$ .

Then Eq(i) becomes,

$$V = V_1 + V_2 + \dots + V_n$$

$$\text{or, } \frac{q}{C} = \frac{q}{C_1} + \frac{q}{C_2} + \frac{q}{C_3} + \dots + \frac{q}{C_n}$$

$$\text{or, } \frac{q}{C} = q \left[ \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \dots + \frac{1}{C_n} \right]$$

$$\text{or, } \frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \dots + \frac{1}{C_n}$$

This is the required expression for total capacitance of series combination. If there are two capacitor of capacitance  $C_1$  and  $C_2$  are used in series. Then,

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2}$$

$$\frac{1}{C} = \frac{C_1 + C_2}{C_1 C_2}$$

$$\therefore C = \frac{\text{Product of capacitor}}{\text{Sum of capacitor}}$$

# Find capacitance when 7 Microfarad (Mf) and 8 Mf are connected in series.

Ans Soln,

$$\text{Given: } C_1 = 7 \mu\text{F}$$

$$C_2 = 8 \mu\text{F}$$

$$\text{So, } C = \frac{C_1 C_2}{C_1 + C_2} = \frac{7 \times 8}{7 + 8} = \frac{56}{15} = 3.73 \mu\text{F}$$

(ii)

## Parallel combination

The kind of combination of capacitor in such a way that all first terminal of capacitor are connected to first common point and all second terminal of

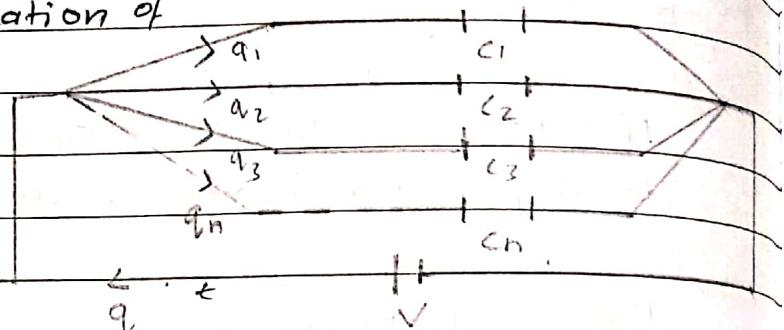


fig:- Parallel Combination

capacitor connected to second common point of battery so that potential is same in all capacitor and charges is divided is known as parallel combinations.

Let us consider a capacitor  $C_1, C_2, \dots, C_n$  are connected in parallel combination with battery of emf  $V$ . Let  $q$  be amount of charge flowing in time  $t$  which is divided into  $q_1, q_2, \dots, q_n$  such that potential in all capacitor is constant.

Therefore,

$$q = q_1 + q_2 + q_3 + \dots + q_n \quad \text{Eq. (i)}$$

$$\text{Since, } q = CV$$

$$q_1 = C_1 V$$

$$q_2 = C_2 V$$

$$\vdots \quad \vdots$$

$$q_n = C_n V$$

Then Eq (i) becomes

$$q = q_1 + q_2 + \dots + q_n$$

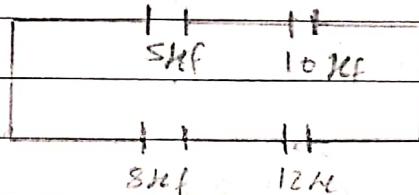
$$CV = C_1 V + C_2 V + \dots + C_n V$$

$$CV = V(C_1 + C_2 + \dots + C_n)$$

$$C = C_1 + C_2 + \dots + C_n \quad \text{(ii)}$$

Hence, Equivalent Capacitance  $C$  is the sum of individual capacitor in parallel combinations.

Qn Calculate total capacitances of given circuit.



Sol:

$$C_{12} = \frac{C_1 C_2}{C_1 + C_2}$$

$$= \frac{5 \times 10}{5+10} = \frac{50}{15} = \frac{10}{3} \mu F$$

Also,

$$C_{34} = \frac{C_3 C_4}{C_3 + C_4} = \frac{8 \times 12}{8+12} = \frac{8 \times 12}{20} = \frac{24}{5} \mu F$$

Therefore,

$$C_T = C_{12} + C_{34}$$

$$= \frac{10}{3} + \frac{24}{5}$$

$$= \frac{50+72}{15} = \frac{122}{15} \mu F$$

# Energy stored in Capacitor (3 marks)

Let us consider capacitor of capacitance (C) is connected to a battery of emf (V) such that Q amount of charge is stored in the capacitor such that the value of capacitance is  $\frac{Q}{V}$

$$Q = CV$$

$$C = \frac{Q}{V} \quad \text{--- (i)}$$

If small charge  $dQ$  is stored in capacitor by small work done  $dW$  provided by Voltage source of battery.

$$\therefore dW = V dq \quad \text{if } V = \frac{W}{dq}$$

Total amount of work done to store charge of  $q$  is given by

$$\int_0^W dW = \int_0^q V dq$$

$$\text{or } W = \int_0^q \frac{q}{C} \cdot dq = \frac{1}{C} \frac{q^2}{2} \Big|_0^q$$

$$\therefore W = \frac{1}{2C} q^2 \rightarrow a)$$

$$\text{or } W = \frac{1}{2C} \cdot C^2 V^2$$

$$\therefore W = \frac{1}{2} CV^2 \rightarrow b)$$

Also, we can write,

$$W = \frac{1}{2} (CV) V$$

$$W = \frac{1}{2} qV \rightarrow c)$$

Eq. (a), (b) & (c) is the required work done which is stored in capacitor in the form of electrical energy.

### # Energy Density ( $U$ )

The energy stored by capacitor per unit volume is known as energy density. It is denoted by ' $U$ ' and its unit is  $J/m^3$ .

Qn Prove that energy density of any capacitor is

$$U = \frac{1}{2} \epsilon E^2$$

Ans Let us consider two parallel plate capacitor such

that there is a separation between the plate. If it a amount of charge is stored in the capacitor by the application of voltage  $V$  such that 'E' electric field is developed between the plate.

Then energy stored in capacitor per unit volume i.e. Energy density is:-

$$U = \frac{\text{Energy Stored}}{\text{Volume}}$$

$$U = \frac{1}{2} CV^2 \rightarrow \text{Eq. (1)}$$

The capacitance between two parallel plate is:-

$$C = \frac{\epsilon_0 A}{d}$$

from Eq. (1)

$$U = \frac{\frac{1}{2} CV^2}{A \cdot d}$$

$$\text{or, } U = \frac{1 \cdot CV^2}{2Ad}$$

$$\text{or, } U = \frac{1}{2Ad} \left( \frac{\epsilon_0 A}{d} \right) \cdot V^2$$

$$\text{or, } U = \frac{1}{2} \epsilon_0 \left( \frac{V}{d} \right)^2$$

$$\boxed{\therefore U = \frac{1}{2} \epsilon_0 E^2} \quad \boxed{\therefore E = \frac{V}{d}}$$

for any medium

$$\boxed{U = \frac{1}{2} \epsilon E^2}$$

Hence, Energy density depends upon medium and

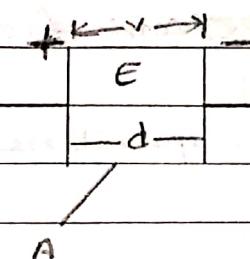


fig:- Energy density of capacitor

electric field between the plate.

## ~~# Capacitance due to spherical capacitor~~

### Electric Current

Electrical Current:-

The rate of change of charge flowing in any particular directions for some interval of time is known as electrical current.

Mathematically,

$$\text{Electrical current} = \frac{\text{charge} (Q)}{\text{time} (t)}$$

It's unit is  $\text{Cs}^{-1}$  or Ampere.

From quantization of charge

$$Q = ne$$

$$\text{Then, } I = \frac{Q}{t}$$

$$I = \frac{ne}{t}$$

Hence, current is rate of flow of  $n$  number of electron.

Qn Why current cannot consider as vector even though it has direction?

Ans: Electric current doesn't follow law of vector algebra that's why it cannot consider as vector even though it has direction.

The instantaneous value of current is  $\frac{dq}{dt} = dI$

Q" Define 1 Ampere current.

Ans 1 ampere current is defined as flow of 1 coulomb charge per 1 sec throughout the electric circuit.

$$\text{i.e. } I = \frac{Q}{t}$$

$$I = \frac{1\text{C}}{1\text{sec}} = 1 \text{ Ampere.}$$

## # Types of Current

There are two types of current on the basis of flow of current regarding the direction or frequency.

### i) Direct Current:-

The type of current in which direction and magnitude remain constant for any interval of time.

Or,

Current with 0 frequency is known as DC.

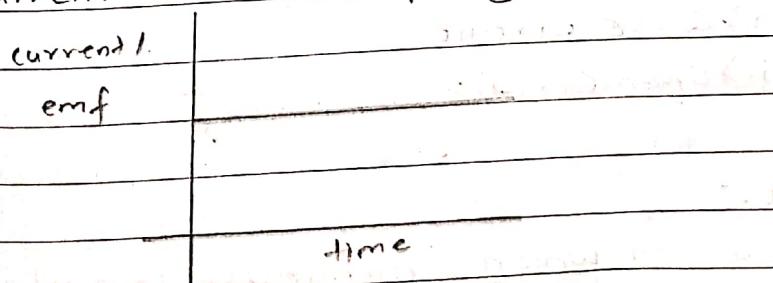
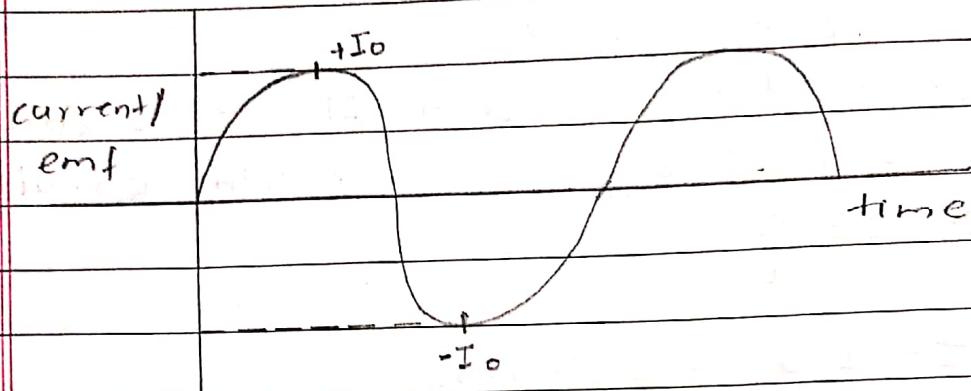


Fig:- Direct current

### ii) Alternating Current (AC)

The type of current in which direction and magnitude reverse periodically is known as AC.

Reason - It is due to the fact that alternating current has finite value of frequency.



$I_o$  = Peak value

## # Conventional flow of current.

It was believed that generally current flows from positive terminal to negative terminal.

i.e. high voltage to low voltage

These kind of behaving the direction of current is known as conventional flow of current.

## # Electric Circuit

The path followed by electric current is called electric current circuit. There are two types of electric circuit.

- i) Close Circuit
- ii) Open Circuit

### i) Close Circuit:

Circuit in which continuous flow of current makes load working is called close circuit.

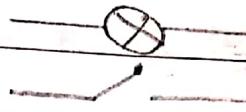
### ii) Open Circuit:

Circuit in which load doesn't work properly

due to absence of current is known as open circuit.

## # Different symbols -

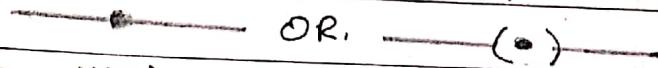
Bulb



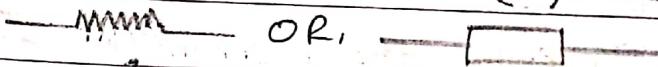
Open Circuit



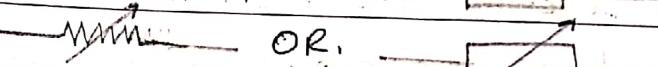
Closed Circuit



Resistor



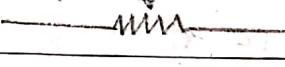
Variable Resistor



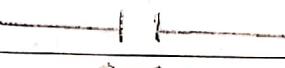
Battery/cell



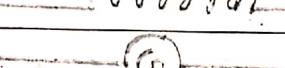
Potential Divider



Capacitor



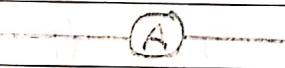
Inductor



Galvanometer



Voltmeter



Ammeter



Alternating Current (AC)



Fuse



## E Current density

The physical parameter used to define the ratio of current per unit Area (A) of any electric circuits is known as current density.

It is denoted by J.

Mathematically,

$$J = \frac{I}{A}$$

Its SI unit is Ampere per m<sup>2</sup> (A m<sup>-2</sup>)

If we place any conductor A normally to the direction of current then:

$$\therefore A = \cos\theta$$

$$\therefore J = \frac{I}{A \cos\theta}$$

<sup>Imp</sup> # Describe the mechanism of metallic conduction and hence derive the expression for drift velocity.

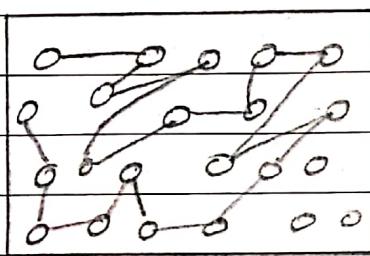


fig a) Random motion of electron without field.

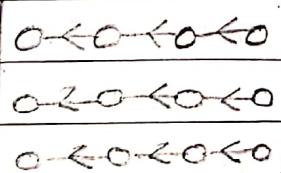


fig b) Motion of electron after electric field

Every metal is composed of the neutron, proton and electron. Neutron is chargeless, Proton is positively charged and electron is negatively charged particle. Since electron is responsible for metallic conduction, there are about  $10^{28} - 10^{31}$  free electron present in metal. If each and every free exit due to thermal collision. It start to move randomly in any direction as shown in fig(a) such that, net effect is zero. Therefore, no electric conduction is possible without electric field.

When we apply electric field all the electrons are aligned in particular direction such that every free electron start to move with the velocity opposite to applied electric field. These velocity is known as drift velocity. These velocity generate some K.E. which is converted into electric

energy such that metallic conduction is possible due to the presence of electric field.

# Relation betw drift velocity, curr current and current density ( $I = neVA$ ).

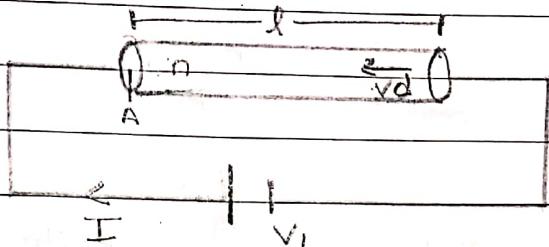


fig:- Drift Velocity

Let us suppose metallic conductor of length (l) and cross section Area (A) is connected to electric field of battery such that (I) amount of current flows through above circuit.

The metallic conductor consists of  $n$ , no. of density which is the ratio of total number of electron to that volume. Then,

$$\text{Volume of conductor } (V) = A \times l$$

$$\text{Total charge of metallic conductor } (Q) = N \times e$$

$$\text{Total no. of electron } (N) = n \cdot A \cdot l$$

Then, amount of current is given by,

$$I = \frac{q}{t}$$

$$I = \frac{Ne}{t}$$

$$I = \frac{nAe}{t}$$

$$I = nAe \left( \frac{l}{t} \right)$$

$$\therefore I = neVA, \text{ where, } V = \frac{l}{t}$$

which is required current due to electric drift  
velocity  $v_B$ .

Similarly,

$$\text{Current density } (J) = \frac{I}{A}$$

$$= \frac{n e v A}{A}$$

$$= n e v$$

which is required current density due to drift  
velocity  $v_B$ .

### # Ohm's Law:-

German scientist George Simon Ohm's in year 1826 discovered the experimental verification for current and potential difference across the metallic conductor which states that "The potential difference betw. two terminal of any conductor is directly proportional to the flow of current." i.e.

$$V \propto I$$

$$V = IR \quad \text{--- Eq. ①}$$

Where,  $R$  is proportionality constant called Resistance which depends upon nature, length and Area of material.

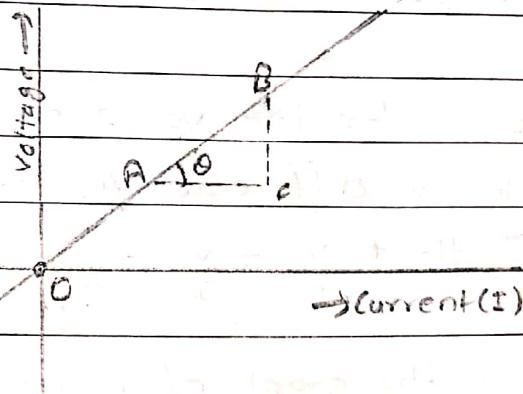
$$\text{i.e. } R = \left( \frac{\rho L}{A} \right) \quad \text{--- Eq. ②}$$

If  $I = 1$  Ampere

$$V = R$$

Hence, resistance of any material is the amount of potential difference when 1 ampere current pass through it.

The eq<sup>n</sup> ① is in the form of straight line passing through origin where in Y-axis we plot potential difference and in X-axis we plot current so that the given I vs V is



From the graph,

$$\tan \theta = \frac{BC}{AC}$$

The slope  $\tan \theta$  gives the value for resistance. ( $m = \tan \theta = R$ )

### # Experimental Verification of Ohm's Law.

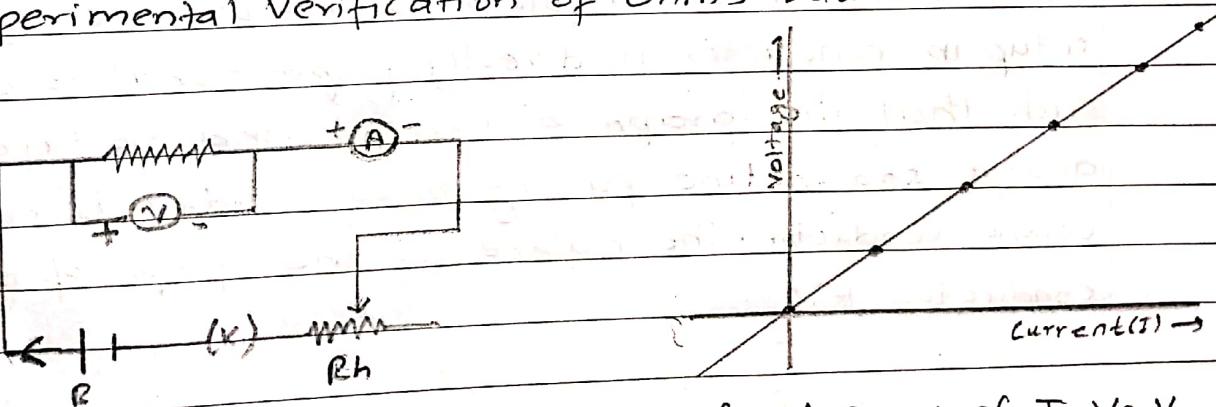


fig a) Current diagram for Ohms Law.

fig b) Graph of I Vs V.

The experimental setup for Ohm's law is given in figure above in which Resistor is connected in series with Battery (B), key (K), variable Resistor ( $R_n$ ) and finally with Ammeter (A). The volt meter is connected in parallel with Resistor so that voltage across R can be noted. Ammeter is used for detection of current. When key (K) is closed, the

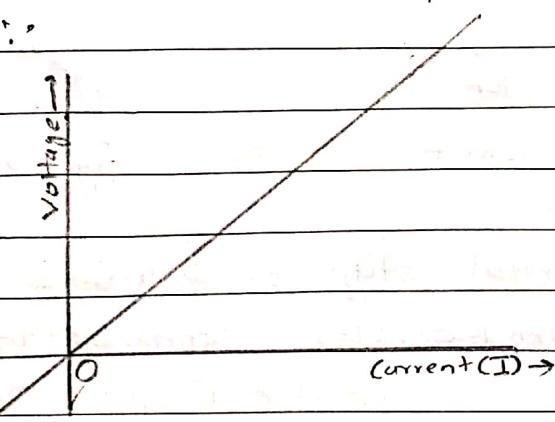
current is developed in Resistor ( $R$ ) and corresponding value of voltage is noted. This process is repeated by maintaining different value of current so that different voltage can be obtained at constant resistance ( $R$ ).

Let  $I_1, I_2 \dots$  be the value of current for respective potential difference  $V_1, V_2 \dots$  at constant value of  $R$  such that  $\frac{V_1}{I_1} = \frac{V_2}{I_2} = \frac{V_3}{I_3} \dots = \text{constant}$ .

If we plot the graph of current and voltage in X and Y-axis respectively then, the nature of the graph is obtained as shown in fig (b) which is eq<sup>r</sup> of straight line passing through origin. This expression confirms Ohm's Law.

### # Ohmic Conductor

The conductor which follows Ohm's Law i.e. voltage setup in conductor is directly proportional to current such that the graph of current and voltage is always straight line passing through origin is known as Ohmic Conductor. The nature of the graph of ohmic conductor is:



Example:- Copper, Silver, Iron, Zinc, Gold, etc.

## Non-Ohmic Conductor

The conductor is ~~directly proportional~~ which doesn't follow Ohm's law such that there is no linear relationship between Voltage and current is known as Non-Ohmic conductor. For example:- semiconductor, transistor, vacuum tube, etc.

The I-V curve of Non-Ohmic conductor is:-

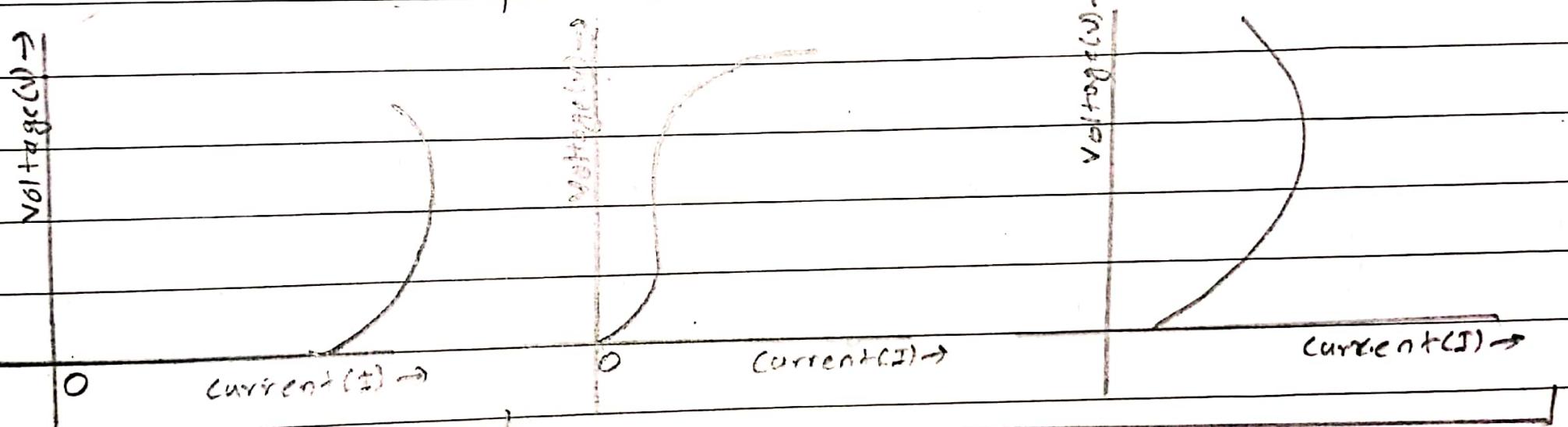


fig:- Semiconductor

fig:- filament