5. ELECTROSTATICS

Synopsis :

1. Study of stationary electric charges at rest is known as **electrostatics**.
2. **Electric Charge** :
   - i) It is a fundamental property of matter and never found free.
   - ii) There are two kinds of charges namely positive and negative. If a body has excess of electrons, it is said to be **negatively charged** and if it is deficient in electrons, it is said to be **positively charged**.
   - iii) Benzamin Frankline introduced the concept of positive and negative charges.
   - iv) Repulsion is the sure test for the detection of a charge.
   - v) In S.I. system the unit of charge is **coulomb.**
   - vi) Charge is **scalar quantity**.
   - vii) Like charges repel and un-like charges attract.
   - viii) Charge is conserved. It can neither be created nor destroyed. It can only be transferred from one object to other.
   - ix) Charge is quantised. The smallest charge is associated with electron (–) and proton (+) is 1.6×10^{-19} coulomb.
   - x) All charges in nature exist as integral multiples of electron charge. q = n.e. $n \rightarrow$ Integer
   - xi) A coulomb is equivalent to a charge of 6.243×10^{18} electrons.
   - xii) When a body is positively charged, its mass slightly decreases
   - xiii) When a body is negatively charged, its mass slightly increases.
   - xiv) In the case of a conductor, its charge spreads over the entire outer surface and in the case of an insulator, its charge is localised
   - xv) Charge given to a conductor always resides on the outer surface of the conductor only.
3. **Charging of bodies :**
   - i) The process of making a neutral body into a charged body is known as **electrification**
   - ii) Electrification is universal phenomenon
   - iii) A body can be charged by any one of the following three ways :

     (a) friction   (b) contact and

     (c) electrostatic induction
4. **Charging by friction** :
   - i) The electricity (i.e., transfer of electrons) that is produced due to friction is called **frictional electricity**
   - ii) When we rub two neutral bodies, there will be some transfer of electrons from one body to the other due to structural modifications because of the frictional forces acting on them.
   - iii) In this method one of the bodies acquires a negative charge while the other gets a positive charge, both of which are equal in magnitude.

Eg: a) When a glass rod is rubbed with silk cloth, glass acquires positive charge and silk cloth acquires negative charge. Electrons are removed from glass rod and are added to silk cloth.

b) When an ebonite rod is rubbed with fur cloth, ebonite rod acquires negative charge and fur cloth acquires positive charge. Electrons are transferred from fur cloth to ebonite rod.

iv) The list of substances called electric series given below is arranged in such a manner that if any two of them rubbed together, the one occurring earlier would be positively charged.

1. Glass	2. Flannel	3. Wool
4. Silk	5. Sealing wax	6. Hard metal
7. Hard rubber	8. Resin	9. Sulphur, etc.

Eg: If we select glass and silk, glass will acquire a positive charge while silk will get a negative charge when glass rod is rubbed with silk

5. **Charging by contact** :

i) A neutral body can be charged by making contact with a charged body.

ii) Here the body will acquire a charge that is the same as that of the charging body.

iii) Thus by contact a similar charge is formed on both the bodies.

iv) In this method first body's charge decreases.

6. **Charging by electrostatic induction** :

i) Induction always precedes attraction

ii) Polarisation of charges in a body when a charged body is present near that is called **induction**.

iii) In induction, a charged body is brought near an uncharged body. Then the uncharged body acquires a charge opposite in sign to that of the charged body.

Induced charge on dielectric slab of dielectric constant K is $q^1 = -q\left[1 - \frac{1}{K}\right]$.

For metals K = α $\therefore$ $q^1 = -q$.

iv) Without a decrease in the charge of the body, which induces by the method of induction, bodies can be charged continuously.

7. **Conductors , insulators and semiconductors:**

i) A body in which electric charge can easily flow through is called **conductor** (e.g. metals).

ii) A body in which electric charge cannot flow is called **insulator** or **dielectric**. (e.g. glass, wool, rubber, plastic, etc.)

iii) Substances which are intermediate between conductors and insulators are called **semiconductors**.(e.g. silicon, germanium, etc)

8. **Electroscope :**

i) An **electroscope** is used to detect the charge on a body.

ii) **Pith ball electroscope** is used to detect a charge and to know the nature of the charge.

iii) **Gold leaf electroscope** which was invented by Bennet detects a charge and the nature of the charge and determines the quantity of the charge.

9. **Coulomb's law :**

i) The force of attraction or repulsion between two charged bodies is directly proportional to the product of their charges and inversely proportional to the square of the distance between them.

ii) It acts along the line joining the two charges considered to be point charges.

iii) $F \propto \frac{q_1 q_2}{d^2}$

iv) $F = \frac{1}{4\pi\varepsilon_o\varepsilon_r} \cdot \frac{q_1 q_2}{d^2}$ (or) $F = \frac{1}{4\pi\varepsilon_o K} \cdot \frac{q_1 q_2}{d^2}$ (or) $F = \frac{1}{4\pi\varepsilon} \cdot \frac{q_1 q_2}{d^2}$

a) where ε is **absolute permittivity**,
K or ε_r is the **relative permittivity** or **specific inductive capacity** and ε_o is the **permittivity of free space**.

b) K or ε_r is also called as **dielectric constant** of the medium in which the two charges are placed.

v) a) **Relative permitivity of a material =**

$$\varepsilon_r = K = \frac{\text{Force between two charges in air}}{\text{Force between the same charges in the medium at the same distance}}$$

$$\varepsilon_r = \frac{F_a}{F_m}$$

b) For air K = 1

c) For metals K = infinity

d) Force between 2 charges depends upon the nature of the intervening medium , where as gravitational force is independent of intervening medium.

vi) For air or vacuum, $F = \frac{1}{4\pi\varepsilon_o} \cdot \frac{q_1 q_2}{d^2}$

since for air or vacuum, $\varepsilon_r = K = 1$

vii) The value of $\frac{1}{4\pi\varepsilon_o}$ is equal to 9×10^9 Nm^2/C^2.

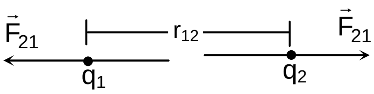
viii) A coulomb is that charge which repels an equal charge of the same sign with a force of 9×10^9 N when the charges are one metre apart in vacuum.

ix) The value of ε_o is 8.86×10^{-12} C^2/Nm^2 (or) 8.86×10^{-12} Fm^{-1}

x) Coulomb force is conservative mutual and internal force.

xi) Coulomb force is true only for static charges.

10. **Coulomb's law in vector form :**



1) $\vec{F}_{12} = \frac{1}{4\pi \in_0} - \frac{q_1 q_2}{r_{12}^2} \hat{r}_{12}$; $\vec{F}_{12} = -\vec{F}_{21}$

Here F_{12} is force exerted by q_1 on q_2 and F_{21} is force exerted by q_2 on q_1.

2) Coulomb's law holds for stationary charges only which are point sized.

3) This law obeys Newton's third law $\left(\text{ie } \vec{F}_{12} = -\vec{F}_{21}\right)$.

11. Force on a charged particle due to a number of point charges is the resultant of forces due to individual point charges i.e. $\vec{F} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 + ...$

12. i) If the force between two charges in two different media is the same for different separations, $F = \frac{1}{K}\frac{1}{4\pi\epsilon_0}\frac{q_1q_2}{r^2}$ = constant .

ii) Kr^2 = constant or $K_1r_1^2 = K_2r_2^2$

iii) If the force between two charges separated by a distance 'r_0' in vacuum is same as the force between the same charges separated by a distance 'r' in a medium, $Kr^2 = r_0^2 \Rightarrow r = \frac{r_0}{\sqrt{k}}$

13. a) Two identical conductors having charges q_1 and q_2 are put to contact and then separated, then each have a charge equal to $\frac{q_1+q_2}{2}$. If the charges are q_1 and $-q_2$, then each have a charge equal to $\frac{q_1-q_2}{2}$.

b) Two spherical conductors having charges q_1 and q_2 and radii r_1 and r_2 are put to contact and then separated then the charges of the conductors after contact are $q_1 = \left(\frac{r_1}{r_1+r_2}\right)(q_1+q_2)$ &

$q_2 = \left(\frac{r_2}{r_1+r_2}\right)(q_1+q_2)$.

c) The force of attraction or repulsion between two identical conductors having charges q_1 and q_2 when separated by a distance d is F. If they are put to contact and then separated by the same distance the new force between them is $F' = \frac{F(q_1+q_2)^2}{4q_1q_2}$

If charges are q_1 and $-q_2$ then $F' = \frac{F(q_1-q_2)^2}{4q_1q_2}$.

d) Between two electron separated by a certain distance $\frac{\text{Electrical force}}{\text{Gravitational force}} = 10^{42}$

Between two protons separated by a certain distance $\frac{\text{Electrical force}}{\text{Gravitational force}} = 10^{36}$

Between a proton and an electron separated by a certain distance $\frac{\text{Electrical force}}{\text{Gravitational force}} = 10^{39}$

e) The relationship between velocity of light, permeability of free space and permittivity of free space is given by the expression $c = 1/\sqrt{(\mu_o\varepsilon_o)}$.

f) If two identical balls each of mass m are hung by silk thread of length 'ℓ' from a same hook and carry similar charges q then.

g) The distance between balls = $\left[\frac{q^2 2\ell}{4\pi\epsilon_0 mg}\right]^{1/3}$

h) The tension in the thread = $\sqrt{(F)^2 + (mg)^2}$

i) If total system is kept in space then angle between threads is 180° and tension in thread is given by T = $\frac{1}{4\pi \epsilon_0}\frac{q^2}{4\ell^2}$

14. A charge Q is divided into q and (Q – q). Then electrostatic force between them is maximum when $\frac{q}{Q}=\frac{1}{2}$ (or) $\frac{q}{(Q-q)}=1$.

15. **Electric field and electric intensity :**

i) The space around an electric charge in which its influence can be felt is known as **electric field**.

ii) The **intensity of electric field (E)** at a point is the force experienced by a unit positive charge placed at that point.

iii) It is a vector quantity.

iv) E = F/ q , unit of E is NC^{-1} or Vm^{-1}

v) Due to a point charge q, the intensity at a point d units away from it is given by the expression $E=\frac{q}{4\pi\varepsilon d^2}$ NC^{-1}. Another unit is volt/metre.

vi) The electric field due to a positive charge is always directed away from the charge.

vii) The electric field due to a negative charge is always directed towards the charge.

viii) The intensity of electric field at any point due to a number of charges is equal to the vector sum of the intensities produced by the separate charges.

16. **Force experienced by a charge Q in an electric field.**

$\vec{F}=Q\vec{E}$ where E is the electric intensity.

i) If Q is positive charge, the force $\vec{F}$ acts in the direction of $\vec{E}$. Acceleration a = $\frac{F}{m}=\frac{QE}{m}$

ii) If Q is negative charge, the force $\vec{F}$ acts in a direction opposite to $\vec{E}$ Acceleration a = $\frac{F}{m}=\frac{QE}{m}$

iii) A charge in an electric field experiences a force whether it is at rest or moving.

iv) The electric force is independent of the mass and velocity of the charged paerticle, it depends upon the charge.

v) A proton and an electron in the same electric field experience forces of samemagnitude but in opposite directions.

vi) Force on proton is accelerating force where as force on electron is retarding force. If the proton and electron are initially moving in the direction of electric field. $\frac{\text{Acceleration of Proton}}{\text{Retardation of electron}}=\frac{\text{mass of electron}}{\text{mass of proton}}$

17. **Dielectric Strength :** It is the minimum field intensity that should be applied to break down the insulating property of insulator.

i) Dielectric strength of air = 3×10^6 V/m

Dielectric strength of Teflon = 60×10^6 Vm^{-1}

ii) The maximum charge a sphere can hold depends on size and dielectric strength of medium in which sphere is placed.

iii) The maximum charge a sphere of radius 'r' can hold in air = $4\pi\in_0 r^2 \times$ dielectric strength of air.

18. When the electric field in air exceeds its dielectric strength air molecules become ionised and are accelerated by fields and the air becomes conducting.

18. **Electric lines of force :**

i) Line of force is the path along which a unit +ve charge, accelerates in electric field.

ii) The tangent at any point to the line of force gives the direction of the field at that point.

iii) Two lines of force never intersect.

iv) Number of lines of force passing normally through unit area around a point is numerically equal to E, the strength of the field at the point.

v) Lines of force always leave or end normally on a charged conductor.

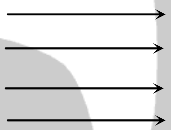
vi) Electric lines of force can never be closed loops.

vii) Lines of force have tendency to contract **longitudinally** and exert a force of repulsion on one another laterally.

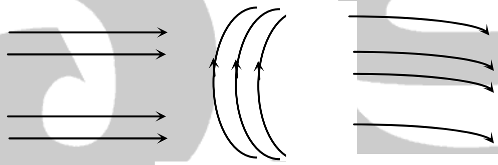
viii) If in a region of space there is no electric field, there will be no lines of force. Inside a conductor there cannot be any line of force.

ix) Number of lines of force passing normally through unit area around a point is numerically equal to E.

x) In uniform field, lines of force are parallel to one another.



Uniform field



Magnitude is not constant | **Direction is not constant** | **Both magnitude and not constant**

Non uniform magnetic field

19. **Difference between electric lines of force and magnetic lines of force :**

i) Electric lines of force never form closed loops while magnetic lines are always closed loops.

ii) Electric lines of force do not exist inside a conductor but magnetic lines of force may exist inside a magnetic material.

20. **Motion of a charged particle in an electric field.**

i) If a charged particle of charge Q is placed in an electric field of strength E, the force experienced by the charged particle = EQ.

ii) The acceleration of the charged particle in the electric field, $a = \frac{EQ}{m}$

iii) The velocity of charged particle after time "t" is $V = at = \left(\frac{EQ}{m}\right)t$ if the initial velocity is zero.

iv) The distance travelled by the charged particle is $S = \frac{1}{2}at^2 = \frac{1}{2}\left(\frac{EQ}{m}\right)t^2$ if the initial velocity is zero

v) When a charged particle is projected into a uniform electric field with some velocity perpendicular to the field, the path traced by it is **parabola**.

vi) The trajectory of a charged particle projected in a different direction from the direction of a uniform electric field is a **parabola.**

vii) When a charged particle of mass m and charge Q remains suspended in an vertical electric field then mg=EQ.

viii)When a charged particle of mass m and charge Q remains suspended in an electric field, the number of fundamental charges on the charged particle is n then

$$mg = E(ne)$$

$$n = \frac{mg}{Ee}$$

xi) The bob of a simple pendulum is given +ve charge and it is made to oscillate in vertically upward electric field, then the time period of oscillation is $T = 2\pi\sqrt{\dfrac{\ell}{g - \dfrac{EQ}{m}}}$

x) In the above case, if the bob is given a –ve charge then the time period is given by $T = 2\pi\sqrt{\dfrac{\ell}{g + \dfrac{EQ}{m}}}$

xi) A charged particle of charge ±Q is projected with an initial velocity u making an angle θ to the horizontal in an electric field directed vertically upward. Then

a) Time of flight = $\dfrac{2u\sin\theta}{g \mp \dfrac{EQ}{m}}$

b) Maximum height = $\dfrac{u^2\sin^2\theta}{2\left(g \mp \dfrac{EQ}{m}\right)}$

c) Range = $\dfrac{u^2\sin 2\theta}{\left(g \mp \dfrac{EQ}{m}\right)}$

xii) Density of electric field inside a charged hollow conducting sphere is zero

xiii) A sphere is given a charge of 'Q' and is suspended in a horizontal electric field. The angle made by the string with the verticle is, $\theta = \tan^{-1}\left(\dfrac{EQ}{mg}\right)$

xiv) The tension in the string is $\sqrt{(EQ)^2 + (mg)^2}$

xv) A bob carrying a +ve charge is suspended by a silk thread in a vertically upward electric field, then the tension in the string is, T = mg - EQ.

xvi) If the bob carries –ve charge, tension in the string is T = mg + EQ

21. **Surface charge density (σ):**

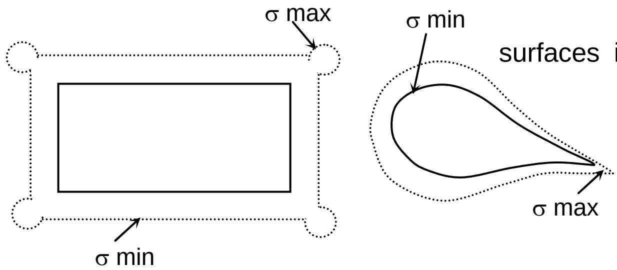
i) The charge per unit area of a conductor is defined as surface charge density.

ii) $\sigma = \frac{q}{A} = \frac{\text{total charge}}{\text{area}}$, when A=1 m^2 then $\sigma = q$

iii) Its unit is coulomb/ meter and its dimensions are ATL^{-2}.

iv) It is used in the formulae for charged disc, charged conductor and infinite sheet of charge etc.

v) $\sigma \propto \frac{1}{r^2}$ i.e. $\frac{\sigma_1}{\sigma_2} = \frac{r_2^2}{r_1^2}$



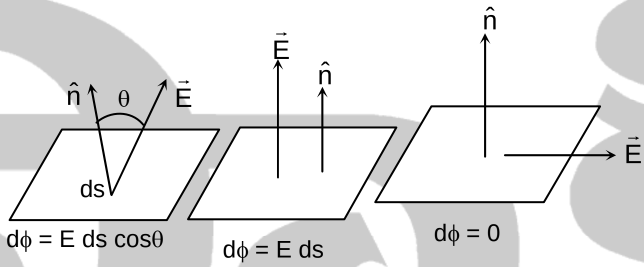
vi) σ is maximum at pointed surfaces and for plane surfaces it is minimum.

vii) σ depends on the shape of the conductor and presence of other conductors and insulators in the vicinity of the conductor.

viii) σ is maximum at the corners of rectangular laminas and at the vertex of conical conductor.

22. **Electric flux :**

i) The number of electric lines of force crossing a surface normal to the area gives electric flux ϕ_E.



ii) Electric flux through an elementary area ds is defined as the scalar product of area and field.
$d\phi_E = \vec{E}.d\vec{s} = Eds\cos\theta$

iii) $\phi_E = \int \vec{E}.d\vec{s}$

iv) Flux will be maximum when electric field is normal to the area ($d\phi = Eds$)

v) Flux will be minimum when field is parallel to area (dφ =t 0)

vi) For a closed surface, outward flux is positive and inward flux is negative.

23. **Gauss's Law :**

i) The total flux linked with a closed surface is $(1/\epsilon_0)$ times the charge enclosed by the closed surface.
$\oint \vec{E}.d\vec{s} = \frac{1}{\epsilon_0} q$

ii) A point charge q is placed inside a cube of edge 'a'. The flux through each face of the cube is $\frac{q}{6\epsilon_0}$.

24. **Electric potential (V):**

1) Electric potential at a point in a field is the amount of work done in bringing a unit +ve charge from infinity to the point.

2) It is equal to the Electric potential energy of unit + ve charge at that point.

3) It is a scalar

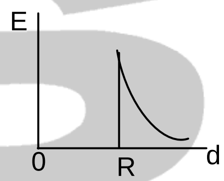
4) S.I unit is volt
5) Potential at a distance 'd' due to a point charge q in air or vacuum is V = $\frac{1}{4\pi\varepsilon_0}.\frac{q}{d}$
6) $V = -\int \vec{E}.\vec{d}x$
7) $\vec{E} = -\frac{dv}{dx}$ (or) V = Ed
8) A positive charge in a field moves from high potential to low potential where as electron moves from low potential to high potential when left free.
9) Work done in moving a charge q through a potential difference V is W = q V joule
10) Gain in the Kinetic energy ; $\frac{1}{2}mv^2 = qV$
11) Gain in the velocity $v = \sqrt{\frac{2qV}{m}}$

25. **Equipotential surface**

1) A surface on which all points are at the same potential
2) Electric field is perpendicular to equipotential surface
3) Work done in moving a charge on equipotential surface is zero.

26. **In the case of a hollow charged sphere.**

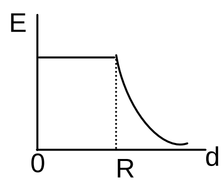
1) Intensity at any point inside the sphere is zero.
2) Intensity at any point on the surface is same and it is maximum $E = \frac{1}{4\pi\varepsilon_0}.\frac{q}{r^2}$



3) Outside the sphere $E = \frac{1}{4\pi\varepsilon_0}.\frac{q}{d^2}$ d = distance from the centre
4) It behaves as if the whole charge is at its centre.
5) Electric field Intensity in vector form $\vec{E} = \frac{1}{4\pi\varepsilon_0}.\frac{q}{d^3}\vec{d}$ or $\vec{E} = \frac{1}{4\pi\varepsilon_0}.\frac{q}{d^2}\hat{d}$
6) The resultant electric field intensity obey's the principle of superposition.
$\vec{E} = \vec{E}_1 + \vec{E}_2 + \vec{E}_3 + \ldots\ldots\ldots\ldots\ldots$

27. **In the case of hollow charged sphere**

1) The potential at any point inside the sphere is same as that at any point on its surface
$V = \frac{1}{4\pi\varepsilon_0}.\frac{q}{r}$



2) It is an equipotential surface.
3) Outside the sphere, the potential varies inversely as the distance of the point from the centre.
$V = \frac{1}{4\pi\varepsilon_0}.\frac{q}{d}$

Note: Inside a non conducting charged sphere electric field is present.

Electric intensity inside the sphere

$E = \frac{1}{4\pi\varepsilon_0} . \frac{Q}{R^3} d$

Here d is the distance from the centre of sphere.

$E \propto d$

28. **Electron volt :**

i) This is the unit of energy in particle physics and is represented as eV.

ii) 1 eV = 1.602×10^{-19} J.

29. **Charged particle in electric field :**

a) When a positive test charge is fired in the direction of an electric field,

i) it accelerates,

ii) its kinetic energy increases and hence

iii) its potential energy decreases.

b) A charged particle of mass m carrying a charge q and falling through a potential V acquires a speed of $\sqrt{2Vq/m}$.

30. **Electric dipole**:

i) Two equal and opposite charges separated by a constant distance is called electric dipole. $\vec{P} = q.2\vec{l}$.

ii) **Dipole moment ($\vec{P}$)** is the product of one of the charges and distance between the charges. It is a vector directed from negative charge towards the positive charge along the line joining the two charges.

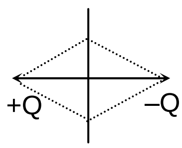
iii) The torque acting on an electric dipole placed in a uniform electric field is given by the relation $\vec{\tau} = \vec{P} \times \vec{E}$ i.e., $\tau = PE\sin\theta$, where θ is the angle between $\vec{P}$ and $\vec{E}$.

iv) The electric intensity(E) on the axial line at a distance 'd' from the centre of an electric dipole is $E = \frac{1}{4\pi\varepsilon_0} \cdot \frac{2Pd}{(d^2 - l^2)^2}$ and on equatorial line, the electric intensity (E) = $\frac{1}{4\pi\varepsilon_0} \cdot \frac{P}{(d^2 + l^2)^{3/2}}$.

v) For a short dipole i.e., if $l^2 << d^2$, then the electric intensity on axial line is given by $E = \frac{1}{4\pi\varepsilon_0} \cdot \frac{2P}{d^3}$.

vi) For a short dipole i.e., if $l^2 << d^2$, then the electric intensity on equatorial line is given by $E = \frac{1}{4\pi\varepsilon_0} \cdot \frac{P}{d^3}$.

vii) The potential due to an electric dipole on the axial line is $V = \frac{1}{4\pi\varepsilon_0} \cdot \frac{P}{(d^2 - l^2)}$ and at any point on the equatorial line it is zero.



viii) Two unlike equal charges +Q and –Q are separated by distance

1) The net electric potential is zero on the perpendicular bisector of the line joining the charges.

2) The bisector is equipoptential and zeropotential line.

3) Work done in moving a charge on this line is zero.

4) Electric intensity at any point on the bisector is perpendicular to the bisector.
5) Electric intensity at any point on the bisector parallel to the bisector is zero.

31. **Electric potential energy :**

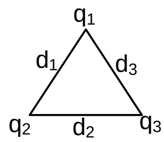
i) A charge placed in an electric field possesses potential energy and is measured by the work done in moving the charge from infinity to that point against the electric field.

ii) If two charges q_1 and q_2 are separated by a distance d, the P.E. of the system is U= $\frac{1}{4\pi\varepsilon_0}\frac{q_1q_2}{d}$

iii) If two like charges (two protons or two electrons) are brought towards each other, the P.E of the system increases.

iv) If two unlike charges (a proton and an electron) are brought towards each other, the P.E. of the system decreases.

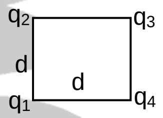
v) If three charges q_1, q_2 and q_3 are situated at the vertices of a triangle (as shown in the figure), the P.E. of the system is



$U = U_{12} + U_{23} + U_{31}$

$$= \frac{1}{4\pi\varepsilon_0}\left(\frac{q_1q_2}{d_1}+\frac{q_2q_3}{d_2}+\frac{q_3q_1}{d_3}\right)$$

vi) If four charges q_1, q_2 , q_3 and q_4 are situated at the corners of a square as shown in the figure, P.E of the system



$$\frac{1}{4\pi\varepsilon_0}\times\left(\frac{q_1q_2}{d}+\frac{q_2q_3}{d}+\frac{q_3q_4}{d}+\frac{q_4d_1}{d}+\frac{q_2q_4}{\sqrt{2}d}+\frac{q_1q_3}{\sqrt{2}d}\right)$$

vii) In the field of a charge Q, if a charge q is moved against the electric field from a distance 'a' to a distance 'b' from Q, the work done W is given by

$$W=(V_b-V_a)q=\frac{1}{4\pi\varepsilon_o}\frac{Qq}{b}-\frac{1}{4\pi\varepsilon_o}\frac{Qq}{a}=\frac{Qq}{4\pi\varepsilon_o}\left[\frac{1}{b}-\frac{1}{a}\right]=\frac{Qq}{4\pi\varepsilon_o}\left[\frac{a-b}{ab}\right]$$

32. **Combined field due to two point charges**

a) Due to two similar charges :

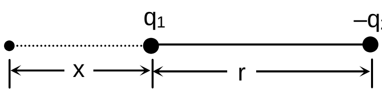
i) If charges q_1 and q_2 are separated by a distance 'r', null point (where resulting field intensity is zero) is formed on the line joining those two charges.

ii) null point is formed with in the charges.

iii) null point is located nearer to weak charge.

iv) If x is distance of null point from q_1,

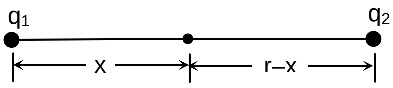
(weak charge) then $\frac{q_1}{x^2}=\frac{q_2}{(r-x)^2}$



$\Rightarrow x=\frac{r}{\sqrt{q_2/q_1}+1}$ Here q_1 and q_2 are like charges

b) Due to two dissimilar charges :

i) If q_1 and q_2 are unlike charges then null point is formed on the line joining two charges.



ii) null point is formed out side the charges.

iii) null point is form nearer weak charge.

iv) x is the distance of null point from q_1(weak charge) then $\frac{q_1}{x^2} = \frac{q_2}{(r+x)^2}$

$$\Rightarrow x = \frac{r}{\sqrt{q_2/q_1} - 1}$$

In the above formulae q_2/q_1 is numerical ratio of charges

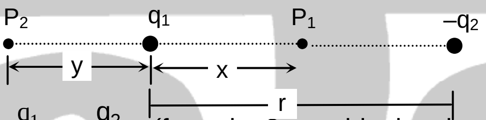
c) Zero potential point due to two charges :

i) If two unlike charges q_1 and q_2 are separated by a distance 'r', the net potential is zero at two points on the line joining them.

ii) one in between them and the other outside the charges.

iii) both the points are nearer to weak charge (q_1).

$\frac{q_1}{x} = \frac{q_2}{(r-x)}$ (for point 1, with in the charges)



$\frac{q_1}{y} = \frac{q_2}{(r+y)}$ (for point 2,out side the charges)

Here q_2 is numerical value of strong charge

$$\Rightarrow x = \frac{r}{\frac{q_2}{q_1}+1} \; ; \; y = \frac{r}{\frac{q_2}{q_1}-1}$$

d) due to two similar charges zero potential point is not formed.

33. **Equipotential surface:**

a) The surface which is the locus of all points which are at the same potential is known as equipotential surface

b) No work is required to move a charge from one point to another on the equipotential surface.

c) No two equipotential surfaces intersect

d) The direction of electric lines of force or direction of electric field is always normal to the equipotential surface.

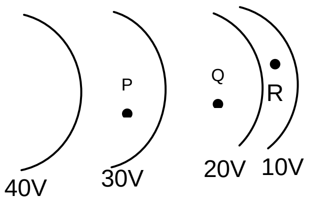
e) Inside a hollow charged spherical conductor the potential is constant. This can be treated as equipotential volume. No work is required to move a charge from the centre to the surface.

f) For an isolated point charge, the equipotental surface is a sphere. i.e. concentric spheres around the point charge are different equipotential surfaces.

g) In a uniform electric field any plane normal to the field direction is an equipotential surface.

h) The spacing between equipotential surfaces enables us to identify regions of strong and weak field.

$$E = -\frac{dV}{dr} \Rightarrow E \propto \frac{1}{dr}$$



$E_P < E_Q < E_R$

34. **Electrical capacity :**

i) Electrical capacity of a conductor is its ability to store electric charge.

ii) The potential acquired by a conductor is directly proportional to the charge given to it i.e., $V \propto Q$.

i.e., $Q \propto V$ or $Q = CV$ where the constant of proportionality 'C' is called the electrical capacity of the conductor.

iii) Thus the capacity of a conductor is defined as the ratio of the charge to the potential.

iv) Its SI unit is farad.

v) 1 milli farad (1 mF) = 10^{-3} farad

1 micro farad (1 μF) = 10^{-6} farad

1 pico farad (1 pF) = 10^{-12} farad

vi) The capacity of a spherical conductor in farad is given by $C = 4\pi\varepsilon_0 r$, where r = radius of the conductor.

vii) If we imagine Earth to be a uniform solid sphere then the capacity of earth

$$C = 4\pi\varepsilon_0 R = \frac{6400 \times 10^3}{9 \times 10^9} = 711\mu F \cong 1 \text{ mF}$$

35. **Dielectric materials, Polar and non polar molecules :**

a) *Dielectric material* : Any material that do not allow the electrical charges to easily pass through them is called insulator or dielectric material or simply a dielectric.

Dielectric is a technical term for an insulator.

b) Non -*polar molecule :*

i) In certain kind of materials, ordinarily the molecules will have symmetric charge distributions.

ii) Such kind of molecules are called non-polar molecules.

iii) In the absence of any external electric field, a non-polar molecule will have its centre of positive charge coinciding with centre of negative charge.

c) *Polar molecule :*

i) Certain dielectrics like water, hydrogenchloride and alcohol are made of molecules that have a non uniform distribution of electric charge.

ii) In such molecules, the positive charge centre will not coincide with the negative charge centre, even in the absence of any external field.

iii) The molecules are polarized even in the absence of any external electric field.

iv) Such kind of molecules are called Polar molecules.

36. **Parallel plate Capacitor :**

i) Condenser (usually, a combination of two conductors) is a device by means of which larger amount of charge can be stored at a given potential by increasing its electric capacity.

ii) Capacitance of a capacitor or condenser is the ratio of the charge on either of its plates to the potential difference between them.

iii) Capacity of a parallel plate condenser without medium between the plates $C_0 = \frac{\varepsilon_0 A}{d}$

A = area of each plate ; d = distance between the plates

iv) With a medium of dielectric constant K completely filling the space between the plates $C = K\frac{\varepsilon_0 A}{d}$

v) The **dielectric constant** of a dielectric material is defined as the ratio of the capacity of the parallel plate condenser with the dielectric between the plates to its capacity with air or vacuum between the plates.

$$K = \frac{C}{C_0} = \frac{\text{Capacity of the condenser with dielectric medium between plates}}{\text{Capacity of the same condeser with air as medium between plates}}$$

vi) When a dielectric slab of thickness 't' is introduced between the plates $C = \frac{\varepsilon_0 A}{d - t + \frac{t}{k}} = \frac{\varepsilon_0 A}{d - t\left(1 - \frac{1}{k}\right)}$

vii) In this case the distance of separation decreases by $t\left(1 - \frac{1}{k}\right)$ and hence the capacity increases

viii) To restore the capacity to original value the distance of separation is to be increased by $t\left(1 - \frac{1}{k}\right)$.

ix) a) If a metal slab of thickness t is introduced between the plates $C = \frac{\varepsilon_0 A}{d - t}$ because for metals K is infinity.

b) If a number of dielectric slabs are inserted between the plates, each parallel to plate surface, then equivalent capacity. $C = \frac{\epsilon_0 A}{d - t_1\left(1 - \frac{1}{K_1}\right) - t_2\left(1 - \frac{1}{K_2}\right) .... - t_n\left(1 - \frac{1}{K_n}\right)}$.

If those slabs completely fill up the gap between the plates leaving without any air gap, $C = \frac{\varepsilon_0 A}{\left(\frac{t_1}{K_1} + \frac{t_2}{K_2} + ... + \frac{t_n}{K_n}\right)}$.

x) In a parallel plate capacitor, the electric field at the edges is not uniform and that field is called as the **fringing field**.

xi) Electric field between the plates is uniform electric intensity $E = \frac{\sigma}{\varepsilon_0} = \frac{Q}{A\varepsilon_0} = \frac{Q}{Cd}$. Here σ is the surface charge density on the plates = Q/A.

xii) Potential difference between the plates $V = E.d = \frac{Q}{\varepsilon_0 A}.d$

xiii) Force on each plate $F = \frac{1}{2}EQ = \frac{1}{2}\frac{Q^2}{Cd} = \frac{1}{2}\frac{CV^2}{d} = \frac{1}{2}\frac{Q^2}{\varepsilon_0 A} = \frac{1}{2}\varepsilon_0 AE^2$

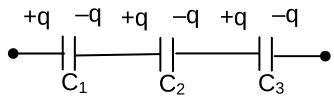
xiv) Energy stored per unit volume of the medium = $\frac{1}{2}\varepsilon_0 E^2$

37. **Combination of Condensers**:

i) When condensers are connected in series

1) All plates have the same charge in magnitude

2) Potential differences between the plates are different



3) $V_1 : V_2 : V_3 = \frac{1}{C_1} : \frac{1}{C_2} : \frac{1}{C_3}$

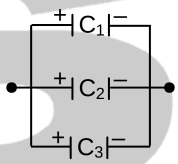
4) Equivalent capacity is C then, $\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$

5) The equivalent capacity is less than the least individual capacity

6) Energies of the condensers $E_1 : E_2 : E_3$
$= \frac{1}{C_1} : \frac{1}{C_2} : \frac{1}{C_3}$

7) Total energy of the combination=E_1+E_2 + E_3.

ii) When condensers are connected in parallel



1) P.D. across each condenser is same

2) Charge of each condenser is different $Q_1 : Q_2 : Q_3 = C_1 : C_2 : C_3$

3) Equivalent capacity of the combination $C = C_1 + C_2 + C_3$

4) The equivalent capacity is greater than the greatest individual capacity

5) Energies of the condensers $E_1 : E_2 : E_3$ =
$C_1 : C_2 : C_3$

6) Total energy of the combination=E_1+E_2+E_3

iii) When n identical condensers each of capacity C

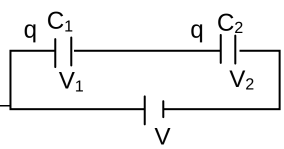
1) Combined in series, the effective capacity
$= C_s = C/n$

2) Combined in parallel, the effective capacity C_p = nc.

3) Ratio of the effective capacities C_s:C_p=1: n^2

iv) **Mixed group :** If there are N capacitors each rated at capacity C and voltage V, by combining those we can obtain effective capacity rated at C^1 and voltage V^1. For this n capacitors are connected in a row and m such rows are connected in parallel.

Then $n = \frac{V^1}{V}$ and $m = \frac{nC^1}{C}$ where mn = N



v) If C_p and C_s are the equivalent capacities of two capacitors of capacity C_1 and C_2 in parallel and series respectively then

$C_1 = \frac{1}{2}\left[C_P + \sqrt{C_p^2 - 4C_PC_S}\right]$ and

$C_2 = \frac{1}{2}\left[C_P - \sqrt{C_P^2 - 4C_PC_S}\right]$

vi) Two capacitors are connected in parallel to a battery as shown in the figure.

i) $V_1 = \frac{VC_2}{C_1 + C_2}$ ii) $V_2 = \frac{VC_1}{C_1 + C_2}$

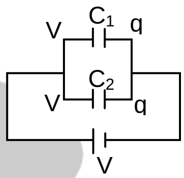
vii) Two capacitors are connected in parallel to a battery as shown in the figure.

i) $q_1 = \frac{qC_1}{C_1 + C_2}$ ii) $q_2 = \frac{qC_2}{C_1 + C_2}$

viii) If n identical capacitors each of capacity C are connected in a square then

a) The resultant capacity between any two adjacent corners A and B = $\frac{4C}{3}$

b) The resultant capacity between any two opposite corners A and C= C



ix) If n identical capacitors each of capacity C are connected in a polygon then

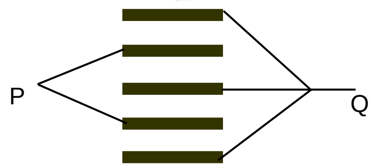
a) The resultant capacity between any two adjacent corners = $\frac{nC}{n-1}$

b) The resultant capacity between any two opposite corners = $\frac{4C}{n}$.

x) a) If n identical capacitors are given then they can be connected in 2^{n-1} different ways by taking all the condensers at a time (n > 2).

b) In n different capacitors are given then they can be connected in 2^n different ways by taking all the condensers at a time.

xi) In a parallel plate capacitor, if n similar plates at equal distance d are arranged such that alternate plates are connected together, the capacitance (C) of the arrangement is $\frac{(n-1)\varepsilon_0 A}{d}$ for air or vacuum and it becomes $\frac{(n-1)\varepsilon_0 AK}{d}$ in a dielectric medium of dielectric constant K.

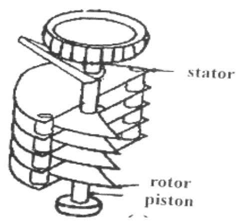


38. **Types of condensers** :

Capacitance of a variable capacitor can be varied gradually by varying the effective area included between the plates.

a) Variable condenser, multiple condenser, paper condenser, electrolytic condenser etc, are the different types of condensers.

b) **Variable capacitor** :



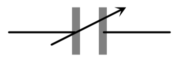
i) In variable capacitor, there are two sets of plates generally made of brass or aluminium.

ii) One set of plates is static or fixed and is known as **stator**.

iii) The other set of plates which rotates over the stator by rotating the pistons called rotor.

iv) This capacitor is generally used in tuning circuits in radio and T.V. receivers.

v) Symbol of variable Capacitor is



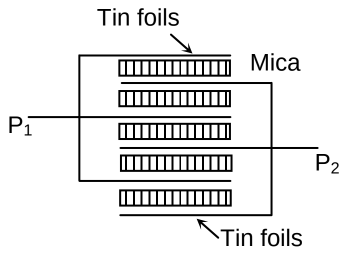
c) **Multiple capacitor:**

i) In a multiple capacitor there are a number of parallel plates with mica sheets as a dielectric between them.

ii) The capacitance is n times the capacitance between any two plates where n = number of mica sheets.

iii) These are used in high frequency oscillating circuits as dielectric constant of mica does not change with temperature.

vi) These are used as standard Capacitors in laboratory.



d) **Paper capacitor :**

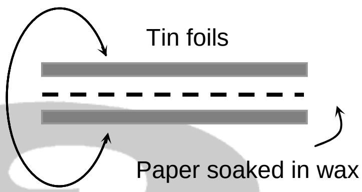
i) In a paper capacitor, paper soaked in wax or oil acts as a dielectric.

ii) Plates are usually tin foils. It can be rolled and sealed in a cylinder.

iii) These days to increase stability, paper is replaced by polystyrene.

vi) These occupy small space and cheaper in cost.

v) These are used in radio circuits and laboratories

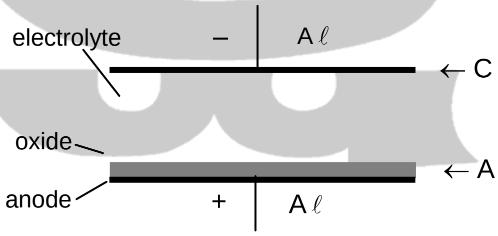


e) **Electrolytic capacitor :**

i) An electrolytic capacitor has two aluminium plates which are placed in a solution of ammonium borate.

ii) When D.C. is passed through the capacitor, very thin film of aluminium oxide is formed on the anode plate.

iii) The thickness of the oxide layer is of the order of 10^{-6} cm.



iv) Oxide layer acts as the dielectric between the plates.

v) This should be connected to proper polarity in a circuit

vi) In this capacitor polarity of terminals will be indicated

vii) Widely used when high capacitances are required.

viii) Capacitor of the order of $10^3 \mu F$

ix) Can be obtained with small volumes

39. **Uses of condenser (Capacitor):**

a. Capacitors area used to establish desired uniform and strong electric fields in small space.

b. Capacitors can confine strong electric field for small volumes. They serve as useful devices for storing electrical energy.

c. A capacitor blocks direct current and allows alternating currents. Capacitors are used in filter circuits.

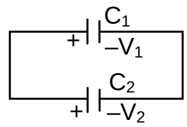
d. Capacitors are used in generation and detection of oscillating electric fields.

e. Capacitors are widely used in tuning circuits of radio and T.V. receivers.

f. To reduce voltage fluctuations in electric power supplies, to transmit pulsed signals and to provide time delays capacitors are essential.

40. **Energy of capacitor :**

i) The electrostatic energy stored in a charged capacitor is equal to $V = \frac{Q^2}{2C}$ or $\frac{CV^2}{2}$ or $\frac{QV}{2}$.



ii) This energy is stored in the uniform electric field that is present between the plates of the capacitor.

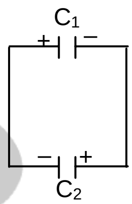
41. **Combination of charged capacitors :**

i) If two condensers of capacities C_1 and C_2 are charged to potentials V_1 and V_2 respectively and are joined in parallel (+ve plate connected to +ve plate), then the common potential

$$V \; \frac{Q_1+Q_2}{C_1+C_2} = \frac{C_1V_1+C_2V_2}{C_1+C_2} \qquad = \frac{1}{2}C_1V_1^2 + \frac{1}{2}C_2V_2^2 \qquad = -\left[\frac{1}{2}C_1V^2 + \frac{1}{2}C_2V^2\right]$$

ii) The loss of energy in this process (manifested as heat) is given by $U = \frac{C_1C_2}{2(C_1+C_2)}(V_1-V_2)^2$.

iii) When two condensers of capacities C_1 and C_2 charged to potentials V_1 and V_2 are connected antiparallel (+ve plate connected to –ve plate) as shown in the figure.



a) Common potential $V = \frac{Q_1-Q_2}{C_1+C_2} \Rightarrow \frac{C_1V_1-C_2V_2}{C_1+C_2}$

b) Loss of energy

$$= \frac{1}{2}C_1V_1^2 + \frac{1}{2}C_2V_2^2 - \frac{1}{2}(C_1+C_2)V^2 \qquad = \frac{1}{2}\frac{C_1C_2}{C_1+C_2}(V_1+V_2)^2$$

c) Loss of energy is more in this case compared with previous case.

42. **Capacitance of spherical condenser** :

a) Capacitance of single isolated sphere $= 4\pi\varepsilon_0 R$ where R is its radius.

b) In two concentric spheres (outer radius a and inner radius b).

i) When the inner is charged and the outer is earthed, then

$$C = \frac{4\pi\varepsilon_0\varepsilon_r ab}{a-b} = 4\pi\varepsilon_0 \cdot \frac{Kab}{(a-b)}$$

ii) When the inner sphere is earthed, then

$$C = \frac{4\pi\varepsilon_0\varepsilon_r a^2}{a-b} = \frac{4\pi\varepsilon_0 K a^2}{a-b}$$

43. **Introduction of dielectric in a charged capacitor**

A dielectric slab (K) is introduced between the plates of the capacitor .

S no	Physical quantity	With battery permanently connected	With battery disconnected
1.	Capacity	K time increases	K times increases
2.	Charge	K times increases	Remains constant
3.	P.D.	Remains constant	K times decreases

4.	Electric Intensity	Remains constant	K times decreases
5.	Energy stored in condenser	K times increases	K times decreases

44. **The distance between the plates of condenser is increased by n times.**

Sno.	Physical quantity	With battery permanently connected	With battery disconnected
1.	Capacity	n time decreases	n times decreases
2.	Charge	n times decreases	Remains constant
3.	P.D.	Remains constant	n times increases
4.	Electric Intensity	n time decreases	Remain constant
5.	Energy stored in condenser	n times decreases	n times increases

45. **Combination of charged spherical drops :**

When ‘n’ identical charged small spherical drops are combined to form a Big drop.

Sno.	Quantity	For each charged small drop	For the big drop
a.	Radius	r	$R = n^{1/3}r$
b.	Charge	q	$Q = n \times q$
c.	Capacity	C	$C^1 = n^{1/3} \times C$
d.	Potential	V	$V^1 = n^{2/3} \times V$
e.	Energy	ν	$\nu^1 = n^{5/3}\ \nu$
f.	Surface density of charge	σ	$\sigma^1 = n^{1/3}.\ \sigma$

46. 1 ab-farad = 10^9 farad,

1 farad = 9×10^{11} stat-farad,

1 coulomb = $3\text{x}10^9$ stat-coulomb,

1 ab-coulomb = 10 coulomb,

1 stat-volt = 300 volt,

1 volt = 10^8 ab-volt.

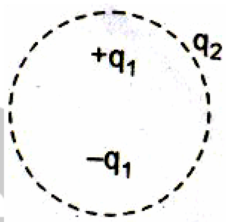
47. **Gauss Law :**

i) **Statement :** The total normal electric flux ϕ_e over a closed surface is $1/\varepsilon_0$ times the total charge Q enclosed within the surface.

$$\phi_e = \left(\frac{1}{\varepsilon_0}\right)Q$$

ii) Gauss Law is applicable for any distribution of charges and any type of closed surface, but it is easy to solve the problem of high symmetry.

iii) At any point over the spherical Gaussian surface, net electric field is the vector sum of electric fields due to $+q_1$, $-q_1$ and q_2.



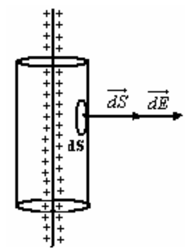
48. **Applications of Gauss Theorem:**

a) **Electric field at a point due to a line charge:**

A thin straight wire over which 'q' amount of charge be uniformly distributed. l be the linear charge density i.e, charge present per unit length of the wire.

$$E = \frac{q}{2\pi \in_0 rl}$$

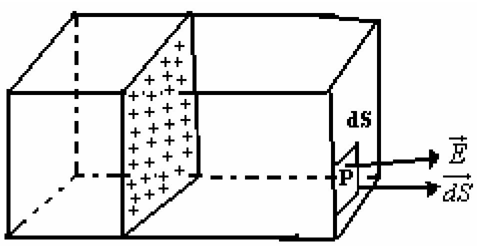
$$E = \frac{\lambda}{2\pi \in_0 r}$$



This implies electric field at a point due to a line charge is inversely proportional to the distance of the point from the line charge.

b) **Electric field intensity at a point due to a thin infinite charged sheet :**

'q' amount of charge be uniformly distributed over the sheet. Charge present per unit surface area of the sheet be σ.



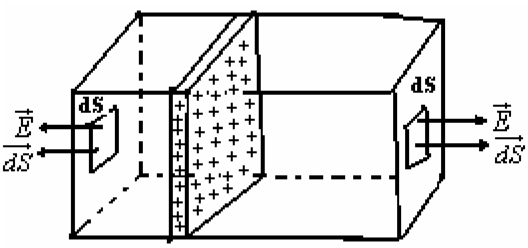
$$E = \frac{q}{2A \in_0}$$

$$E = \frac{q}{2 \in_0} \text{ where } \sigma = \frac{q}{A}$$

E is independent of the distance of the point from the charged sheet.

c) **Electric field intensity at a point due to a thick infinite charged sheet :**

'q' amount of charge be uniformly distributed over the sheet. Charge present per unit surface area of the sheet be σ.



$$E = \frac{q}{A \in_0} = \frac{\sigma}{\in_0}$$

Electric field at a point due to a thick charged sheet is twice that produced by the thin charged sheet of same charge density.

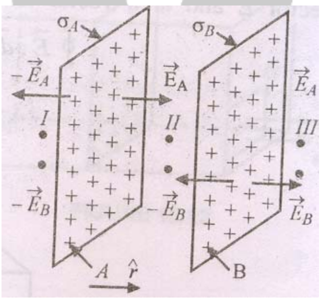
d) **Electric intensity due to two thin parallel charged sheets:**

Two charged sheets A and B having uniform charge densities σ_A and σ_B respectively.

In region I :

$$E = \frac{1}{2 \in_0}\left(\sigma_A + \sigma_B\right)$$

In region II :



$$E_{II} = \frac{1}{2 \in_0}\left(\sigma_A - \sigma_B\right)$$

In region III :

$$E_{III} = \frac{1}{2 \in_0}\left(\sigma_A + \sigma_B\right)$$

e) **Electric field due to two oppositely charged parallel thin sheets :**

$$E_I = -\frac{1}{2 \in_0}[\sigma + (-\sigma)] = 0$$

$$E_{II} = \frac{1}{2 \in_0}[\sigma - (-\sigma)] = \frac{\sigma}{\in_0}$$

$$E_{III} = \frac{1}{2 \in_0}(\sigma - \sigma) = 0$$

f) **Electric field due to a charged Spherical shell**

'q' amount of charge be uniformly distributed over a spherical shell of radius 'R'

$\sigma =$ Surface charge density, $\sigma = \dfrac{q}{4\pi R^2}$

i) **When point 'P' lies outside the shell :**

$$E = \frac{1}{4\pi \in_0} \times \frac{q}{r^2}$$

This is the same expression as obtained for electric field at a point due to a point charge. Hence a charged spherical shell behaves as a point charge concentrated at the centre of it.

$$E = \frac{1}{4\pi \in_0} \frac{\sigma.4\pi R^2}{r^2} \quad \because \sigma = \frac{q}{4\pi r^2}$$

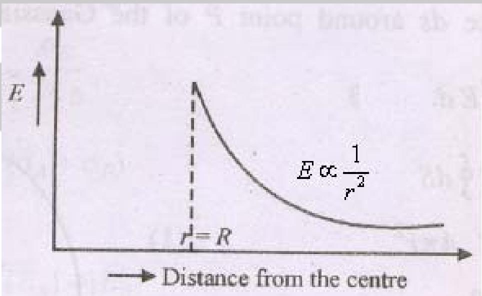
$$E = \frac{\sigma.R^2}{\in_0 r^2}$$

ii) **When point 'P' lies on the shell :**

$$E = \frac{\sigma}{\in_0}$$

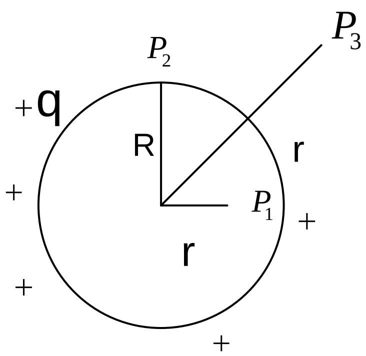
iii) **When Point 'P' lies inside the shell:**

E = 0



The electric intensity at any point due to a charged conducting solid sphere is same as that of a charged conducting sperical shell.

g) **Electric Potential (V) due to a spherical charged conducting shell (Hollow sphere)**

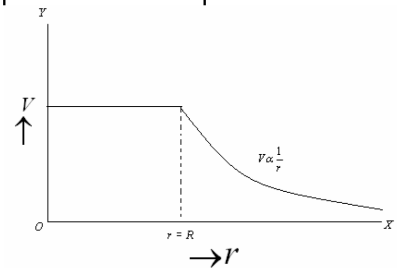


i) When point (P_3) lies outside the sphere $(r > R)$, the electric potential, $V = \dfrac{1}{4\pi\varepsilon_0}\dfrac{q}{r}$

ii) When point (P_2) lies on the surface $(r = R)$, $V = \dfrac{1}{4\pi\varepsilon_0}\dfrac{q}{R}$

iii) When point (P_1) lies inside the surface $(r < R), V = \frac{1}{4\pi\varepsilon_0}\frac{q}{R}$.

Note: The electric potential at any point inside the sphere is same and is equal to that on the surface.



Note: The electric potential at any point due to a charged conducting sphere is same as that of a charged conducting spherical shell.

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