GIST OF THE LESSON

Electrostatic force of interaction acting between two stationary point charges is given by

$$F = \frac{1}{4\pi\varepsilon_0}\cdot\frac{q_1 q_2}{r^2}$$

where q_1, q_2 are magnitude of point charges, r is the distance between them and ε_0 is permittivity of free space.

Here, $\frac{1}{4\pi\varepsilon_0} = 9 \times 10^9$ N-m²/C²

The value of ε_0 is 8.85×10^{-12} $C^2/N\text{-}m^2$.

If there is another medium between the point charges except air or vacuum, then ε_0 is replaced by $\varepsilon_0 K$ or $\varepsilon_0\varepsilon_r$ or ε.

where K or ε_r is called dielectric constant or relative permittivity of the medium.

$K = \varepsilon_r = \varepsilon / \varepsilon_0$ where, ε = permittivity of the medium.

For air or vacuum, K = 1 For water K = 81 For metals, $K = \infty$

In Medium Culomb's force becomes $F_m = \frac{F_0}{K}$

Coulomb Law implies:

Force on q_1 due to q_2 = – Force on q_2 due to q_1

$F_{12} = -F_{21}$

The forces due to two-point charges are parallel to the line joining point charges; such forces are called central forces and electrostatic forces are conservative forces.

Electric Field:

The space in the surrounding of any charge in which its influence can be experienced by other charges is called electric field.

Electric Field Lines:

"An electric field line is an imaginary line or curve drawn through a region of space so that its tangent at any point is in the direction of the electric field vector at that point. The relative closeness of the lines at some place gives an idea about the intensity of electric field at that point."

Properties of Field Lines:

(i) Two field lines can never intersect.
(ii) Electric field lines always begin on a positive charge and end on a negative charge.
(iii) In Charge Free region field line are continuous curves without any breaks.
(iv) Drawing of field lines is proportional to the magnitude of charge. and do not start or stop in mid space.
(v) Strength of electric field at a point is directly proportional to the number of field lines passing per unit area of an element held normal to the direction of the field.
(vi) direction of field lines is always normal to the surface of the conductor.
(vii) Field lines never form closed loops.

Electric Field Intensity (E):

The electrostatic force acting per unit positive charge on a point in electric field is called electric field intensity at that point.

Electric field intensity $E = \frac{F}{q}$

Its SI unit is NC^{-1} or V/m and its dimension is $[MLT^{-3}A^{-1}]$.

It is a vector quantity and its direction is in the direction of electrostatic force acting on positive charge.

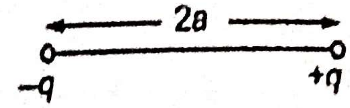
Electric field intensity due to a point Charge:

due to a point charge q at a distance r is given by

Magnitude - $E = \frac{1}{4\pi\varepsilon_0}\cdot\frac{q}{r^2}$

Electric Dipole:

An electric dipole consists of two-point charges of equal magnitude and opposite sign separated by a very small distance, e.g., a molecule of HCL, a molecule of water etc.



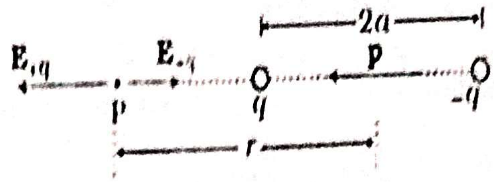
Electric Dipole Moment: Product of magnitude of either charge and distance between them. i.e. $p = q(2a)$

Its SI unit is 'coulomb-metre' and its dimension is [LTA].

It is a vector quantity and its direction is from negative charge towards positive charge.

Electric Field Intensity and Potential due to an Electric Dipole:

(i) On Axial Line:



Electric field intensity

$$E = \frac{1}{4\pi\varepsilon_0}\frac{2pr}{(r^2 - a^2)^2}$$

If $r >> 2a$, then $E = \frac{1}{4\pi\varepsilon_0}\frac{2p}{r^3}$ (Short Dipole)

Electric potential $V = \frac{1}{4\pi\varepsilon_0}\frac{p}{r^2 - a^2}$

If $r >> 2a$, then $V = \frac{1}{4\pi\varepsilon_0}\frac{p}{r^2}$ (Short Dipole)

(ii) On Equatorial Line:

Electric field intensity $E = \frac{1}{4\pi\varepsilon_0}\frac{p}{(r^2 + a^2)^{3/2}}$

If $r >> 2a$, then $E = \frac{1}{4\pi\varepsilon_0}\frac{p}{r^3}$ (Short Dipole)

Electric potential $V = 0$

(iii) At any Point along a Line Making θ Angle with Axis

Electric field intensity

Magnitude of electric field

$$E = \frac{1}{4\pi\varepsilon_0}\frac{p\sqrt{1+3\cos^2\theta}}{r^3}$$

Electric potential $V = \frac{1}{4\pi\varepsilon_0}\frac{p\cos\theta}{r^2 - a^2\cos^2\theta}$

If $r >> 2a$, then $V = \frac{1}{4\pi\varepsilon_0}\frac{p\cos\cos\theta}{r^2}$ (Short Dipole)

Torque on a Electric Dipole in Uniform Electric Field:

Torque acting on an electric dipole placed in uniform electric field is given by

$\tau = pE\sin\theta$

or $\tau = p \times E$

When $\theta = 90°$, then $\tau_{max} = pE$ (Maximum)

When electric dipole is parallel to electric field, it is in stable equilibrium and when it is anti-parallel to electric field, it is in unstable equilibrium. (In this Case Torque = 0)

Electric Dipole in Non-Uniform Electric Field:

When an electric dipole is placed in a non-uniform electric field, then a resultant force as well as a torque act on it.

Net force on electric dipole = $(qE_1 - qE_2)$, along the direction of greater electric field intensity.

Therefore, electric dipole undergoes rotational as well as linear motion.

Work done to rotate an electric dipole in Uniform electric Field:

Work done is rotating an electric dipole in a uniform electric field from angle θ_1 to θ_2 is given by

$W = pE(\cos\theta_1 - \cos\theta_2) = -pE(\cos\theta_2 - \cos\theta_1)$

If initially it is in the direction of electric field, then work done in rotating through an angle θ,

$W = pE(1 - \cos\theta)$.

Potential Energy of a Dipole:

Potential energy of an electric dipole in a uniform electric field is given by

$U = -pE\cos\theta = -p.E$

Stable Equilibrium:

When angle between p and E is 0 degree.

Unstable Equilibrium:

When angle between p and E is 180°.

Electric Flux (φ_E):

Electric flux over an area is equal to the total number of electric field lines crossing this area.

Electric flux through a small area element dS is given by

$$d\varphi_E = E.\,dS$$

where E= electric field intensity and dS = area vector.

Its SI unit is Nm^2C^{-1}.

For a curved surface, it is divided into smaller area element and flux through each element is calculated to find total flux i.e.

$$\varphi_E = \sum_{i=1}^{n} E.\Delta s = \oint E.ds$$

Gauss's Theorem:

The electric flux over any closed surface is $1/\varepsilon_0$ times the total charge enclosed by that surface, i.e.,

$$\varnothing_E = \oint E.ds = \frac{Q_{in}}{\varepsilon_0}$$ where Q_{in} = Net Charge enclosed in the surface.

Important points regarding Gauss's Law:

(i) The law is valid for a surface of any shape and size.

(ii) Q_{in} includes only those charges which are inside the closed surface (may be located anywhere in the surface)

(iii) E in LHS is due to all the charges located inside or outside the surface.

(iv) Any violation of Gauss law will indicate the departure from inverse square law or Coulomb's law.

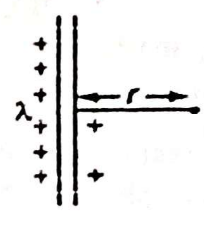
Note: If a charge q is placed at the centre of a cube, then total electric flux linked with the whole cube = q/ε_0, electric flux linked with one face of the cube = $q/6\varepsilon_0$.

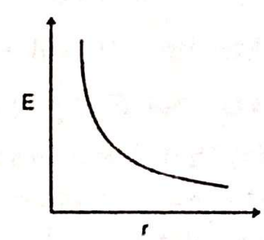
Electric Field Intensity due to an Infinite Line Charge:

$$E = \frac{\lambda}{2\pi\varepsilon_0 r}$$

(Direction –Radially outwards for q > 0 and inwards or q<0)

where λ is linear charge density and r is distance from the line charge.





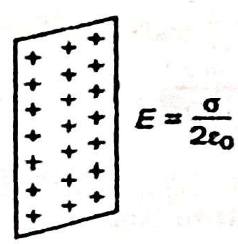
Electric Field Near an Infinite Plane Sheet of Charge:

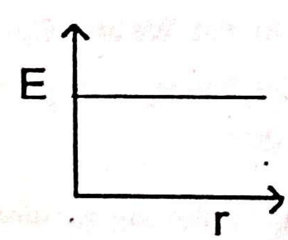
$E = \sigma / 2\varepsilon_0$

where σ = surface charge density.

If infinite plane sheet has uniform thickness, then

$E = \sigma / \varepsilon_0$



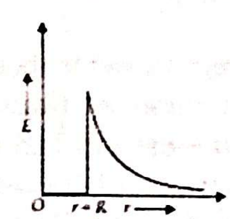


Electric Field Intensity due to an Uniformly Charges Spherical Shell/ Conducting Sphere (of radius R):

(i) At a point lying outside the shell (r > R) $\quad E = \frac{1}{4\pi\varepsilon_0}.\frac{q}{r^2}$

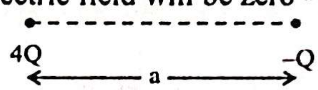
(ii) At a point on the Surface of the shell (r =R) $\quad E = \frac{1}{4\pi\varepsilon_0}.\frac{q}{r^2}$

(iii) At a point inside the shell: $E = 0$



MULTIPLE CHOICE QUESTIONS:

1. When the distance between the charged particles is halved, the force between them becomes
   (a) One-fourth (b) Half (c) Double (d) Four times
2. Two charged spheres separated at a distance d exert a force F on each other. If they are immersed in a liquid of dielectric constant 2, then what is the force (if all conditions are same)
   (a) $\frac{F}{2}$ (b) F (c) $2F$ (d) $4F$
3. A hollow insulated conducting sphere is given a positive charge of $10\mu C$. What will be the electric field at the centre of the sphere if its radius is 2 meters
   (a) Zero (b) $5\mu Cm^{-2}$ (c) $20\mu Cm^{-2}$ (d) $8\mu Cm^{-2}$
4. An electric dipole consisting of two opposite charges of $2 \times 10^{-6}C$ each separated by a distance of $3cm$ is placed in an electric field of 2×10^5 N/C. The maximum torque on the dipole will be
   (a) $12 \times 10^{-1}Nm$ (b) $12 \times 10^{-3}Nm$ (c) $24 \times 10^{-1}Nm$ (d) $24 \times 10^{-3}Nm$
5. The electric field due to a dipole at a distance r on its axis is
   (a) Directly proportional to r^3 (b) Inversely proportional to r^3
   (c) Directly proportional to r^2 (d) Inversely proportional to r^2
6. If E_a be the electric field strength of a short dipole at a point on its axial line and E_e that on the equatorial line at the same distance, then
   (a) $E_e = 2E_a$ (b) $E_a = 2E_e$ (c) $E_a = E_e$ (d) None of the above
7. A charge q is located at the centre of a cube. The electric flux through any face is
   (a) $\frac{4\pi q}{6(4\pi\varepsilon_0)}$ (b) $\frac{\pi q}{6(4\pi\varepsilon_0)}$ (c) $\frac{q}{6(4\pi\varepsilon_0)}$ (d) $\frac{2\pi q}{6(4\pi\varepsilon_0)}$
8. The position of the point where net electric field will be zero -



   (a) (1+ a) m from 4Q (b) a m from – Q
   (c) 1m from 4Q (d) Neutral point not posible

HINTS AND SOLUTIONS:

1. Answers: (d) Sol. $F \propto \frac{1}{r^2}$; so when r is halved the force becomes four times.
2. (a) Sol. $F \propto \frac{1}{K}$ i.e. $\frac{F_{medium}}{F_{air}} = K$
3. (a) Sol. The intensity of electric field inside a hollow conducting sphere is zero.
4. (b) Sol. Maximum torque = pE = $2 \times 10^{-6} \times 3 \times 10^{-2} \times 2 \times 10^5 = 12 \times 10^{-3}$ N-m.
5. (b) Sol. $E = \frac{1}{4\pi\varepsilon_0} \cdot \frac{2p}{r^3}$
6. (b) Sol. We have $E_a = \frac{2kp}{r^3}$ and $E_e = \frac{kp}{r^3}$; $\therefore E_a = 2E_e$
7. (a) Sol. $\varphi_{face} = \frac{q}{6\varepsilon_0} = \frac{4\pi q}{6(4\pi\varepsilon_0)}$
8. (b)

ASSERTION AND REASON QUESTIONS

In the following questions, two statements are given –one labelled Assertion (A) and other labeled Reason (R).

Select the correct answer to these questions from the options as given below.

A. If both Assertion and Reason are true and Reason is the correct explanation of Assertion.
B. If both Assertion and Reason are true but Reason is not the correct explanation of Assertion.
C. If Assertion is true but Reason is false.
D. If both Assertion and Reason are false.

1. ASSERTION : When charged balloon is put against on insulating wall, it get stick to the wall.
   REASON : Wall acquire a net negative charge & thus attract balloon.

2. ASSERTION (A): In a non-uniform electric field, a dipole may have translatory as well as rotational motion.
REASON (R): In a non-uniform electric field, a dipole experiences a force as well as torque.

3.ASSERTION (A): Gauss law is applicable only for symmetric charge distribution.
REASON (R): In gauss law, electric field is due to only those charges which are present inside the closed surface.

4. ASSERTION: A point charge q_0 is kept outside a solid metallic sphere, the electric field inside the sphere is zero.
REASON : Induced charge does not contribute to electric field or potential at a given point.

5. ASSERTION (A): No torque acts on an electric dipole when its dipole moment is in a direction opposite to the electric field.
REASON (R): An electric dipole is in stable equilibrium when placed in a uniform electric field with its dipole moment opposite to the field.

6. ASSERTION (A): Charge cannot exist without mass.
REASON: The particles such as photon or neutrino which have no (rest) mass are uncharged.

7. ASSERTION (A) : An electron has a negative charge.
REASON (R) : Electrons move away from a region of lower potential to a region of higher potential.

8. ASSERTION (A) : If a point charge q is placed in front of an infinite grounded conducting plane surface, the point charge will experience a force.
REASON (R): This force is due to the induced charge on the conducting surface which is at zero potential.

HINTS AND SOLUTIONS:

1.	C	2.	A	3.	D	4.	C	5.	C
6.	B	7.	B	8.	A				

VERY SHORT ANSWER TYPE QUESTIONS

1. If a dipole is kept in uniform electric field E, diagrammatically represent the position of the dipole in stable and unstable equilibrium and write the expression for the torque acting on the dipole in both the cases.

Solution: - Stable Equilibrium:

The dipole is aligned parallel to the electric field (angle $\theta = 0°$).

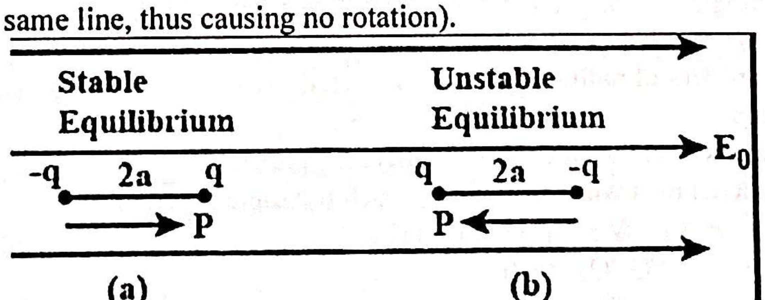
Torque: $\tau = 0$ (The torque is zero because the forces on the positive and negative charges are equal and opposite, and they act along the same line, thus causing no rotation).

Unstable Equilibrium:

The dipole is aligned anti-parallel to the electric field (angle $\theta = 180°$).

Torque:

$\tau = 0$ (The torque is zero because the forces on the positive and negative charges are equal and opposite, and they act along the same line, thus causing no rotation).



2. A spherical balloon carries a charge that is uniformly distributed over its surface. As the balloon is blown up and increases in size, how does the electric flux come out of the surface change? Give reason.

Solution:- The electric flux coming out of the balloon's surface remains unchanged as the balloon is blown up and increases in size. This is because the electric flux is directly proportional to the enclosed charge, and the total charge on the balloon's surface remains constant.

3. An electric dipole of length 10 cm having charges $\pm 6 \times 10^{-3}$, placed at 30° with respect to a uniform electric field, experiences a torque of $6\sqrt{3}$ Nm. Calculate the magnitude of the electric field.

Solution: so, dipole moment of dipole, $P = qd = 6 \times 10^{-3}\ C \times (10cm)$

$$= 6 \times 10^{-3}\ C \times (10/100)\ m = 6 \times 10^{-3}\ C.m$$

and angle between dipole, P and external electric field, E is, $\theta = 30^\circ$

we know, torque $= P.E \sin\theta = 6\sqrt{3} = 6 \times 10^{-4} \times E \times \sin 30^\circ = \sqrt{3} \times 10^{4} = E \times (1/2)$

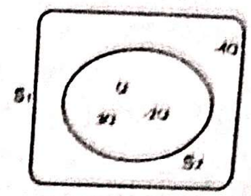
$$\text{or, } E = 2\sqrt{3} \times 10^{4}\ N/C$$

4. (a) Define electric flux. Write its SI unit. Is it a scalar or vector?

Solution: Electric flux: It is the number of electric field lines passing through a surface normally which is give as $\varphi = E\Delta S\cos\theta$

S.I unit of flux = Nm^2C^{-1} .It is a Scalar quantity.

5. Find ratio of electric flux through the surface S_1 and S_2 as shown in figure



Answer: $\varphi_1 = \frac{2Q}{\epsilon_0}$ and $\varphi_2 = \frac{-2Q}{\epsilon_0}$ and $\frac{\varphi_1}{\varphi_2} = 1 : -1$

6. Two small balls, each with a charge Q, hang from the same point by insulating strings of length L from a fixed support. Consider the setup in a region of zero gravity and in equilibrium.

(a) What will be the angle between the two strings?

(b) What will be the tension in each of the strings?

Solution – (a) The angle between the two strings will be 180°.

(b) Tension in each string will be equal to the electrostatic force of repulsion between the two charged balls. $F = \frac{Q^2}{4\pi\epsilon_0(2L)^2}$

7. A thundercloud carries a charge of +50 C at a height of 4000 m and a charge of -50 C at a height of 2000 m from the ground. An airplane crosses through the charged thundercloud at a height of 3000 m from the ground. Find the magnitude and the direction of the electric field acting on the airplane as its crosses through the charged-up thundercloud.

Solution: Electric field due to +50 C above the airplane: $\frac{kq}{r^2} = 9 x 10^9 \left(\frac{50}{1000^2}\right)$

$$= 4.5 \times 10^5\ N/C, \text{ acting downwards.}$$

Electric field due to -50 C above the airplane: $\frac{kq}{r^2} = 9 x 10^9 \left(\frac{50}{1000^2}\right)$

$$= 4.5 \times 10^5\ N/C, \text{ acting downward}$$

So, the total electric field acting on the airplane = $4.5 \times 10^5\ N/C + 4.5 \times 10^5\ N/C$

$$= 9 \times 10^5\ N/C, \text{ acting downwards.}$$

8. Two charged conducting spheres of radii a and b are connected to each other by a wire. Find the ratio of the electric fields at their surfaces.

Solution - The electric potential V at the surface of a sphere is given by: $V = KQ/r$

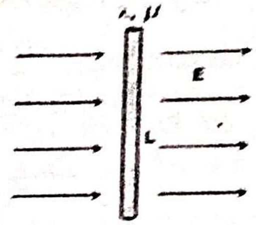
When connected by a wire, the spheres reach the same potential.

i.e. $V_1 = V_2$ or $kQ_1/a = kQ_2/b$

or $Q_1/Q_2 = a/b$

Now ratio of electric field $\frac{E_1}{E_2} = \frac{\frac{kQ_1}{a^2}}{\frac{kQ_2}{b^2}} = \frac{Q_1 b^2}{Q_2 a^2}$ or $\frac{E_1}{E_2} = = \frac{a b^2}{b a^2} = \frac{b}{a}$

SHORT ANSWER TYPE QUESTIONS



1. Define electric dipole moment. Is it a scalar or vector ? Derive the expression for the electric field of a dipole on the equatorial plane of the dipole.

Solution: Electric dipole moment is defined as the product of any one of the charges and the length of the electric dipole. $p = q\,(2a)$

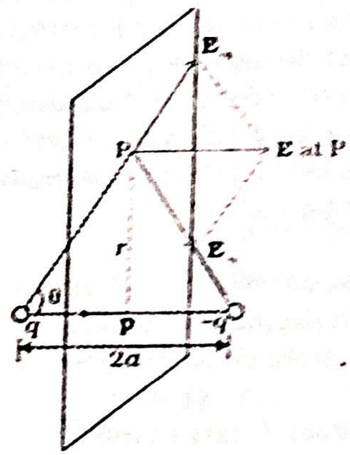
q = One of the charges and $2a$ = Length of the electric dipole.

Its direction is from negative charge to positive charge. Its SI unit is coulomb metre.

Electric field of a dipole on the equatorial plane of the dipole:

The magnitudes of the electric fields at point 'P' due to the two charges +q and –q are given by

$$E_q = \frac{kq}{(r^2+a^2)} \quad \& \quad E_{-q} = \frac{kq}{(r^2+a^2)}$$



which are equal in magnitude.

The directions of E+q and E–q are as shown in Fig.

Clearly, the components normal to the dipole axis cancel away.

The components along the dipole axis add up.

The total electric field is opposite to dipole moment p.

Net electric field at point P is

$$E = E_q\cos\theta + E_{-q}\cos\theta$$

$$= 2\,E_q\cos\theta$$

$$\text{Or } E = 2 \times \frac{kq}{(r^2+a^2)} \times \frac{a}{(r^2+a^2)^{\frac{1}{2}}}$$

$$\text{Or } E = \frac{2kp}{(r^2+a^2)^{\frac{3}{2}}}$$ **(Direction – Opposite to direction of p)**

At large distances (r >> a) (or for short dipole), this reduces to

$$E = \frac{2kp}{r^3} \qquad \text{In vector form } E = -\frac{2kp}{r^3}$$

2. Using Gauss's law deduce the expression for the electric field due to a uniformly charged spherical conducting shell of radius R at a point (i) outside and (ii) inside the shell.

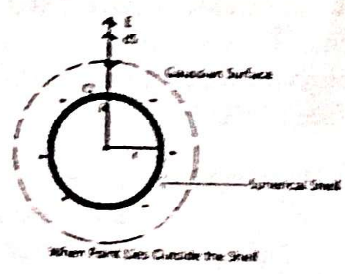
Plot a graph showing variation of electric field as a function of r > R and r < R (r being the distance from the centre of the shell

Solution : Let σ be the uniform surface charge density of a thin spherical shell of radius R . The situation has spherical symmetry. The field at any point P, outside or inside, can depend only on r (the radial distance from the centre of the shell to the point) and must be radial (i.e., along the radius vector).

(i) Field outside the shell:

Consider a point P outside the shell with radius vector r.

To calculate E at P, we take the Gaussian surface to be a sphere of radius r and with centre O, passing through P.



All points on this sphere are equivalent relative to the given charged configuration. (That is what we mean by spherical symmetry.) The electric field at each point of the Gaussian surface, therefore,

has the same magnitude E and is along the radius vector at each point.

Thus, E and dS at every point are parallel and the flux through each element is E dS.

Summing over all dS, the flux through the Gaussian surface is E × 4πr2 .

The charge enclosed is $\sigma\,(4\pi R^2)$.

By Gauss's law $\varphi = \frac{q_{in}}{\epsilon_0}$

Or $E \times 4\pi r^2 = \frac{\sigma\,(4\pi R^2)}{\epsilon_0}$

Or $E = \frac{\sigma R^2}{\epsilon_0 r^2} = \frac{1}{4\pi\epsilon_0}\frac{q}{r^2}$ where $\sigma = q(4\pi R^2)$ is surface charge density.

The electric field is directed outward if $q > 0$ and inward if $q < 0$. This, however, is exactly the field produced by a charge q placed at the centre O. Thus for points outside the shell, the field due to a uniformly charged shell is as if the entire charge of the shell is concentrated at its centre.

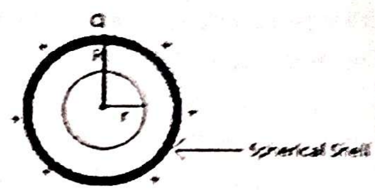
(ii) Field inside the shell: In this case the Gaussian surface is again a sphere through P centred at O.

The flux through the Gaussian surface, calculated as before, is $E \times 4\pi r^2$.

However, in this case, the Gaussian surface encloses no charge.

Gauss's law then gives $E \times 4\pi r^2 = 0$ i.e., $E = 0\ (r < R)$

that is, the field due to a uniformly charged thin shell is zero at all points inside the shell



When Point Lies Inside the Shell

3. State Gauss's law in electrostatic. Use this law to derive an expression for the electric field due to a uniformly charged infinite plane sheet having uniform charge density $+\sigma$. Obtain the expression for the amount of work done in bringing a point charge q from infinity to a point, distance r, in front of the charge sheet.

Solution: Gauss's Law:

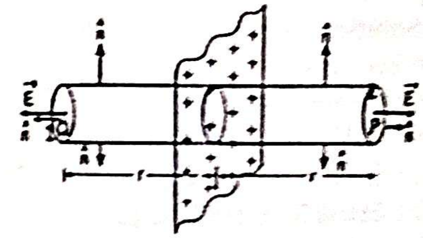
Electric flux of electric field through a close surface held in vacuum is 1 upon ε_0 times total charge enclosed by the surface.

i.e. $\varphi = \frac{q_{in}}{\epsilon_0}$

Direction of E:- Let σ be the uniform surface charge density of an infinite plane sheet. We take the x-axis normal to the given plane. By symmetry, the electric field will not depend on y and z coordinates and its direction at every point must be parallel to the x-direction.

Magnitude of E: We take the Gaussian surface to be a cylindrical surface of cross-sectional area A, as shown.

(A rectangular parallelepiped will also do.) As seen from the figure, only the two faces 1 and 2 will contribute to the flux; electric field lines are parallel to the other faces and they, therefore, do not contribute to the total flux.



The unit vector normal to surface 1 is in –x direction while the unit vector normal to surface 2 is in the +x direction. Therefore, flux E.ΔS through both the surfaces are equal and add up. Therefore the net flux through the Gaussian surface is 2 EA. The charge enclosed by the closed surface is σA.

Therefore by Gauss's law, $\varphi = \frac{q_{in}}{\epsilon_0}$

$$2\,EA = \sigma A/\varepsilon_0$$

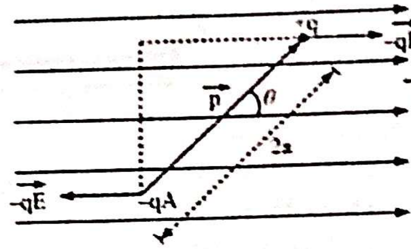
$$\text{or, } E = \sigma/2\varepsilon_0$$

Vectorically, $\mathbf{E} = \sigma/2\varepsilon_0\,\mathbf{n}$ where **n** is a unit vector normal to the plane and going away from it.

Work Done: $W = q\,[V(r) - V(\infty)] = q\,[E\,r - 0] = q\frac{\sigma}{2\epsilon_0}r$

4. Show that an electric dipole held in uniform electric field will not undergo any translator motion. Hence derive an expression for the torque experienced by the dipole.

Solution:



Let us consider an electric dipoleof dipole moment

p = q(2a)

Where, p = Electric dipole moment ,

q = One of the charges and

2a = Length of the electric dipole.

It makes an angle θ with the direction of electric field as shown.

Net force on the dipole = qE – qE = 0

Hence dipole will not undergo translator motion.

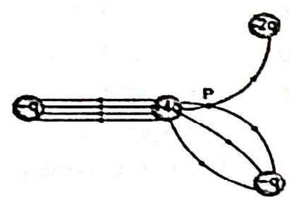
Due to different line of action of force , it experiences a torques which is given by

τ = magnitude of either force × Perpendicular distance between the two forces

$= q E (2a \sin\theta)$

or $\tau = p E \sin\theta$ or $\tau = p \times E$

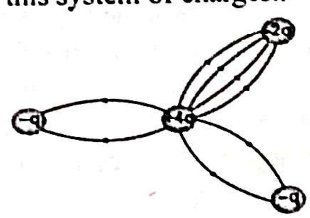
5. The figure below shows an arrangement of four charges along with some electric field lines drawn between the charges.



(a) Identify three things that are incorrect in this figure.

(b) Draw a correct diagram representing the electric field lines for this system of charges..

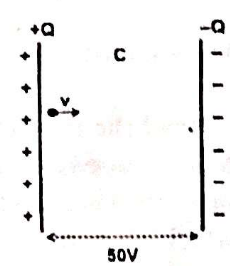
Solution:



(a) Electric field lines cross each other as shown at point P.
Number of field lines that end on the negative charges is not proportional to their charges.The field lines drawn between +4q and –q are shown as parallel and equidistant.

(b) The correct representation: (shown in fig)

6. A small ball of mass 2 x 10^{-16} kg carrying a charge q = - 2 μC is fired from the positive conducting plate towards the negative conducting plate with a speed of 3 x 10^6 m/s. (figure)



Will the ball strike the negative plate? Give mathematical working for the answer.

Solution : The Ball hits the negative plate if KE of the ball is greater then Work done against the field .

Now KE of the Ball $E = mv^2/2 = 9 \times 10^{-4}$ J

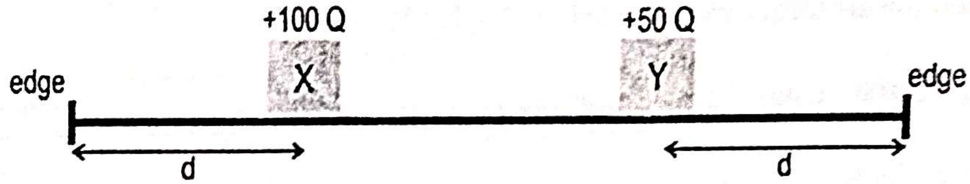
& work to be done against the electric field is $W = U = qV = 2 \times 10^{-6} \times 50 = 10^{-4}$ J

Since the KE of the ball > Energy required to move through the field between the plates of conducting sheets, the ball will strike the negative plate.

SOURCE BASED QUESTION:

1. Read the following passage carefully and answer the questions that follow after paragraph-

Two small metal blocks (X and Y) of the same mass m are placed on an insulated frictionless surface such that both of them are at the same distance from the edge of the surface as shown in the image below. The charge on block X is +100 Q and that on Y is +50 Q. The two blocks are held in position by an external force.



(i) The external force is require to held them in position since

(a) Both will attract each other with equal magnitude of electrostatic force.

(b) Both will repel each other with equal magnitude of electrostatic force.

(c)X will repel Y with greater magnitude of electrostatic force.

(d) Y will repel X with greater magnitude of electrostatic force.

(ii) If the external force holding the blocks in their respective positions is removed, then which of the following will happen?

(a) Block X will reach the edge first.

(b) Block Y will reach the edge first.

(c) Both the blocks will reach the edge at the same time.

(d) The blocks will NOT move from their positions.

(iii). If block Y is replaced with another block Z with the same charge but mass 2m, which of the following will happen when the external force holding the blocks in their respective positions is removed?

(a) Block X will reach the edge first.

(b) Block Z will reach the edge first.

(c) Both blocks will reach the edge at the same time.

(d) The blocks will NOT move from their positions.

(iv). The two blocks X and Y are momentarily brought in contact and placed again in the same initial position as shown in the image.

Which block will reach the edge first, once the external force holding them in their positions is removed?

(a) Block X will reach the edge first.

(b) Block Y will reach the edge first.

(c)Both blocks will reach the edge at the same time.

(d) The blocks will NOT move from their positions.

(v) If nature of charge on Y is altered and they are released, what will be the velocity of their centre of mass ?

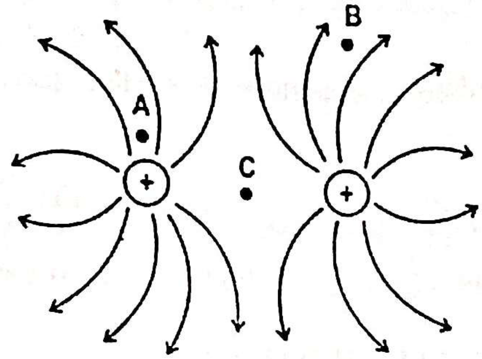
(a) 10 m/s towards right (b) 10 m/s towards left (c) zero (d) none of these

Ans – (i) (b) (ii) (c) (iii) (a) (iv) (c) (v) (c)

2. Read the following passage carefully and answer the questions that follow after paragraph-

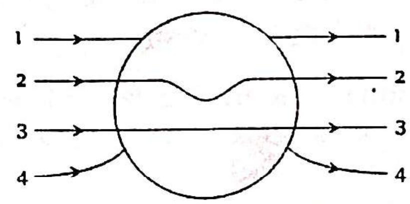
A field line is a graphical visual aid for visualizing vector fields. It consists of an imaginary integral curve which is tangent to the field vector at each point along its length. A diagram showing a representative set of neighbouring field lines is a common way of depicting a vector field in scientific and mathematical literature; this is called a field line diagram. They are used to show electric fields, magnetic fields, and gravitational fields among many other types.

(i) Study the given electric field representation and identify one **INCORRECT** qualitative impression given by this representation.



(a) The electric field at point A is stronger than at point B.
(b)The electric field distribution is two-dimensional.
(c)The electric field at point C is zero.
(d)The electric field always points away from a positive charge.

(ii) A metallic solid sphere is placed in a uniform electric field. The electric field lines follow the path(s) shown in the figure. Which among the four correctly describes electric field line-



(a) 1 (b) 2 (c) 3 (d) 4

(iii) Which of the following is not the property of electric field lines
(a) Electric field line form closed loop.
(b) Electric field line emerges from positive charge.
(c) Electric field line can not have sudden breaks in charge free Region.
(d) No two Electric field lines can intersect each other.

(iv) Electric field lines about negative point charge are
(a) Circular, anticlockwise (b) Circular, clockwise
(c) Radial, inward (d) Radial, outward

Answer: (i) (B)The electric field distribution is two-dimensional.
(ii) (d) 4
(iii) (a)Electric field line form closed loop.
(iv) (c) Radial, inward

3. Read the following passage carefully and answer the questions that follow after paragraph-

Gauss Theorem: Electric flux of electric field through a close surface held in vacuum is one upon ε_0 times total charge enclosed by the surface.

i.e. $\varphi = \frac{q_{in}}{\epsilon_0}$

where q_{in} included only those charges which are located inside the closed surface. Gauss theorem can be conveniently applied to find electric field due to the given charge distribution by assuming any closed surface imagined around the charge distribution called Gaussian Surface. The law is applicable for a Gaussian Surface of any shape and Size.

(i) Two charges of magnitude -2Q and +Q are located at points (a, 0) and (4a, 0) respectively. What is the electric flux due to these charges through a sphere of radius '3a' with its Centre at origin?
(a) Q/ϵ_0 (b) $-2Q/\epsilon_0$ (c) $3Q/\epsilon_0$ (d) $-3Q/\epsilon_0$

(ii) A charge q is placed at the Centre of a cube of side l. What is the electric flux passing through each face to the cube?
(a) $q/5\epsilon_0$ (b) $q/9\epsilon_0$ (c) $q/6\epsilon_0$ (d) q/ϵ_0

(iii) Chares outside the Closed surface does not contribute in electric flux through the surface since due to outside charges

(a) number of filed lines are countless
(b) no field lines can get through the surface
(c) number of field lines entering the surface is equal to number of field lines leaving the surface.
(d) no field lines are emitted.

(iv) SI unit of electric flux is

(a) N^2mC (b) V m (c) Nm^2C^{-1} (d) both (b) and (c)

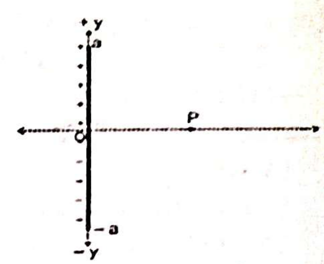
Answer: (i) (B) $-2Q/\epsilon_0$ (ii) (C) $q/6\epsilon_0$ (iii) (C) (iv) (D) both (b) and (c)

LONG ANSWER TYPE QUESTIONS:

1. A spherical Gaussian surface encloses a positive charge q. Find net electric flux through the surface. Explain with a reason what happens to the net electric flux through the Gaussian surface if:
(a) the charge is tripled.
(b) the volume of the sphere is tripled.
(c)the shape of the Gaussian surface is changed into a cuboid.
(d) the charge is moved into another location inside the Gaussian surface

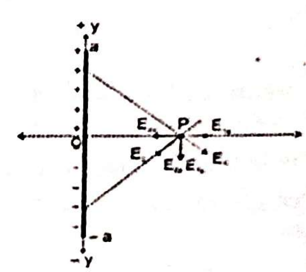
Solution: electric flux through the surface is $\varphi = \frac{q}{\epsilon_0}$
(a) The net flux is also tripled because as per Gauss law the net flux is proportional to the net charge enclosed.
(b) Regardless of the volume of the enclosed surface, if the net charge enclosed is the same, the net flux remains the same as per Gauss law.
(c)No change in the net flux as it doesn't depend upon the shape of the closed surface.
(d) As long as the new location of the charge remains inside the Gaussian surface, there is no change in net flux.

2. (a) Given is a line of charge of uniform linear density. A charge +q is distributed uniformly between y = 0 and y = a and charge –q is distributed uniformly between y = 0 and y = -a.



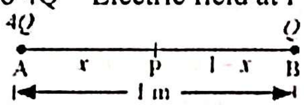
Explain how the direction of the resultant electric field at point P can be obtained. Represent using a vector diagram.
(b) Two point charges $4Q$, Q are separated by 1 m in air. At what point on the line joining the charges is the electric field intensity zero?

Solution
(a) The x-components of E_1 and E_2, due to two equidistant points on either side of O, cancel each other. The resultant electric field is due to the superposition of the y-components of E_1 and E_2.
The direction of the net electric field is along the negative y-axis. This is true for all pairs of equidistant points on either side of O.



(b) Let the point be at a distance x from 4Q charge.
Electric field at P due to 4Q = Electric field at P due to Q

$$\frac{k(4Q)}{x^2} = \frac{kQ}{(1-x)^2}$$



$$\frac{2}{x} = \mp\frac{1}{1-x}$$

Therefore x = 2/3 m or 2m.
Since 2m is not possible so answer is 2/3 metre from charge 4Q.

3. (a) State Gauss's law in electrostatic. Use this law to derive an expression for the electric field due to an infinitely long straight uniformly charged wire having linear charge density λ C/m.

(b) Obtain the expression for the amount of work done in bringing a point charge q from infinity to a point, distance r, in front of the line charge.
(c) An infinite line charge produces a field of 9×10^4 N/C at a distance of 2 cm. Calculate the linear charge density.

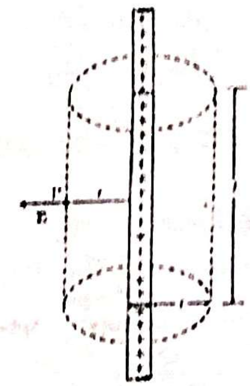
Solution:

(a) Gauss's Law:

Electric flux of electric field through a close surface held in vacuum is 1 upon ϵ_0 times total charge enclosed by the surface.

i.e. $\varphi = \frac{q_{in}}{\epsilon_0}$

Electric field due to an infinitely long straight uniformly charged wire:



For a wire of infinite length, the electric field is everywhere radial in the plane cutting the wire normally, and its magnitude depends only on the radial distance r. To calculate the field, we imagine a cylindrical Gaussian surface, as shown in the. Since the field is everywhere radial, **Electric flux through the two ends of the cylindrical Gaussian surface is zero.** At the cylindrical part of the surface, E is normal to the surface at every point, and its magnitude is constant, since it depends only on r. The surface area of the curved part is $2\pi rl$, where l is the length of the cylinder.

Using Gauss Law on surface S, $\varphi = \frac{q_{in}}{\epsilon_0}$

$$E.2\pi rl = \frac{\lambda l}{\epsilon_0}$$

$$E = \frac{\lambda}{2\pi\epsilon_0} = \frac{2k\lambda}{r}$$

In Vector form $E = \frac{\lambda}{2\pi\epsilon_0} n = \frac{2k\lambda}{r} n$

Where n is the radial unit vector in the plane normal to the wire passing through the point.
E is directed outward if λ is positive and inward if λ is negative.

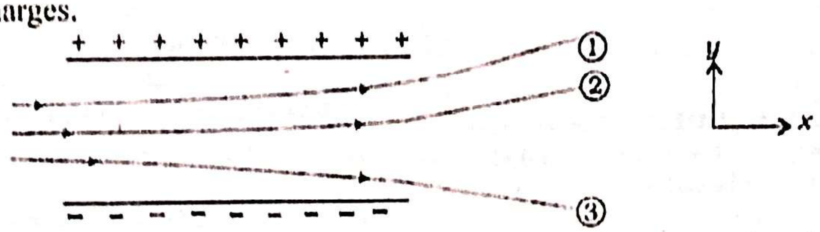
(b) $W = \int_{\infty}^{r} E.dr = \int_{\infty}^{r} Edr\cos\pi = -\int_{\infty}^{r} \frac{2k\lambda}{r} dr = -2k\lambda \log_e r$

(c) Using

$E = \frac{\lambda}{2\pi\epsilon_0} = \frac{2k\lambda}{r}$ or $\lambda = \frac{Er}{2k}$

Substituting the values we get $\lambda = \frac{9 \times 10^4 \times 2 \times 10^{-2}}{2 \times 9 \times 10^9} = 10^{-7}$ N/C

4. (a) Figure shows tracks of three charged particles in a uniform electrostatic field. Give the sign of these charges.



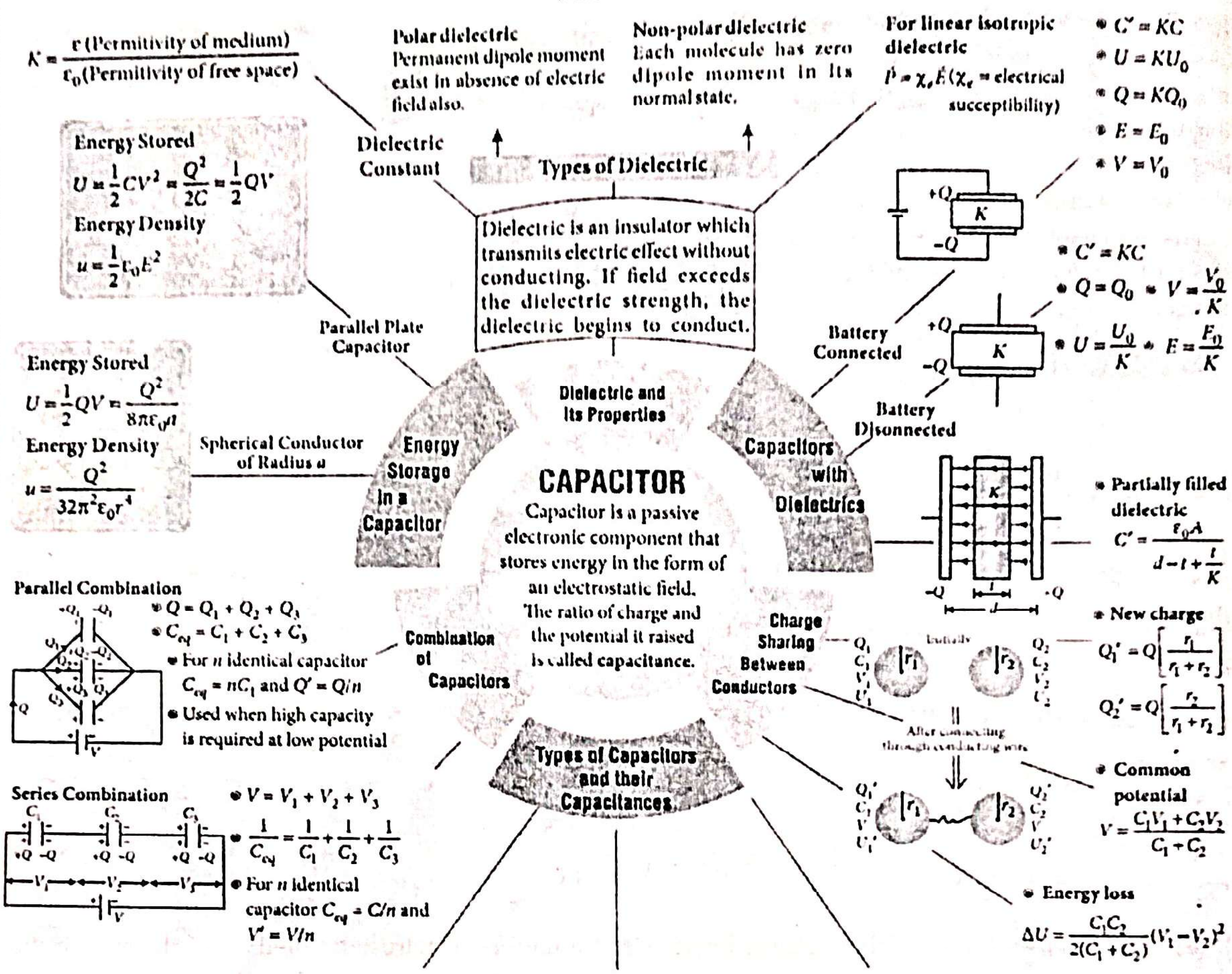
Solution : (a) Charge 1 - negative charge, charge 2 – negative charge , charge 3 - positive charge.

CHAPTER–2: ELECTROSTATIC POTENTIAL AND CAPACITANCE

Syllabus:- Electric potential, potential difference, electric potential due to a point charge, a dipole and system of charges; equipotential surfaces, electrical potential energy of a system of two-point charges and of electric dipole in an electrostatic field.

Conductors and insulators, free charges and bound charges inside a conductor. Dielectrics and electric polarization, capacitors and capacitance, combination of capacitors in series and in parallel, capacitance of a parallel plate capacitor with and without dielectric medium between the plates, energy stored in a capacitor (no derivation, formulae only)

MIND MAP

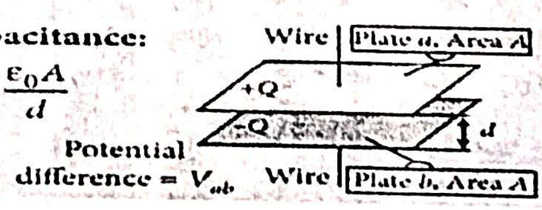


Parallel Plate Capacitor

It consists of two large plates placed parallel to each other with a separation d.

Capacitance:

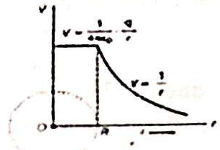
$$C = \frac{\varepsilon_0 A}{d}$$



GIST OF THE CHAPTER

The concept of electric potential and capacitor used in daily life as

1. **Power Distribution:** Electric potential, or voltage, is what drives current flow in electrical circuits, ensuring that power is delivered to devices.
2. **Electronic Devices:** Electric potential is used to control the movement of charges, as seen in TV screens, electron microscopes, and other devices.



Variation of potential due to charged shell with distance r from its centre

3. **Lightning Rods:** Lightning rods are designed to facilitate the transfer of charge, preventing damage during lightning strikes
4. **High-Voltage Transmission Lines:** Smooth surfaces are used on high-voltage transmission lines to prevent charge leakage
5. **Household Appliances:** In refrigerators, air conditioners, and other appliances, capacitors help start motors efficiently and reduce power consumption.
6. **Audio Equipment:** Capacitors are crucial in audio equipment for filtering out unwanted noise and stabilizing signals, ensuring clear and reliable sound.
7. **Camera Flashes:** Capacitors store energy to provide a burst of power for camera flashes, allowing them to capture images in low-light conditions.
8. **Automotive Systems:** In hybrid and electric vehicles, capacitors are used for energy recuperation systems.
9. **Medical Devices:** Capacitors are used in medical devices like defibrillators to deliver a burst of energy to restore a normal heartbeat.

Electrostatic potential (V)

Electrostatic potential (V) at any point in a region with electrostatic field is the work done in bringing a unit positive charge (without acceleration) from infinity to that point.

$$V = -\int_{\infty}^{r} \vec{E}.\vec{dr}$$

https://ophysics.com/em4.html

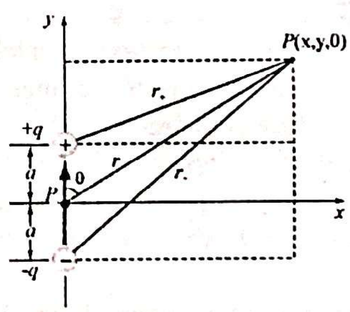
1. Electric potential due to point charge $V = \frac{1}{4\pi\varepsilon_0}\frac{q}{r}$
2. A system of charges $q_1, q_2, \ldots, q_n$ with position vectors $r_1, r_2, \ldots, r_n$ relative to some origin

The potential V at any point P due to the total charge configuration is the algebraic sum of the potentials due to the individual charges

$$V = V_1 + V_2 + V_3 + \text{------------} + V_n$$

$$V = \frac{1}{4\pi\varepsilon_0}\left(\frac{q_1}{r_{1P}} + \frac{q_2}{r_{2P}} + \frac{q_3}{r_{3P}} + \cdots \ldots \ldots + \frac{q_n}{r_{nP}}\right)$$

3. Electric potential due to Electric dipole



(i) At any point

$$V = \frac{1}{4\pi\varepsilon_0}\frac{p\cos\theta}{r^2} \text{ or } V = \frac{1}{4\pi\varepsilon_0}\frac{\vec{p}.\hat{r}}{r^2}$$

(ii) At a point on the dipole axis ($\theta = 0, \pi$)

$$V = \frac{1}{4\pi\varepsilon_0}\frac{q}{r} \text{ or } V = -\frac{1}{4\pi\varepsilon_0}\frac{q}{r}$$

(iii) Potential in the equatorial plane ($\theta = \frac{\pi}{2}$)

$$V = 0$$

4. Electric potential uniformly charged spherical shell

(i) At a point outside the shell (r > R)

$$V = \frac{1}{4\pi\varepsilon_0}\frac{q}{r}$$

(ii) At a point on the surface of shell (r = R)

$$V = \frac{1}{4\pi\varepsilon_0}\frac{q}{R}$$

(iii) At a point inside the shell (r < R)

$$V = \frac{1}{4\pi\varepsilon_0}\frac{q}{R}$$

Electric Potential Difference (ΔV)

It is the work done against electric field in moving a unit positive charge from one point to other. That is

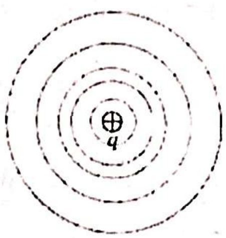
$$V_2 - V_1 = -\int_1^2 \vec{E}.\vec{dr}$$

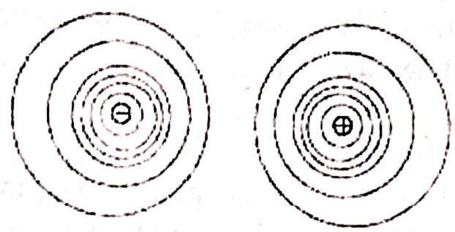
If W_{12} is work done in moving a charge q from one point to another point then

$$V_2 - V_1 = \frac{W_{12}}{q} \longrightarrow W_{12} = q(V_2 - V_1)$$

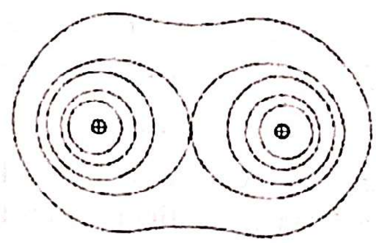
EQUIPOTENTIAL SURFACES

1. The electric potential is the same at all locations on the surface.
2. The electric field lines are always perpendicular to the equipotential surface.
3. Two equipotential surfaces cannot intersect.
4. No work is required to move a charge along an equipotential surface because the potential difference is zero along the surface.
5. No work is required to move a charge along an equipotential surface because the potential difference is zero along the surface.
6. Shape of equipotential surfaces

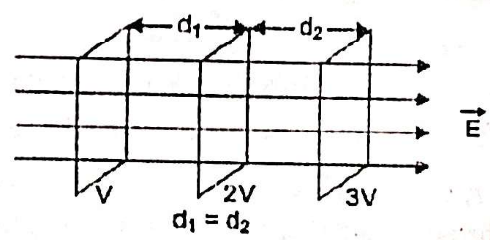




Point charge
a dipole



Two identical positive charges



Uniform electric field

Relation between field and potential

$$E = -\frac{dV}{dr}$$

(i) Electric field is in the direction in which the potential decreases steepest.

(ii) Its magnitude is given by the change in the magnitude of potential per unit displacement normal to the equipotential surface at the point.

Electric Potential Energy(U)

Potential energy of charge q at a point (in the presence of field due to any charge configuration) is the work done by the external force (equal and opposite to the electric force) in bringing the charge q from infinity to that point.

(i) Potential energy for a system of two charges q_1 and q_2 is

$$U = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r_{12}}$$

(ii) Potential energy of a system of two charges in an external field

$$U = q_1\, V(r_1) + q_2\, V(r_2) + \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r_{12}}$$

(iii) Potential energy of a dipole in an external field

The amount of work done by the external torque rotating dipole from angle θ_0 to angle θ_1 at an infinitesimal angular speed and without angular acceleration will be given by

$W = pE(\cos\theta_0 - \cos\theta_1)$

This work is stored as the potential energy of the system. Take $\theta_0 = \frac{\pi}{2}$ and $\theta_1 = 0$

$U = -pE\cos\theta = -\vec{p}.\vec{E}$

Simulation link for topic:- Capacitor

https://phet.colorado.edu/en/simulations/capacitor-lab-basics

MULTIPLE CHOICE QUESTIONS

1. A uniform electric field pointing in positive x-direction exists in a region. Let A be the origin, B be the point on the x-axis at x = + 1 cm and C be the point on the y-axis at y = + 1 cm. Then, the potentials at the points A, B and C satisfy

(a) $V_A < V_B$ (b) $V_A > V_B$ (c) $V_A < V_C$ (d) $V_A > V_C$

2. Which statement is not correct for an equipotential surface?

(a) Electric field intensity is always perpendicular to the equipotential surface.
(b) Potential difference between any two points on it is zero.
(c) Equipotential surfaces are spherical in shape.
(d) No work is required to move a charge on an equipotential surface

3. An electron mass m and charge e travels from rest through a potential difference of V. What will be the final velocity of electron?

(a) eV (b) $\frac{2eV}{m}$ (c) $\sqrt{\frac{2eV}{m}}$ (d) $\sqrt{\frac{2mV}{e}}$

4. Four point charges –Q, -q, 2q and 2Q are placed, one at each corner of the square. The relation between Q and q for which the potential at the centre of the square zero, is

(a) Q = -q (b) $Q = \frac{-1}{q}$ (c) Q = q (d) $Q = \frac{1}{q}$

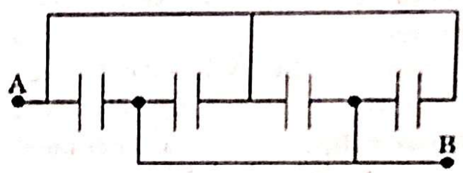
5. A hollow metal sphere of radius 10 cm is charged such that the potential on its surface is 80 V. The ratio of potential at a distance 5cm from the centre of the sphere to the potential at the surface of sphere is

(a) 1:2 (b) 2:1 (c) 1:1 (d) 1:4

6. There is one charged isolated air capacitor and *U* is the energy stored in it. Separation between the plates of the capacitor is increased to double of the initial value. Energy stored becomes

(a) U/2 (b) 2U (c) U/3 (d) 3U

7. Four condensers are joined as shown in the figure and the capacity of each condenser is 8 μF. The equivalent capacity between the points A and B will be:



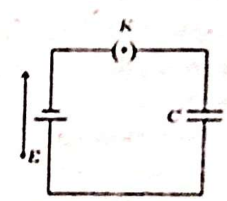
(*a*) 16 μF (*b*) 8 μF
(c) 32 μF (*d*) 2 μF

8. A parallel plate capacitor is connected to a battery as shown in Fig. Consider two situations:

A: Key K is kept closed and plates of capacitors are moved apart using insulating handle.

B: Key K is opened and plates of capacitors are moved apart using insulating handle.

Choose the correct option(s).



(a) In A : Q remains same but C changes.
(b) In B : V remains same but C changes.
(c) In A : V remains same and hence Q changes.
(d) In B : C remains same and hence V changes.

ANSWERS

1. (b) $E = -\frac{dV}{dr}$, Direction of electric field must be in the direction of the decreasing order of electric potential.
2. (c) Shape of equipotential surface depends on charge or distribution of charges
3. (c) $eV = \frac{1}{2}mv^2 \Rightarrow v = \sqrt{\frac{2eV}{m}}$
4. (b) $\frac{1}{4\pi\varepsilon_0}\frac{-Q}{R} + \frac{1}{4\pi\varepsilon_0}\frac{-q}{R} + \frac{1}{4\pi\varepsilon_0}\frac{2Q}{R} + \frac{1}{4\pi\varepsilon_0}\frac{2q}{R} = 0 \Rightarrow Q = \frac{-1}{q}$
5. (c) Value of potential inside and on the surface of a charged spherical shell is same
6. (b) As capacitor is isolated so charge on capacitor remains same

   New capacitance $C' = \frac{C}{2}$ and $V' = 2V$

   Hence, new energy $U' = 2U$
7. (c) All capacitors are connected in parallel so $C_{eq} = C_1 + C_2 + C_3 + C_4$ so $C_{eq} = 32\ \mu F$
8. (c) As it is connected to battery so V remains same but as capacitance changes so charge changes

ASSERTION-REASON QUESTIONS

Select the correct answer to these questions from the codes (a), (b), (c) and (d) as given below:

(a) Both assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of Assertion (A).

(b) Both assertion (A) and Reason (R) are true and Reason (R) is NOT the correct explanation of Assertion (A).

(c) Assertion (A) is true and Reason (R) is false.

(d) Assertion (A) is false and Reason (R) is also false.

1. **Assertion (A):** Electric field is always normal to equipotential surfaces and along the direction of decreasing order of potential.
Reason (R): Negative gradient of electric potential is electric field.

2. **Assertion (A):** Electric field inside a hollow conducting sphere is zero.
Reason (R): Charge is present on the surface of conductor.

3. **Assertion (A):** Work done in moving a charge between any two points in a uniform electric field is independent of the path followed by the charge between these two points.
Reason (R): Electrostatic forces are non conservative.

4. **Assertion (A):** Electric potential and electric potential energy are two different quantities.
Reason (R): For a test charge Q and a point charge Q, the electric potential energy becomes equal to the potential.

5. **Assertion (A):** When the distance between the parallel plates of a parallel plate capacitor is halved and the dielectric constant of the dielectric used is made three times, then the capacitance becomes three times.
Reason (R): Capacitance does not depend upon the external battery connected.

6. **Assertion (A):** Circuit containing capacitors should be handled very carefully even when the power is off.
Reason (R): The capacitors may break down at any time.

7. **Assertion (A):** Capacity of a conductor is independent on the amount of charge on it.
Reason (R): Capacitance depends on the dielectric constant of surrounding medium, shape and size of the conductor.

8. **Assertion (A):** Two parallel metal plates having charge +Q and –Q are facing at a distance between them. The plates are now immersed in kerosene oil and the electric potential between the plates decreases.
Reason (R): Dielectric constant of kerosene oil is less than 1.

ANSWERS

1. Option (A) is correct. **Explanation:** $E = -\frac{dV}{dr}$

So, the electric field is always perpendicular to equipotential surface. Negative gradient of electric potential is electric field. So, direction of electric field must be in the direction of the decreasing order of electric potential.

2. Option (A) is correct. **Explanation:** Since no charge resides in the surface of a hollow sphere, the electric field also zero inside. So, assertion is true. For hollow conducting sphere, the charged reside on the surface only. So, reason is also true and it explains the assertion properly.

3. Option (C) is correct. **Explanation:** Work done in moving a charge between any two points in a uniform electric

field = charge × potential difference. So, it is independent of the path followed by the charge. Hence the assertion is true. Electrostatic forces are conservative type. Hence, the reason is false.

4. Option (C) is correct. **Explanation:** Electric potential and electric potential energy are two different quantities.

Hence the assertion is true. Electric potential is defined as the potential energy per unit charge. Hence V = P.E./q

So, the reason is false.

5. Option (B) is correct. **Explanation:** Initial capacitance $C_1 = C = \frac{K\varepsilon_0 A}{d}$

$$C_2 = \frac{3K\varepsilon_0 A}{d/2}$$

So $C_2 = 6C_1$, Hence the assertion is true

6. Option (C) is correct. **Explanation:** Even when power is off capacitor may have stored charge which may discharge through human body and thus one may get a shock.

So, assertion is true. Breakdown of capacitors requires high voltage.

So, reason is false.

7. Option (A) is correct. **Explanation:** $C = \frac{\varepsilon_0 A}{d}$

In the expression, there is no involvement of charge. So, capacitance is independent of charge. Hence the assertion is true.

It depends on permittivity of the surrounding medium and the area of the plate. So, reason is also true.Reason explains the assertion.

8. Option (C) is correct. **Explanation:** Electric field for parallel plate capacitor in vacuum

$$E = \frac{\sigma}{\varepsilon_0}$$

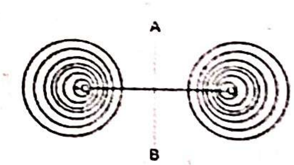
Electric field in dielectric $E' = \frac{\sigma}{K\varepsilon_0}$

Since the value of K for Kerosene oil is greater than 1, then E'< E. Hence the assertion is true. Dielectric constant of Kerosene oil is greater than 1. Hence the reason is false.

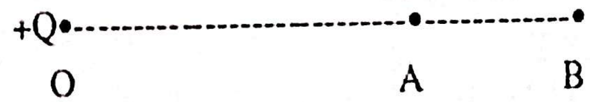
VERY SHORT ANSWER TYPE QUESTIONS (2 MARKS)

1. Draw an equipotential surface for a system consisting of two charges Q, –Q separated by a distance r in air. Locate the points where the potential due to the dipole is zero.

Ans. The equipotential surface for the system is as shown. Electric potential is zero at all points in the plane passing through the dipole equator AB.



2. A point charge +Q is placed at point O as shown in the figure. Is the potential difference $V_A - V_B$ positive, negative or zero?

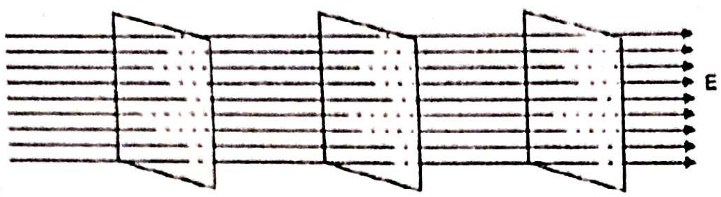


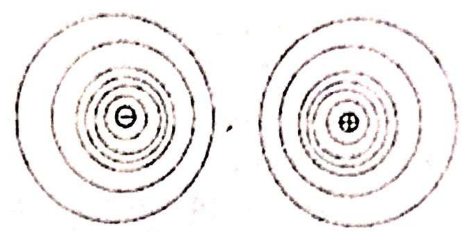
Ans. The potential due to a point charge decreases with increase of distance.

So, $V_A - V_B$ is positive.

3. Draw an equipotential surface in (i) a uniform electric field and (ii) a dipole

Ans. (i) (ii)



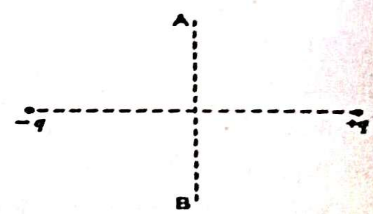


4. "For any charge configuration, equipotential surface through a point is normal to the electric field." Justify.

Ans. The work done in moving a charge from one point to another on an equipotential surface is zero. If electric field is not normal to the equipotential surface, it would have non-zero component along the surface. In that case work would be done in moving a charge on an equipotential surface.

5. A charge 'q' is moved from a point A above a dipole of dipole moment 'p' to a point B below the dipole in equatorial plane without acceleration. Find the work done in the process.

Ans. Work done in the process is zero. Because equatorial plane of a dipole is equipotential surface and work done in moving charge on equipotential surface is zero.



$W = q(V_B - V_A) = q \times 0 = 0$

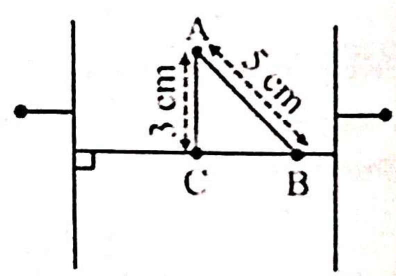
6. A charged particle (+q) moves in a uniform electric field ($\vec{E}$) in the direction opposite to $\vec{E}$. What will be the effect on its electrostatic potential energy during its motion?

Ans. When charge +q moves in opposite direction to electric field then work done is negative.

$\Delta U = -W$

so, change in potential energy is positive, the potential energy increases.

7. Two large plane parallel conducting plates are kept 8 cm apart as shown in figure. The potential difference between them is V. Find potential difference between the points A and B (shown in the figure) ?

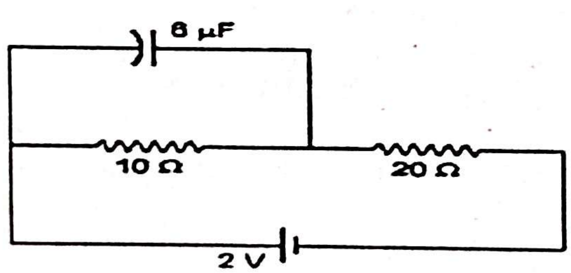


Ans. As $V = E\,d$

$V = E(8)$

Therefore $V_{AB} = E(4) = \left(\frac{V}{8}\right)4 = \frac{V}{2}$

8. Find the charge on the capacitor as shown in the circuit.

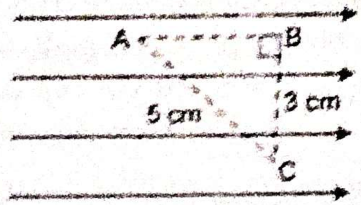


Ans. Total resistance, $R = 10\Omega + 20\Omega = 30\Omega$, So the current, $I = \frac{V}{R} = \frac{2}{30} = \frac{1}{15}$ A

Potential difference, $V = IR = \frac{1}{15} \times 10 = \frac{2}{3}$ V. Therefore, charge $Q = CV = 6 \times \frac{2}{3} = 4\ \mu C$

SHORT ANSWER TYPE QUESTIONS

1. Three points A, B and C lie in a uniform electric field (E) of $5 \times 10^3\ NC^{-1}$ as shown in the figure,
Find the potential difference between (i) A and B, and (ii) A and C.



Ans. (i) Potential difference between A and B = $E \times (AB) = 5 \times 10^3 \times (4 \times 10^{-2}) = 200$ volt

(ii) The line joining B to C is perpendicular to electric field, so potential of B = potential of C i.e., $V_B = V_C$

Distance AB = 4 cm

Potential difference between A and C = $E \times (AB)$

$= 5 \times 10^3 \times (4 \times 10^{-2}) = 200$ volt

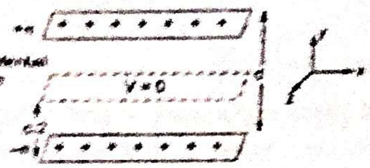
2. Two uniformly large parallel thin plates having charge densities $+\sigma$ and $-\sigma$ are kept in the X-Z plane at a distance 'd' apart. Sketch an equipotential surface due to electric field between the plates. If a particle of mass m and charge '$-q$' remains stationary between the plates, what is the magnitude and direction of this field?

Ans. (i) Weight mg acts vertically downward

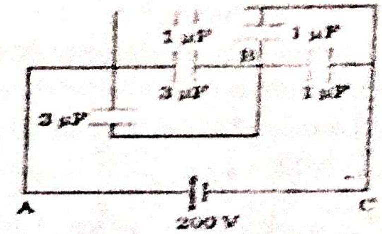
(ii) Electric force qE acts vertically upward.

so $mg = qE$

$E = \frac{mg}{q}$



3. Calculate the potential difference between points A and B as shown in figure



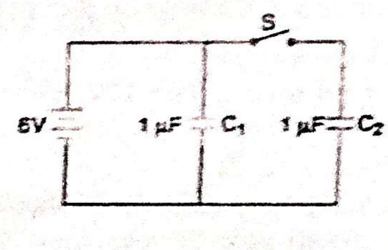
Ans. Equivalent capacitance $= \frac{5}{2}\ \mu F$

Charge supplied by battery $= \frac{5}{2} \times 200 = 500\ \mu C$

Potential difference between A and B is 80V

4. Figure shows two identical capacitors, C_1 and C_2, each of 1 mF capacitance connected to a battery of 6 V. Initially switch 'S' is closed. After sometimes 'S' is left open and dielectric slabs of dielectric constant K = 3 are inserted to fill completely the space between the plates of the two capacitors.

How will the (i) charge and (ii) potential difference between the plates of the capacitors be affected after the slabs are inserted?



Ans. When switch S is closed, p.d. across each capacitor is 6V

$V_1 = V_2 = 6$ V and $C_1 = C_2 = 1\ \mu C$

$\therefore$ Charge on each capacitor

$q_1 = q_2 (= CV) = (1\ \mu F) \times (6\ V) = 6\ \mu C$

When switch S is opened, the p.d. across C1 remains 6 V, while the charge on capacitor C_2 remains 6 µC. After insertion of dielectric between the plates of each capacitor, the new capacitance of each capacitor becomes

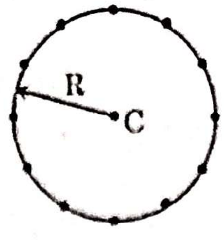
$C'_1 = C'_2 = 3 \times 1\ \mu F = 3\ \mu F$

Charge on capacitor C_1, $q'_1 = C'_1 V_1 = (3\ \mu F) \times 6\ V = 18\ \mu C$ Charge on capacitor C_2 remains 6 µC

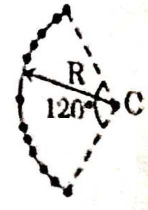
Potential difference across C_1 remains 6 V. Potential difference across C_2 becomes

$V_2' = \frac{6}{3} = 2\ V$

5. (a) Twelve negative charges of same magnitude are equally spaced and fixed on the circumference of a circle of radius R as shown in Fig. (i). Relative to potential being zero at infinity, find the electric potential and electric field at the centre C of the circle.
(b) If the charges are unequally spaced and fixed on an arc of 120° of radius R as shown in Fig. (ii), find electric potential at the centre C.



(i)



(ii)

Ans. (a) Potential due to single charge at C, $V = \frac{1}{4\pi\varepsilon_0}\frac{q}{R}$

Net potential at C is $V = \frac{-1}{4\pi\varepsilon_0}\frac{12q}{R}$

Due to symmetry of distribution of charge, electric fields are cancel each other, so E = 0

(b) Potential is scalar quantity so orientation is irrelevant

Hence potential at C is $V = \frac{-1}{4\pi\varepsilon_0}\frac{12q}{R}$

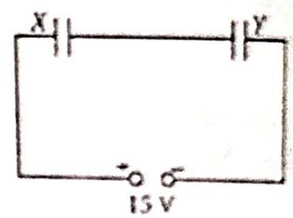
6. Three point charges +Q, –2Q and –3Q are placed at the vertices of an equilateral triangle ABC of side L. If these charges are displaced to the mid points A_1, B_1 and C_1 respectively, calculate the amount of work done in shifting the charges to the new locations.

Ans. $U_{initial} = \frac{1}{4\pi\varepsilon_0}\frac{Q^2}{l}$

$U_{final} = \frac{1}{4\pi\varepsilon_0}\frac{2Q^2}{l}$

$W = U_{final} - U_{initial} = \frac{1}{4\pi\varepsilon_0}\frac{Q^2}{l}$

7. Two parallel plate capacitors X and Y have the same area of plates and same separation between them. X has air between the plates while Y contains a dielectric medium $\varepsilon_r = 4$.
(i) Calculate the capacitance of each capacitor if equivalent capacitance of the combination is 4 µF.
(ii) Calculate the potential difference between the plates of X and Y.



Ans.(i) $\frac{C_Y}{C_X} = 4$ and $\frac{C_Y C_X}{C_X + C_y} = 4\mu F$

After solving $C_X = 5\ \mu F$ and $C_Y = 20\mu F$

(ii) in series charge on each capacitor is same so) $\frac{V_X}{V_Y} = 4$

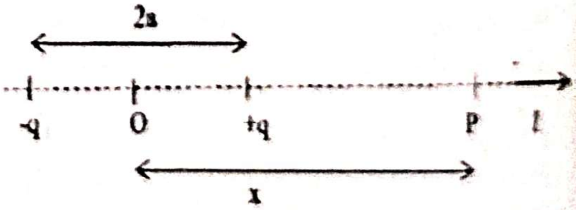
$V_X + V_Y = 15$

After solving $V_X = 12V$, $V_Y = 3V$

LONG ANSWER TYPE QUESTIONS

1. (i) An electric dipole (dipole moment $\vec{p} = p\hat{\imath}$), consisting of charges - q and q, separated by distance 2a, is placed along the x-axis, with its centre at the origin. Show that the potential V, due to this dipole, at a point x, (x >> a) is equal to $\frac{1}{4\pi\varepsilon_0}\frac{\vec{p}.\hat{\imath}}{x^2}$

(ii) Two isolated metallic spheres S_1 and S_2 of radii 1 cm and 3 cm respectively are charged such that both have the same charge density $\left(\frac{2}{\pi} X\ 10^{-9}\right)$C/m².. They are placed far away from each other and connected by a thin wire. Calculate the new charge on sphere S_1.



Ans.(i) Derive expression of potential at P, $V = \frac{1}{4\pi\varepsilon_0}\frac{p}{x^2 - a^2}$

As p is along x-axis so

$V = \frac{1}{4\pi\varepsilon_0}\frac{\vec{p}.\hat{\imath}}{x^2 - a^2}$

If $x >> a$

$V = \frac{1}{4\pi\epsilon_0} \frac{p.l}{x^2}$

(ii) Charge on $S_1 = \sigma \times 4\pi r^2 = \left(\frac{2}{\pi} \times 10^{-9}\right) \times 4\pi (1 \times 10^{-2})^2 = 8 \times 10^{-13}$ C

Charge on $S_2 = \sigma \times 4\pi r^2 = \left(\frac{2}{\pi} \times 10^{-9}\right) \times 4\pi (3 \times 10^{-2})^2 = 72 \times 10^{-13}$ C

When connected by thin wire they acquire common potential V and charge remains conserved

$$Q_1 + Q_2 = Q_1' + Q_2' \qquad \text{and} \qquad \frac{Q_1'}{Q_2'} = \frac{r_1}{r_2}$$

On solving $Q_1' = 2 \times 10^{-12}$ C

2. (i) Derive an expression for potential energy of an electric dipole p in an external uniform electric field E. When is the potential energy of the dipole (1) maximum, and (2) minimum?

(ii) Three point charges q, 2q and nq are placed at the vertices of an equilateral triangle. If the potential energy of the system is zero, find the value of n.

Ans. (i) Derivation of expression of potential energy

$$U(\theta) = -pE\cos\theta = -\vec{p}.\vec{E}$$

(1) Potential energy is maximum $\theta = 180^0$

(2) Potential energy is minimum $\theta = 0^0$

(ii) Consider an equilateral triangle of side a

$$\text{Potential energy } U = \frac{kq_1q_2}{a} + \frac{kq_2q_3}{a} + \frac{kq_3q_1}{a}$$

$$U = \frac{k\,q.2q}{a} + \frac{k\,2q.nq}{a} + \frac{k\,q.nq}{a}$$

According to question U=0

$$\text{So } \frac{k\,q.2q}{a} + \frac{k\,2q.nq}{a} + \frac{k\,q.nq}{a} = 0, \qquad \text{After solving } n = -\frac{2}{3}$$

CASE STUDY TYPE QUESTIONS

1. The figure shows four pairs of parallel identical conducting plates, separated by the same distance 2.0 cm and arranged perpendicular to x-axis. The electric potential of each plate is mentioned. The electric field between a pair of plates is uniform and normal to the plates.

(i) For which pair of the plates is the electric field E along î?

(A) I (B) II (C) III (D) IV

(ii) An electron is released midway between the plates of pair IV. It will :

(A) move along î at constant speed (B) move along -î at constant speed

(C) accelerate along î (D) accelerate along -î

(iii) Let E_1, E_2, E_3 and E_4 be the magnitudes of the electric field between the pairs of plates, I, II, III and IV respectively, then:

(A) $E_1 > E_2 > E_3 > E_4$ (B) $E_3 > E_4 > E_1 > E_2$

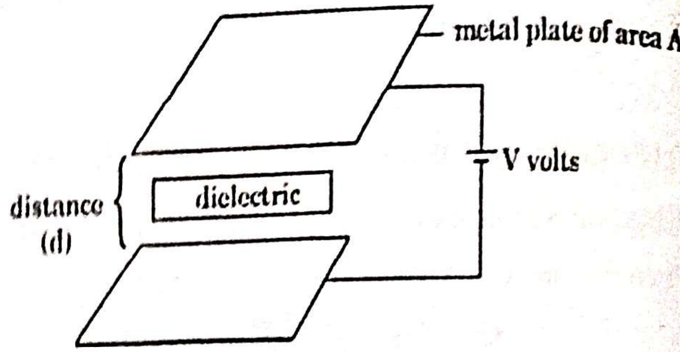
(C) $E_4 > E_3 > E_2 > E_1$ (D) $E_2 > E_3 > E_4 > E_1$

(iv) An electron is projected from the right plate of set I directly towards its left plate. It just comes to rest at the plate. The speed with which it was projected is about :

(Take (e/m) =1.76 X 10^{11} C/kg)

(A) 1.3 X 10^5 m/s (B) 2.6 X 10^6 m/s (C) 6.5 X 10^3 m/s (D) 5.2 X 10^7 m/s

2. A parallel plate capacitor is an arrangement of two identical metal plates kept parallel, a small distance apart. The capacitance of a capacitor depends on the size and separation of the two plates and also on the dielectric constant of the medium between the plates. Like resistors, capacitors can also be arranged in series or parallel or a combination of both. By virtue of electric field between the plates, charged capacitors store energy.



Q(a) The capacitance of a parallel plate capacitor increases from 10μF to 80μF on introducing a dielectric medium between the plates. Find the dielectric constant of the medium.

Q(b) n capacitors, each of capacitance C, are connected in series. Find the equivalent capacitance of the combination.

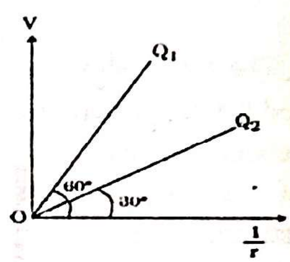
Q(c) A capacitor is charged to a potential (V) by connecting it to a battery. After some time, the battery is disconnected and a dielectric is introduced between the plates. How will the potential difference between the plates, and the energy stored in it be affected ? Justify your answer.

3. Electrostatics deals with the study of forces, fields and potentials arising from static charges. Force and electric field, due to a point charge is basically determined by Coulomb's law. For symmetric charge configurations, Gauss's law, which is also based on Coulomb's law, helps us to find the electric field. A charge/a system of charges like a dipole experience a force/torque in an electric field. Work is required to be done to provide a specific orientation to a dipole with respect to an electric field.

Answer the following questions based on the above:

Q(a) Consider a uniformly charged thin conducting shell of radius R. Plot a graph showing the variation of V with distance r from the centre, for points $0 < r < 3R$.

Q(b) The figure shows the variation of potential V with $\frac{1}{r}$ for two point charges Q_1 and Q_2, where V is the potential at a distance r due to a point charge. Find $\frac{Q_1}{Q_2}$.



Q(c) An electric dipole of dipole moment $\vec{p}$ is initially kept in a uniform electric field $\vec{E}$ such that $\vec{p}$ is perpendicular to $\vec{E}$. Find the amount of work done in rotating the dipole to a position at which $\vec{p}$ becomes antiparallel to $\vec{E}$.

ANSWERS

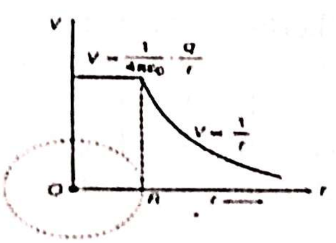
Ans.1. (i) (D) IV (ii) (D) accelerate along $-\hat{i}$ (iii) (C) $E_4 > E_3 > E_2 > E_1$

(iv) (B) 2.6×10^6 m/s

Ans.2 (a) K=8 (b) $C_s = \frac{C}{n}$

(c) Potential difference decreases by a factor 1/K, Energy reduces by a factor 1/K

Ans. 3 (a)



(b) $\frac{Q_1}{Q_2} = \frac{\tan 60}{\tan 30} = 3$

(c) Work done = + pE

CHAPTER-03 - CURRENT ELECTRICITY

SYLLABUS

Electric current, flow of electric charges in a metallic conductor, drift velocity, mobility and their relation with electric current; Ohm's law, V-I characteristics (linear and non-linear), electrical energy and power, electrical resistivity and conductivity, temperature dependence of resistance, Internal resistance of a cell, potential difference and emf of a cell, combination of cells in series and in parallel, Kirchhoff's rules, Wheatstone bridge.

CONCEPT MAP

Current Density Conductance Conductivity

$J = \frac{dI}{dA\cos\theta}$

Reciprocal of resistance is known as conductance.

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

Electric Current

I = charge/time = $\frac{dq}{dt}$, If flow is uniform I = $\frac{q}{t}$

CURRENT ELECTRICITY

Ohm's Law Resistance & Resistivity

$I \propto V \Rightarrow V = IR$

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

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

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

Drift Velocity & Mobility of Charges

Drift velocity $V_d = \frac{-eE}{m}\tau$

$v_d = \frac{i}{neA} = \frac{J}{ne} = \frac{\sigma E}{ne} = \frac{E}{\rho ne}$

Current $I = neAV_d$

Current Density $J = \frac{i}{A} = nev_d$

$\Rightarrow I = \frac{nAe^2E}{m}\tau$

$\Rightarrow I = \frac{nAe^2V}{ml}\tau$

$I \propto V$

Resistance & Resistivity

$R = \rho\frac{l}{A} = \frac{m}{ne^2\tau}\cdot\frac{l}{A}$

From $R = \rho\frac{l}{A}$, $\rho = \frac{m}{ne^2\tau}$

Reciprocal of resistivity is called conductivity (σ) i.e. $\sigma = \frac{1}{\rho}$

Drift velocity per unit electric field is called mobility of electron

$\mu = \frac{V_d}{E} = \frac{-e}{m}\tau$

Kirchhoff's Law

Current law (*KCL*) is the algebraic sum of currents meeting at a junction is zero. *i.e.* $\Sigma I = 0$.

Voltage law (KVL) is the algebraic sum of the changes in potential in complete traversal of a closed loop is zero. *i.e.* $\Sigma V = 0$

Wheatstone Bridge

The bridge is said to be balanced when deflection in galvanometer is zero *i.e.* no current flows through the galvanometer. On mutually changing the position of cell and galvanometer this condition will not change.

Electric Cell

Emf of cell (*E*) : The potential difference across the terminals of a cell when it is not supplying any current.

Potential difference (*V*) : The voltage across the terminals of a cell when it is supplying current to external resistance.

Internal resistance (*r*) : In case of a cell the opposition of electrolyte to the flow of current through it.

In Series combination of cells- $E_{eq} = E_1 + E_2$ and $r_{eq} = r_1 + r_2$

In Parellel combination of cells- $E_{eq} = \frac{E_1r_2 + E_2r_1}{r_1 + r_2}$ and $r_{eq} = \frac{r_1r_2}{r_1 + r_2}$

In charging $V > E$.

In open circuit of a cell $V = E$

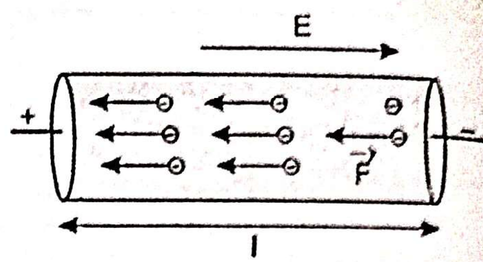
GIST OF THE CHAPTER

ELECTRIC CURRENT

- The electric current in measured by 'rate of flow of charge'.Or Charge flowing per second from any cross section of the conductor is called electric current,
- Current i = charge/time = $\frac{dq}{dt}$, if flow is uniform i = $\frac{Q}{t}$
- **Unit :** Ampere (A), Dimension : $(M^0L^0T^0A^1)$
- 1 ampere = 1 coulomb/second. i.e. if 1 coulomb of charge flows per second then 1 ampere of current is said to be flowing.

- 1 ampere of current means the flow of 6.25×10^{18} electrons per second through any cross section of conductor
- If n electrons pass through any cross section in every t seconds then $i = \frac{ne}{t}$ where $e = 1.6 \times 10^{-19}$ coulomb.
- The conventional direction of current is taken to be the direction of flow of positive charge, *i.e.* field
- Value of the current is same throughout the conductor, irrespective of the cross section of conductor at different points.
- Net charge in a current carrying conductor is zero at any instant of time.

Note : A current carrying conductor cannot said to be charged, because in conductor the current is caused by electron (free electron). The no. of electron (negative charge) and proton (positive charge) in a conductor is same. Hence the net charge in a current carrying conductor is zero.



- Electric field outside a current carrying conductor is zero, but it is non zero inside the conductor and is given by $e = -\frac{v}{l}$

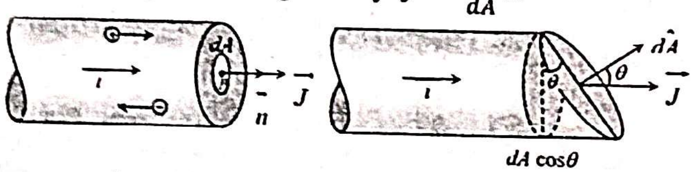
Note : The electric field inside charged conductor is zero, but it is non zero inside a current carrying conductor

Note : Current is a scalar quantity because it does not obey law of vector

CURRENT DENSITY

Current density at any point inside a conductor is defined as a vector having magnitude equal to current per unit area surrounding that point. Remember area is normal to the direction of charge flow (or current passes) through that point.

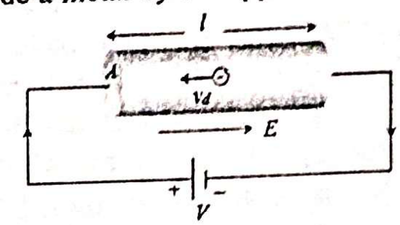
- Current density at point *P* is given by $\vec{J} = \frac{di}{dA}\vec{n}$



- If the cross-sectional area is not normal to the current, but makes an angle θ with the direction of current then $J = \frac{di}{dA\cos\theta} \Rightarrow di = JdA\cos\theta = \vec{J}.\vec{dA} \Rightarrow i = \int \vec{J}\cdot\vec{dA}$
- If current density $\vec{J}$ is uniform for a normal cross-section A then J= i/A
- Current density J is a vector quantity. It's direction is same as that of **E**. It's S.I. unit is *amp/m²* and dimension $[L^{-2}A]$.
- In case of uniform flow of charge through a cross-section normal to it as $i = nqvA \Rightarrow J = \frac{i}{A} = nqv$
- Current density relates with electric field as $\vec{J} = \sigma\vec{E} = \frac{\vec{E}}{\rho}$; where σ= conductivity and ρ= resistivity or specific resistance of substance.

Drift Velocity

Drift velocity is the average uniform velocity acquired by free electrons inside a metal by the application of an electric field which is responsible for current through it. Drift velocity is very small it is of the order of $10^{-4} m/s$ as compared to thermal speed ($\simeq 10^5 m/s$) of electrons at room temperature.

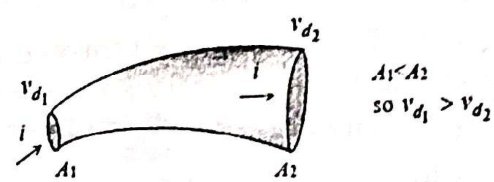


If suppose for a conductor n = Number of electron per unit volume of the conductor,

A = Area of cross-section, V = potential difference across the conductor, E = electric

field inside the conductor, i = current, J = current density, ρ = specific resistance, σ conductivity $\left(\sigma = \frac{1}{\rho}\right)$ then current relates with drift velocity as $i = neAv_d$ we can also write $v_d = \frac{i}{neA} = \frac{J}{ne} = \frac{\sigma E}{ne} = \frac{E}{\rho ne} = \frac{V}{\rho l n e}$.

- The direction of drift velocity for electron in a metal is opposite to that of applied electric field (*i.e.* current density $\vec{J}$). $v_d \propto E$ *i.e.*, greater the elecic field, larger will be the drift velocity.
- When a steady current flows through a conductor of non-uniform cross-section drift velocity varies inversely with area of cross-section $\left(v_d \propto \frac{1}{A}\right)$



- If diameter (d) of a conductor is doubled, then drift velocity of electrons inside it will not change.

Relaxation time (τ) : The time interval between two successive collisions of electrons with the positive ions in the metallic lattice is defined as relaxation time $\tau = \frac{\text{mean free path}}{\text{r.m.s. velocity of electrons}} = \frac{\lambda}{v_{rms}}$. With rise in temperature v_{rms} increases consequently τ decreases.

Mobility : Drift velocity per unit electric field is called mobility of electron *i.e.* $\mu = \frac{v_d}{E}$. It's unit is $\frac{m^2}{volt-sec}$.

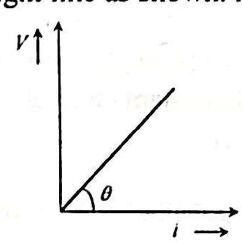
Ohm's Law

If the physical conditions of the conductor (length, temperature, mechanical strain etc.) remains some, then the current flowing through the conductor is directly proportional to the potential difference across it's two ends *i.e.* $i \propto V \Rightarrow V = iR$ where R is a proportionality constant, known as electric resistance.

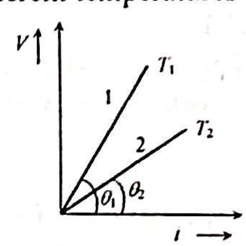
(1) Ohm's law is not a universal law, the substances, which obey ohm's law are known as ohmic substance.

(2) Graph between V and i for a metallic conductor is a straight line as shown. At different temperatures V-i curves are different.

Ohm's law is true For metallic conductors at low temperature Because with rise in temperature resistance of conductor increase, so graph between V and i becomes non linear.



(A) Slope of the line = tan θ = R



(B) Here $\tan\theta_1 > \tan\theta_2$ So $R_1 > R_2$ *i.e.* $T_1 > T_2$

Resistance

- The property of substance by virtue of which it opposes the flow of current through it, is known as the resistance.
- **Formula of resistance :** For a conductor if l = length of a conductor A = Area of cross-section of conductor, n = No. of free electrons per unit volume in conductor, τ = relaxation time then resistance of conductor $R = \rho\frac{l}{A} = \frac{m}{ne^2\tau}.\frac{l}{A}$; where ρ = resistivity of the material of conductor
- **Unit and dimension :** It's S.I. unit is *Volt/Amp.* or *Ohm* (Ω).It's dimension is $[ML^2T^{-3}A^{-2}]$
- **Dependence of resistance :** Resistance of a conductor depends upon the following factors.

(i) Length of the conductor :Resistance of a conductor is directly proportional to it's length *i.e.* $R \propto l$ and inversely proportional to it's area of cross-section *i.e.* $R \propto \frac{1}{A}$

(ii) Temperature : For a conductor

If $\quad R_0$ = resistance of conductor at $0°C$

$\qquad R_t$ = resistance of conductor at $t°C$

and α, β = temperature co-efficient of resistance

then $R_t = R_0(1 + \alpha t)$ for $t \leq 300°C$ or $\alpha = \frac{R_t - R_0}{R_0 \times t}$

If R_1 and R_2 are the resistances at $t_1°C$ and $t_2°C$ respectively then $\frac{R_1}{R_2} = \frac{1+\alpha t_1}{1+\alpha t_2}$.

The value of α is different at different temperature. Temperature coefficient of resistance averaged over the temperature range $t_1°C$ to $t_2°C$ is given by $\alpha = \frac{R_2 - R_1}{R_1(t_2 - t_1)}$ which gives

$R_2 = R_1 [1 + \alpha (t_2 - t_1)]$.

Resistivity (ρ), Conductivity (σ) and Conductance (C)

Resistivity : From $R = \rho \frac{l}{A}$; If $l = 1m$, $A = 1\ m^2$ then $R = \rho$ *i.e.* resistivity is numerically equal to the resistance of a substance having unit area of cross-section and unit length.

- Unit and dimension : It's S.I. unit is *ohm×m* and dimension is $[ML^3T^{-3}A^{-2}]$
- (ii) It's formula : $\rho = \frac{m}{ne^2\tau}$
- (iii) Resistivity is the intrinsic property of the substance. It is independent of shape and size of the body (*i.e.* l and A).

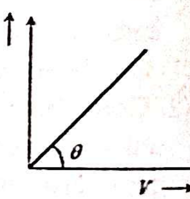
For different substances their resistivity is also different

$$\underset{(Maximum\ for\ fused\ quartz)}{\rho_{insulator}} > \rho_{alloy} > \rho_{semi-conductor} > \underset{(Minimum\ for\ silver)}{\rho_{conductor}}$$

- Resistivity depends on the temperature. For metals $\rho_t = \rho_0(1 + \alpha \Delta t)$ *i.e.* resistivity increases with temperature.
- Resistivity increases with impurity and mechanical stress.

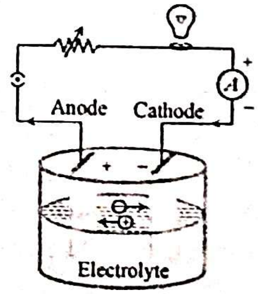
Conductivity : Reciprocal of resistivity is called conductivity (σ) *i.e.* $\sigma = \frac{1}{\rho}$ with unit *mho/m* and dimensions $\quad [M^{-1}L^{-3}T^3A^2]$.

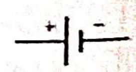
Conductance: Reciprocal of resistance is known as conductance. $C = \frac{1}{R}$ It's unit is $\frac{1}{\Omega}$ or Ω^{-1}.



Cell

The device which converts chemical energy into electrical energy is known as electric cell. Cell is a source of constant emf but not constant current.





Symbol of cell

(1) **Emf of cell (E) :** The potential difference across the terminals of a cell when it is not supplying any current is called it's emf.

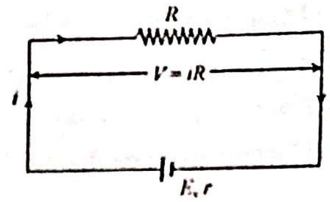
(2) **Potential difference (V) :** The voltage across the terminals of a cell when it is supplying current to external resistance is called potential difference or terminal voltage.

Potential difference is equal to the product of current and resistance of that given part *i.e.* $V = iR$.

(3) **Internal resistance (r) :** In case of a cell the opposition of electrolyte to the flow of current through it is called internal resistance of the cell. The internal resistance of a cell

depends on the distance between electrodes ($r \propto d$), area of electrodes [$r \propto (1/A)$] and nature, concentration ($r \propto C$) and temperature of electrolyte [$r \propto$ (1/ temp.)].
A cell is said to be ideal, if it has zero internal resistance.

Cell in Various Positions



(1) Closed circuit : Cell supplies a constant current in the circuit.

(i) Current given by the cell $i = \frac{E}{R+r}$

(ii) Potential difference across the resistance $V = iR$

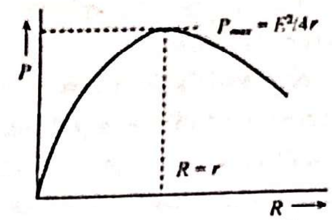
(iii) Potential drop inside the cell = ir

(iv) Equation of cell $E = V + ir$ $(E>V)$

(v) Internal resistance of the cell $r = \left(\frac{E}{V} - 1\right) \cdot R$

(vi) Power dissipated in external resistance (load)

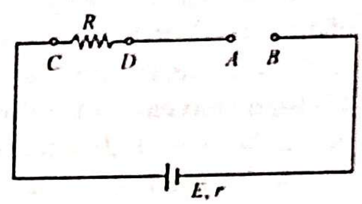
$$P = Vi = i^2R = \frac{V^2}{R} = \left(\frac{E}{R+r}\right)^2 .R$$



Power delivered will be maximum when $R = r$ so $P_{max} \frac{E^2}{4r}$.

This statement in generalised from is called "*maximum power transfer theorem*".

(vii) When the cell is being charged *i.e.* current is given to the cell then $E = V - ir$ and
$E<V$.

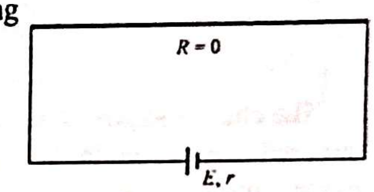


(2) Open circuit : When no current is taken from the cell it is said to be in open circuit

(i) Current through the circuit $i = 0$

(ii) Potential difference between A and B, $V_{AB} = E$

(iii) Potential difference between C and D, $V_{CD} = 0$



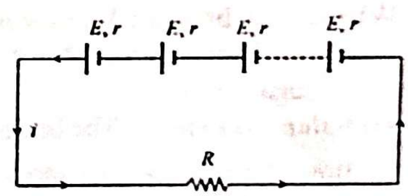
(3) Short circuit : If two terminals of cell are join together by a thick conducting wire

(i) Maximum current (called short circuit current) flows momentarily $i_{sc} = \frac{E}{r}$

(ii) Potential difference $V = 0$

Grouping of Cells

(1) Series grouping : In series grouping anode of one cell is connected to cathode of
other cell and so on. If n identical cells are connected in series



(i) Equivalent emf of the combination $E_{eq} = nE$

(ii) Equivalent internal resistance $r_{eq} = nr$

(iii) Main current = Current from each cell= $i = \frac{nE}{R+nr}$

(iv) Potential difference across external resistance $V = iR$

(v) Potential difference across each cell $V' = \frac{V}{n}$

(vi) Power dissipated in the external circuit = $\left(\frac{nE}{R+nr}\right)^2 .R$

(vii) Condition for maximum power $R = nr$ and $P\left(\frac{E^2}{4r}\right)_{max}$

(viii) This type of combination is used when $nr<<R$.

(2) Parallel grouping : In parallel grouping all anodes are connected at one point and all cathode are connected together at other point. If n identical cells are connected in parallel.

(i) Equivalent emf $E_{eq} = E$

(ii) Equivalent internal resistance $R_{eq} = r/n$

(iii) Main current $i = \frac{E}{R+r/n}$

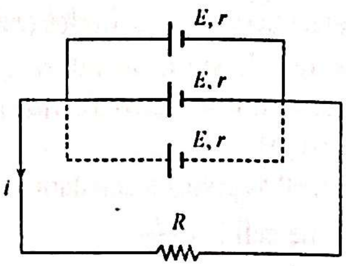
(iv) Potential difference across external resistance = p.d. across each cell = $V = iR$

(v) Current from each cell $i' = \frac{i}{n}$

(vi) Power dissipated in the circuit $P = \left(\frac{E}{R+r/n}\right)^2 . R$

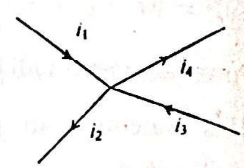
(vii) Condition for max. power is $R = r/n$ and $P\left(\frac{E^2}{4r}\right)_{max}$

(viii) This type of combination is used when $nr >> R$



Kirchoff's Laws

(1) **Kirchoff's first law :** This law is also known as junction rule or current law (*KCL*). According to it the algebraic sum of currents meeting at a junction is zero *i.e.* $\Sigma i = 0$. In a circuit, at any junction the sum of the currents entering the junction must equal the sum of the currents leaving the junction. $i_1 + i_3 = i_2 + i_4$



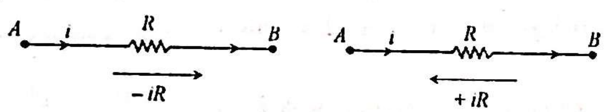
(ii) This law is simply a statement of "*conservation of charge*".

(2) **Kirchoff's second law :** This law is also known as loop rule or voltage law (KVL) and according to it "the algebraic sum of the changes in potential in complete traversal of a mesh (closed loop) is zero", *i.e.* $\Sigma V = 0$

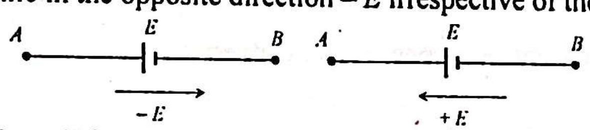
(i) This law represents "*conservation of energy*".

(3) **Sign convention for the application of Kirchoff's law :** For the application of Kirchoff's laws following sign convention are to be considered

(i) The change in potential in traversing a resistance in the direction of current is $-iR$ while in the opposite direction $+iR$



(ii) The change in potential in traversing an emf source from negative to positive terminal is $+E$ while in the opposite direction $-E$ irrespective of the direction of current in the circuit.



Wheatstone bridge : Wheatstone bridge is an arrangement of four resistance which can be used to measure one of them in terms of rest. Here arms *AB* and *BC* are called ratio arm and arms *AC* and *BD* are called conjugate arms

(i) Balanced bridge : The bridge is said to be balanced when deflection in galvanometer is zero *i.e.* no current flows through the galvanometer or in other words $V_B = V_D$. In the balanced condition $\frac{P}{Q} = \frac{R}{S}$, on mutually changing the position of cell and galvanometer this condition will not change.

(ii) Unbalanced bridge : If the bridge is not balanced current will flow from *D* to *B* if $V_D > V_B$ *i.e.* $(V_A - V_D) < (V_A - V_B)$ which gives $PS > RQ$.