Chapter-12

Electrostatics

"The study of electric charges at rest under the action of electric force is called Electrostatics."

12.1 Coulomb's Law

This law was by CHARLES COULOMB a French military engineer is 1874 AD.

Statement:

"The force between two point charges is directly proportional to the product of the magnitude of charges and inversely proportional to the square of the distance between them."

$$F \propto q_1 q_2$$

$$F \propto \frac{1}{r^2}$$

$$F \propto \frac{q_1 q_2}{r^2}$$

$$\boxed{F = k\frac{q_1 q_2}{r^2}}$$

k = Constant of proportionality.

The value of "k" depends on:

1) The nature of the medium between the charges.

2) The system of units in which F, q, r are measured.

Effect of Medium on the Coulomb's Force

Case-1:

When medium between the charges is Free Space (vacuum):

$$k = \frac{1}{4\pi\epsilon_o}$$

ϵ_o = An electrical constant.

ϵ_o = permittivity of free space.

$$\boxed{\epsilon_o = 8.85 \times 10^{-12}\ C^2\ N^{-1}\ m^{-2}}$$

$$k = \frac{1}{4\pi\epsilon_o}$$

$$k = \frac{1}{4 \times 3.14 \times 8.85 \times 10^{-12}}$$

$$\boxed{k = 9 \times 10^9\ N\ m^2\ C^{-2}}$$

Coulomb's Force in Free Space is

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

Information

Units of k:

$$F = k\frac{q_1 q_2}{r^2}$$

$$k = \frac{F r^2}{q_1 q_2}$$

$$k = \frac{N m^2}{C \cdot C}$$

$$k = N m^2 C^{-2}$$

$$\epsilon_o = C^2 N^{-1} m^{-2}$$

Vector Form:

$$\boxed{\vec{F} = \frac{1}{4\pi\epsilon_o} \cdot \frac{q_1 q_2}{r^2}\,\hat{r}}$$

Case-2:

When Medium between the charges is an insulator called Dielectric:

In the presence of a dielectric medium, the electrostatic Force decreases by a Factor ϵ_r.

ϵ_r = Relative permittivity of the medium.

ϵ_r has different values for different materials.

$$\boxed{F' = \frac{1}{4\pi\epsilon_o\epsilon_r} \cdot \frac{q_1 q_2}{r^2}}$$

$$F' = \frac{1}{\epsilon_r}\left[\frac{1}{4\pi\epsilon_o}\,\frac{q_1 q_2}{r^2}\right]$$

$$F' = \frac{1}{\epsilon_r} \cdot F$$

$$\boxed{F' = \frac{F}{\epsilon_r}}$$

As $\epsilon_r > 1$

So, $F' < F$

Note:

ϵ_r has no units.

For Air $\epsilon_r = 1.0006 \simeq 1$.

Coulomb's Forces is a Mutual Force

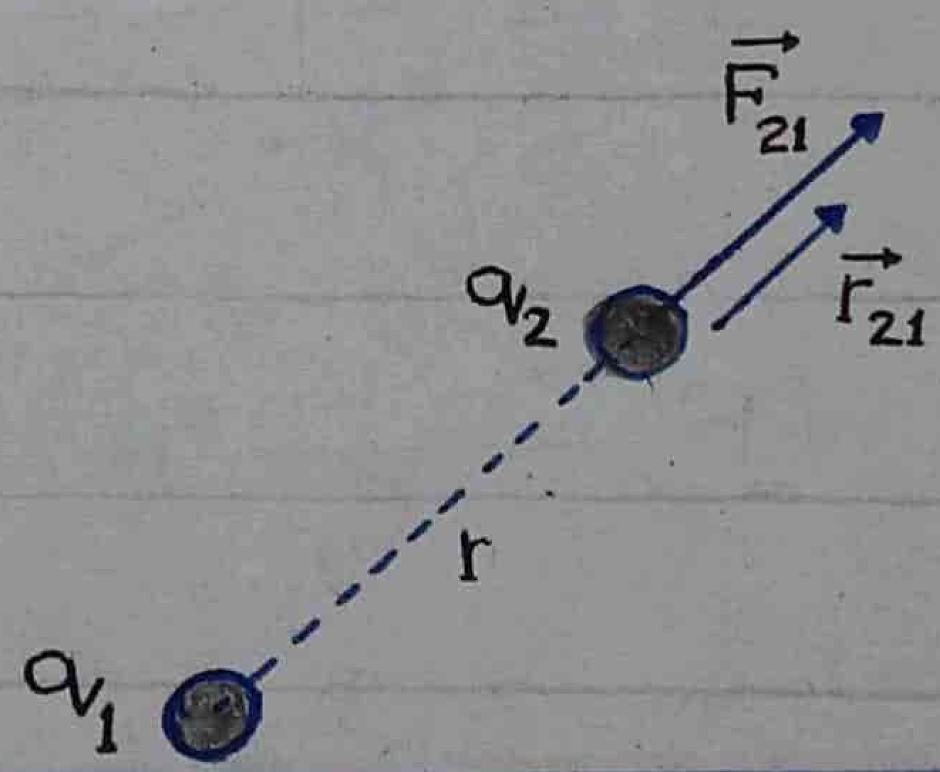
If q_1 exerts a force on q_2, then q_2 also exerts a force on q_1.
These forces are equal in magnitude, but opposite direction.

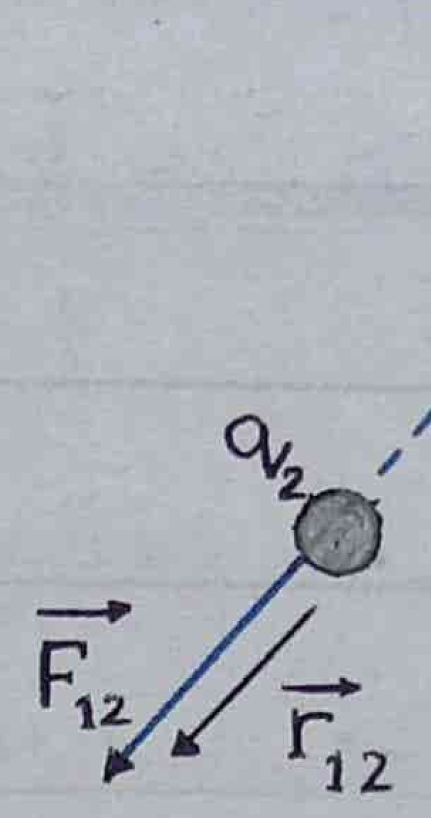
$$\vec{F}_{21} = -\vec{F}_{12}$$

$\vec{F}_{21}$ = Force on charge q_2 due to charge q_1.
$\vec{F}_{12}$ = Force on charge q_1 due to charge q_2.

$\vec{r}_{21}$ = Unit Vector directed from q_1 to q_2.
$\vec{r}_{12}$ = Unit vector directed from q_2 to q_1.

$$\vec{F}_{21} = \frac{1}{4\pi\epsilon_o}\frac{q_1 q_2}{r^2}\hat{r}_{21}$$





$$\vec{F}_{12} = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r^2} \hat{r}_{12}$$

But $\hat{r}_{21} = -\hat{r}_{12}$

$$\vec{F}_{21} = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r^2} (-\hat{r}_{12})$$

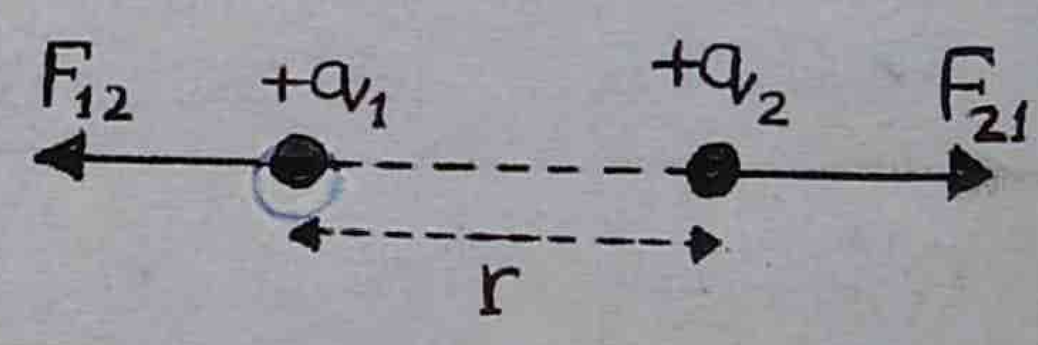
$$\vec{F}_{21} = -\left[\frac{1}{4\pi\epsilon_0} \cdot \frac{q_1 q_2}{r^2} \hat{r}_{12}\right]$$

$$\vec{F}_{21} = -\vec{F}_{12}$$

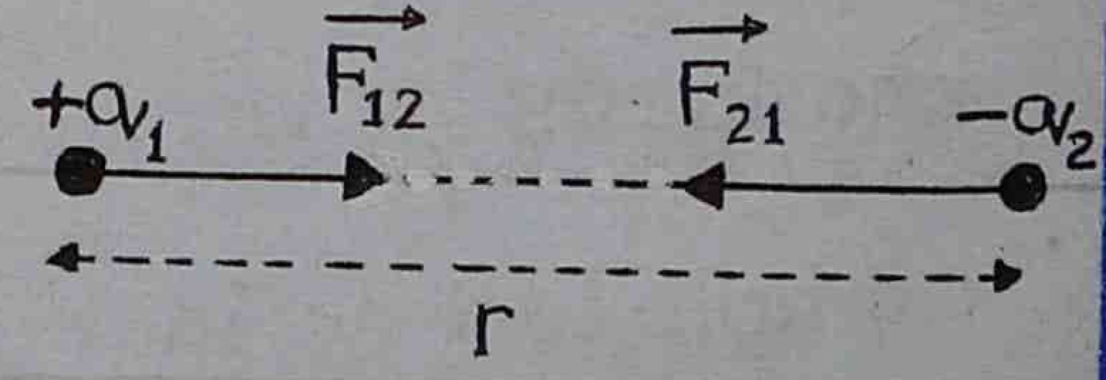
Types of Forces:

The sign of charges tells us the type of force.

1) When the charges are similar [(+ve , +ve) or (−ve , −ve)]. The force is +ve and it is force of Repulsion.



2) When the charges are opposite (+ve , −ve), the force is −ve and it is a force of attraction.



12.2 Fields of Force

By

1- Newton's Law of Gravitation and

2- Coulomb's Law

We calculate the magnitude and direction of

1- Gravitational Force

2- Electric Force

Micheal Faraday introduced the concept of Electric Field:

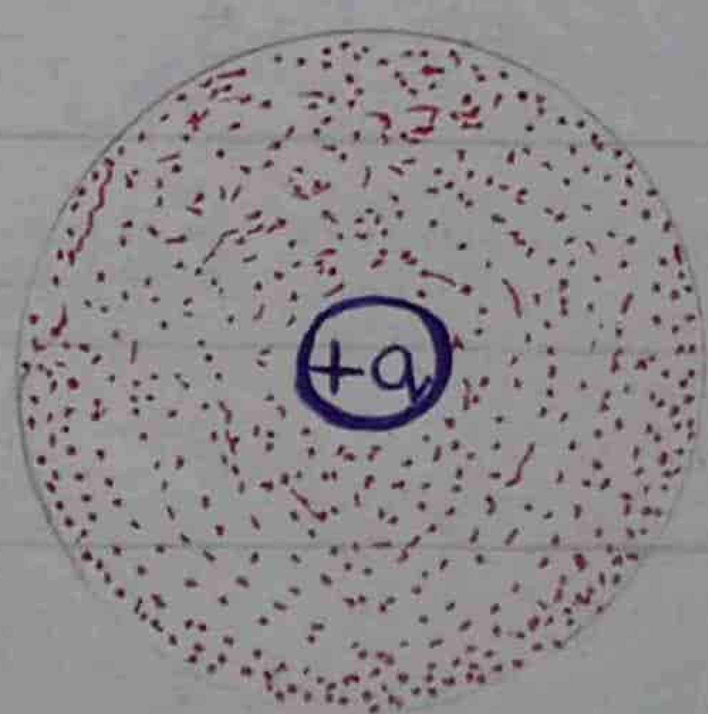
According to this theory an electric exists in the space around the charge. This Force Field (Electric Field) exerts electric Force on another charge placed in it.

Explanation:

The interaction of two charges produces an electric Force. This process is completed in two steps.

Step-1:

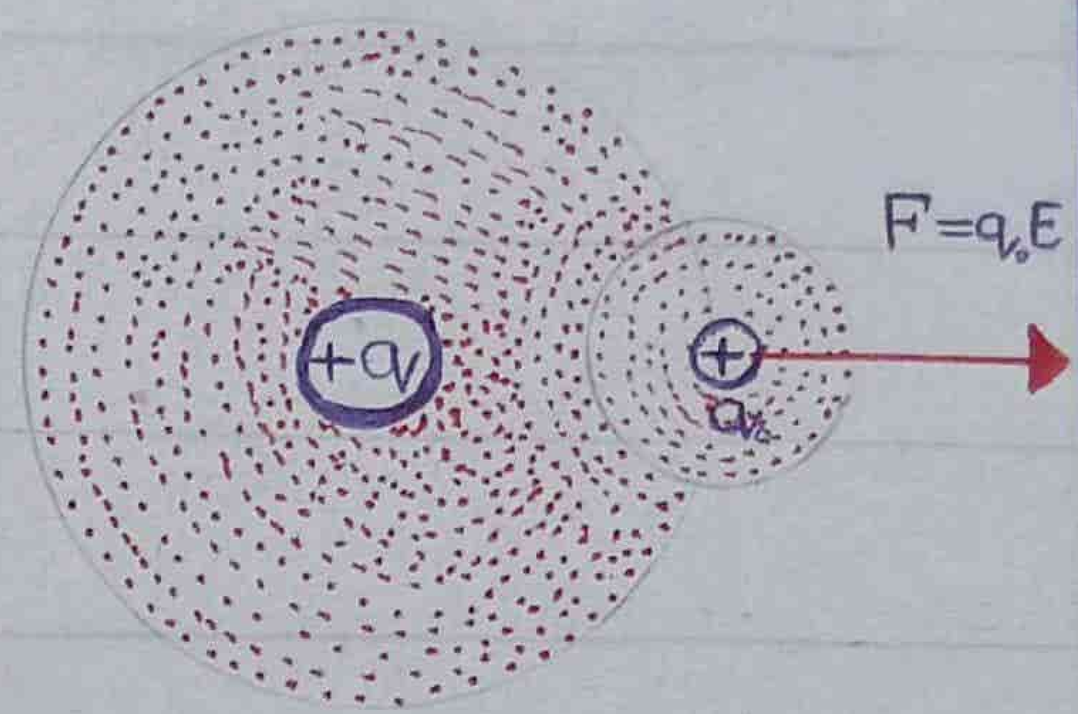
A charge produces an electric Field around it. Fig (a).



Fig(a)

Step-2:

When a test charge "q_o" is brought in this field, the field of charge "q" interacts with q_o and and produces an electric force.



$$\vec{F} = q_o \vec{E}$$

Electric Field:

"The space or region around a charge in which its effect is felt by a unit positive charge (test charge: q_o) is called electric field."

Electric Field Strength or Electric Field Intensity

"The electric field intensity $\vec{E}$ at a point is defined as the forced experienced by a unit positive charge q_o placed at that point."

$$\boxed{\vec{E} = \frac{\vec{F}}{q_o}}$$

Electric Field Intensity = Force per unit charge

Unit of $\vec{E}$:

$$\boxed{NC^{-1} \quad \text{OR} \quad \frac{N}{C}}$$

$\vec{E}$ is a vector quantity.

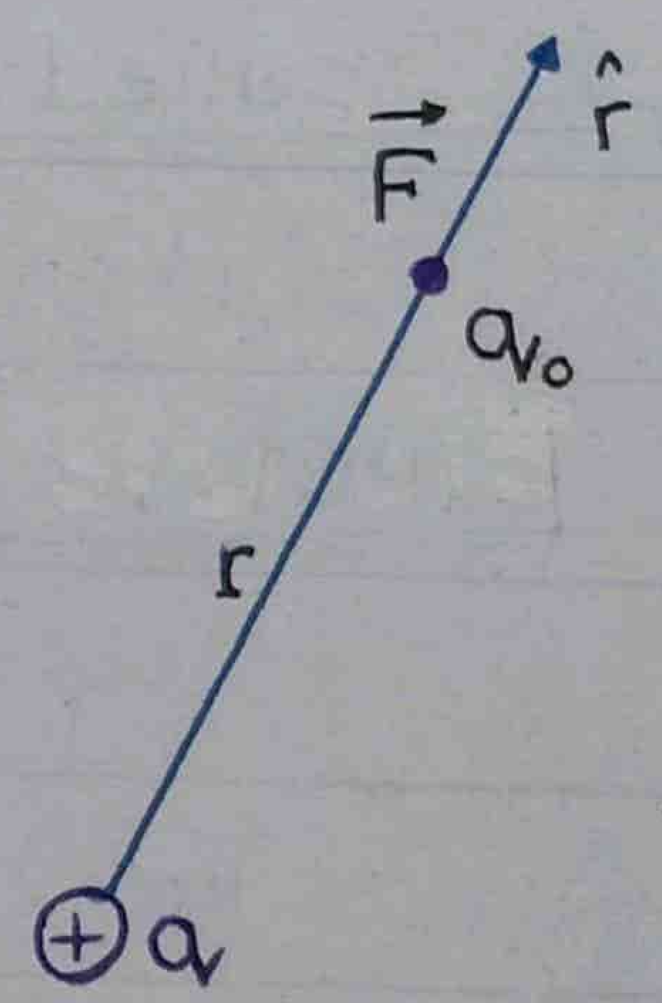
Its direction is same as that of force.

Explanation:

Force between charge $+q$ and a test charge q_o is

$$\vec{F} = \frac{1}{4\pi\epsilon_o} \frac{q\, q_o}{r^2} \hat{r} \qquad (\text{In Vacuum})$$

$\hat{r}$ = Unit vector directed from $+q$ towards q_o.



$$\vec{E} = \frac{1}{q_o} \vec{F}$$

$$\vec{E} = \frac{1}{\cancel{q_o}} \frac{1}{4\pi\epsilon_o} \frac{q\,\cancel{q_o}}{r^2} \hat{r}$$

$$\boxed{\vec{E} = \frac{1}{4\pi\epsilon_o} \frac{q}{r^2} \hat{r}}$$

Magnitude of $\vec{E}$:

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

- $E \propto q$
- $E \propto \frac{1}{r^2}$

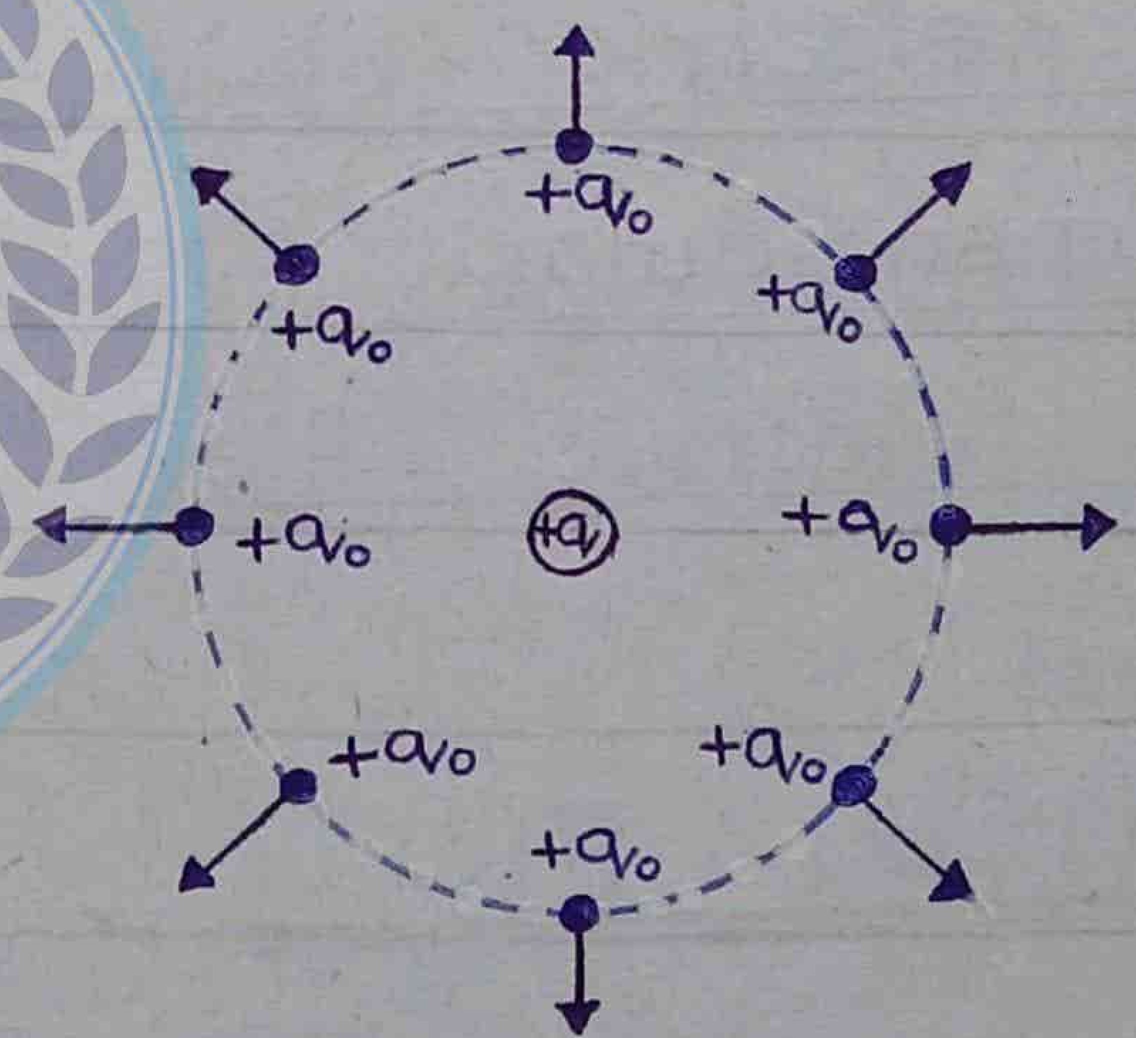
12.3 Electric Field Lines

Micheal Faraday gave the idea of Electric Field Lines or Lines of Force. Electric Field Lines provide information about the direction and strength of electric field at various places.

Definition:

The path along which a unit positive charge (test charge) moves in an electric field is called electric field lines or electric line of force.

Explanation:



We place positive test charges q_0 at different places but at equal distances from a charge $+q$. Each test charge will experience a repulsive force. It is indicated by arrows in Fig (a).

1- The electric Field created by a positive charge is directed radially outward. Fig (b).

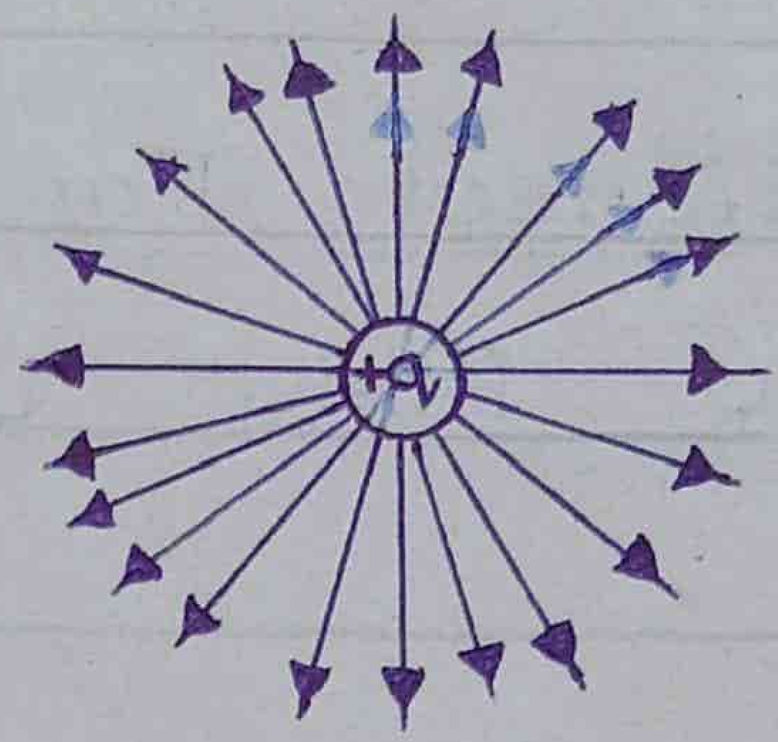


Fig (b)

2- The electric Field produced by a negative charge is directed radially inward.

Fig (c)

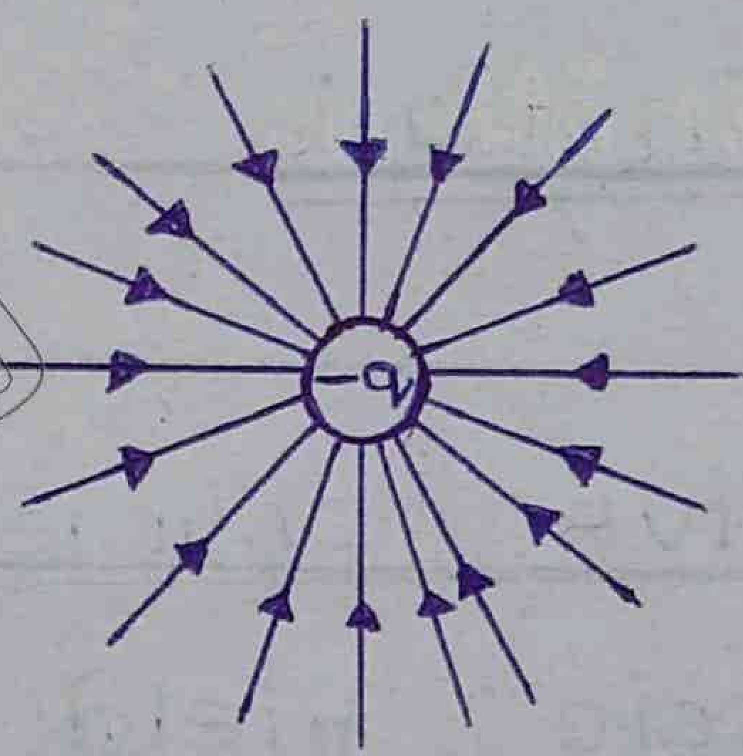


Fig (c)

Strength of Electric Field.

The number of electric Field lines per unit area passing perpendicularly is proportional to the magnitude of electric Field.

Strong Field:

"When the number of lines per unit area is large," the Field is strong, In strong Field the lines of Force are closer to each other.

This is why Field is stronger near the charges.

Weak Field:

"When the number of lines per unit area is small, the field is weak." In the weak field, the lines of force are not closer. This is why field is weaker away from the charges.

Field between two similar charges:

The electric field lines are curved in case of two similar charges. Fig (a) shows the pattern of lines near two similar charges.

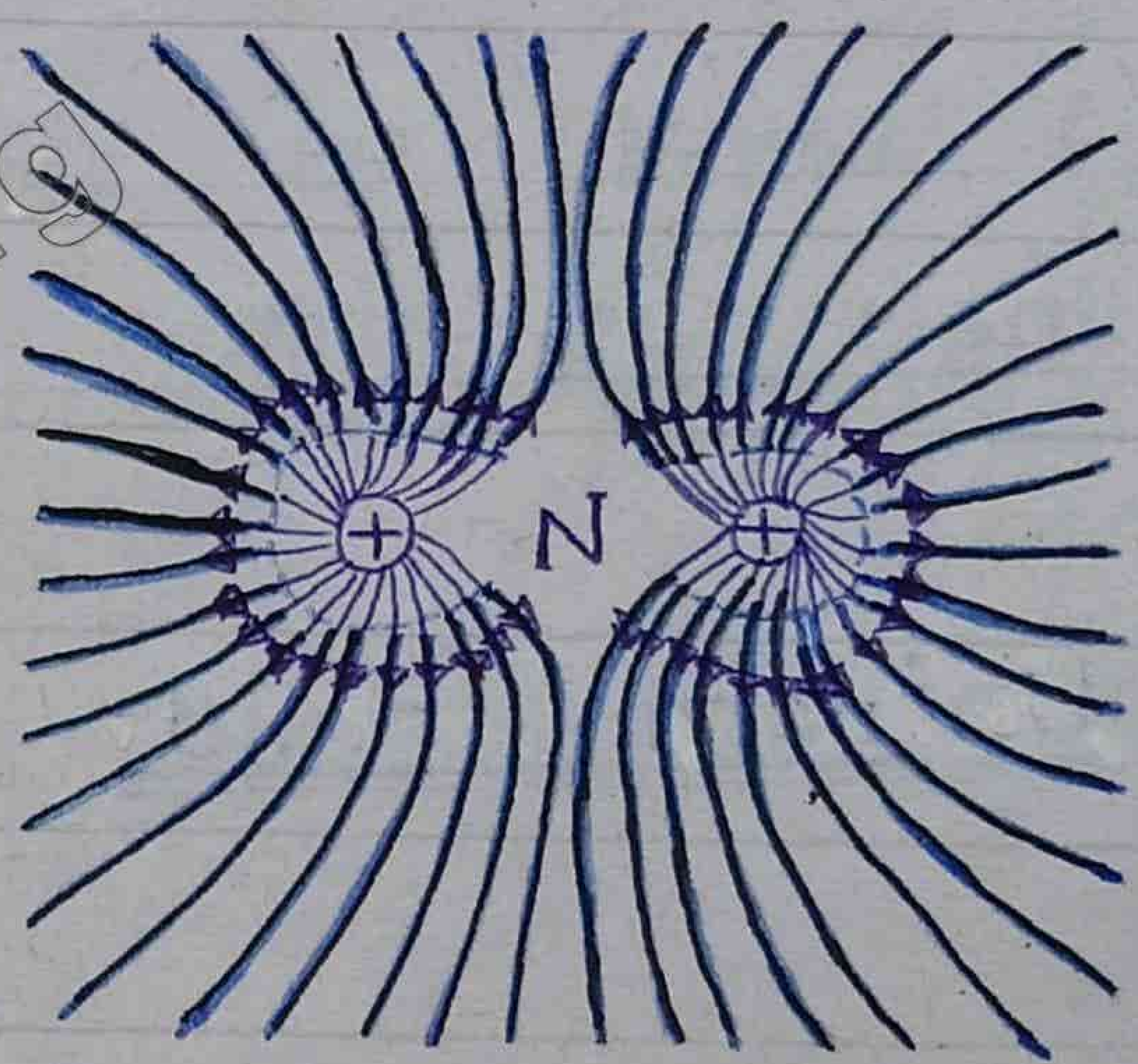


Fig (a)

Neutral Zone OR Zero Field Spot

The middle region between the two charges is a neutral zone or zero field spot. It is indicated by N. At the point N

$$\vec{E} = 0$$

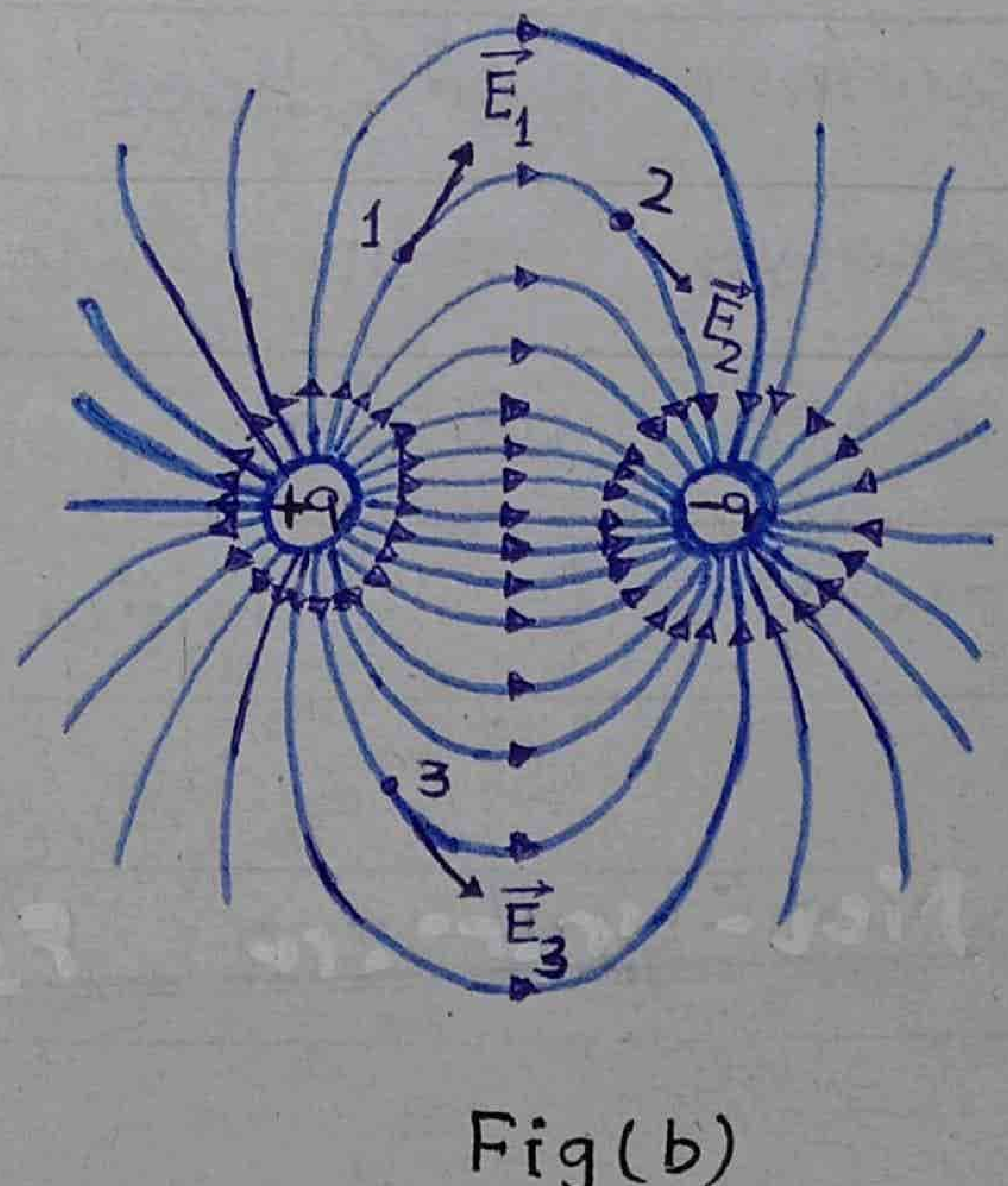
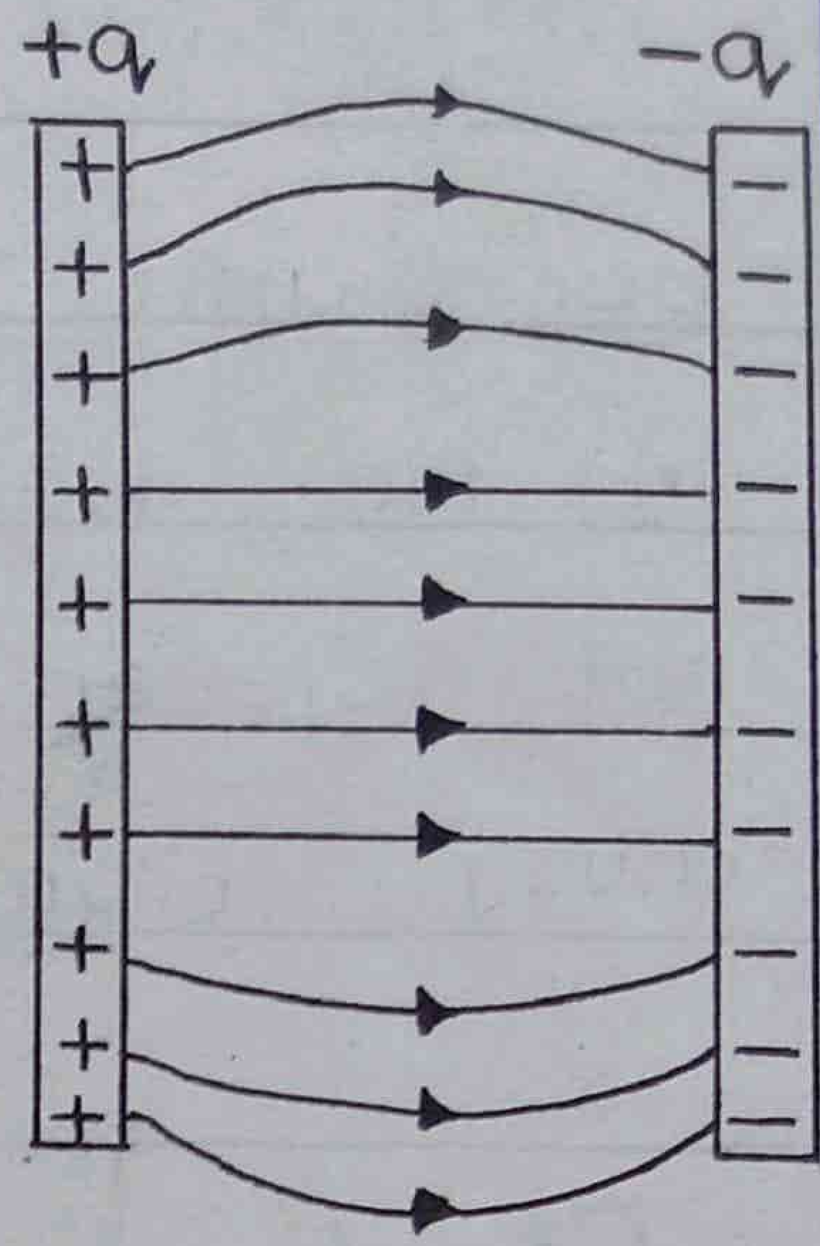


Fig (b)

Field between two Opposite charges:



Fig(c)

Fig (c) shows that the field pattern of two opposite charges of same magnitude.

"The field lines start from +ve charge and end on the -ve charge." The direction of electric field intensity at any point is given by tangent drawn to the field line at that point.

Uniform Field:

"When the electric field lines are equally spaced and parallel, then the field is uniform."

In this case the same number of lines pass per unit area. Fig (c) Shows the field lines between the plates of a parallel plate capacitor. The field is uniform at the middle region.

Non-uniform Field:

"When the electric

Field lines are not equally spaced and are not parallel, then the Field is not uniform.

The field is non-uniform at the edges of the plates of a parallel plate capacitor.

Properties of Electric Field Lines:

1- Electric Field lines originate (start) From positive charges and terminate (end) on the negative charges.

2- The tangent to a Field line at any point gives the direction of electric Field at that point.

3- The lines are closer where the Field is strong, the lines are Farther apart (دُور) where the Field is weak.

4- No two electric Field lines intersect (cross) each other. This is because $\vec{E}$ has only one direction at any given point. If the lines cross each other, $\vec{E}$ could have more than one direction, which is not possible. So, electric field lines do not intersect each other.

12.4 Applications of Electrostatics

1- Xerography (Photocopier)

The copying process is called 'Xerography'. It is a combination of Greek words 'Xeros' and 'graphos' which means "dry writting".

Fig. 12.11 The basics of photocopying. The lamp transfers an image of the page to the drum, which leaves a static charge. The drum collects toner dust and transfers it to the paper. The toner is melted onto the paper

Work Principle:

"The lamp transfers an image of the page to the drum, which leaves a static charge. The drum collects toner dust and transfers it to the paper. The toner is melted onto the page."

Construction

1- Lamp:

The lamp transfers an image of the page to the drum.

2- Drum:

The heart of the machine is drum, which is an Aluminium cylinder. It is an excellent conductor.

3- Selenium surface:

Aluminium cylinder is coated with a layer of Selenium.

Selenium is insulator in the dark. It becomes a conductor when light falls on it. Selenium is a photoconductor.

When the drum is exposed to light, the electrons from Aluminium pass through the conducting selenium and neutralize the positive charge.

4- Toner:

It is a special dry black power. When negatively charged toner spread over the drum, it sticks to the positive charged areas.

5- Sheet of Paper:

The toner from the drum is shifted to a sheet of paper on which the photocopy is produced.

6- Heated Pressure Rollers:

They melt toner onto the paper to fix impression of the document.

Working:

When a positive charge is spread over the selenium, it will remain there as long as it remains in dark.

When the drum is exposed to an image of the document, the dark and light areas of the document produce similar areas on the drum. The dark areas retain their positive charge, but the light areas become conducting and lose their positive charge. They become neutral. In this way, a positive charged image of the document remains on the Selenium Surface.

Now spread a negatively

charged toner over the drum. It sticks to the positively charged areas. So, the toner is transferred onto a sheet of paper. Heated pressure rollers melt the toner onto the paper. This produces a "Power Print" i.e., a photocopy.

2- Inkjet Printers:

An inkjet printer is a type of printer which uses electric charge in its operation.

Fig. 12.12 (a) An inkjet printer.

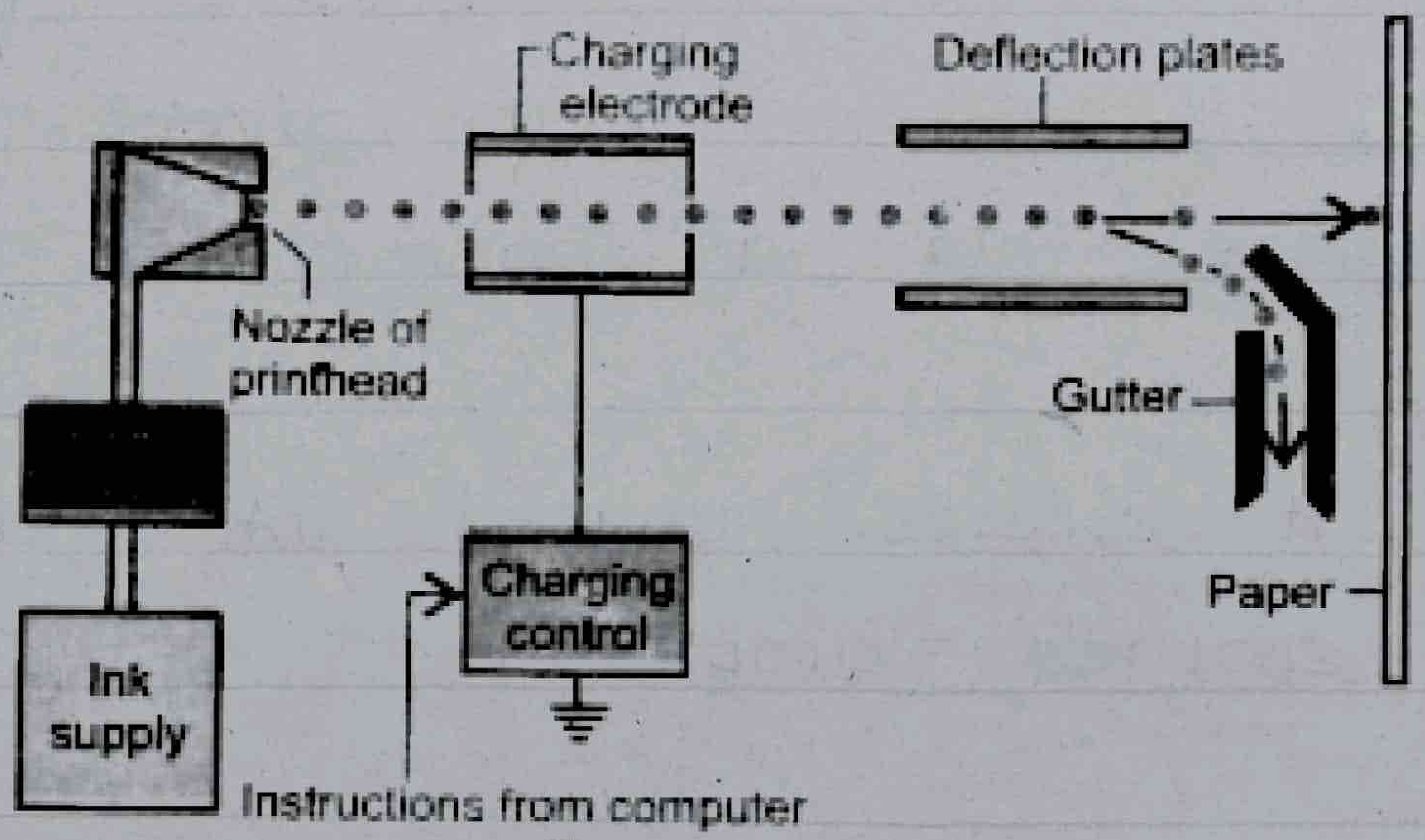


Fig. 12.12 (b) An inkjet printhead ejects a steady flow of ink droplets. The charging electrodes are used to charge the droplets that are not needed on the paper. Charged droplets are deflected into a gutter by the deflection plates, while uncharged droplets fly straight onto the paper

Construction

1- Printhead :

It shuttles (اِدھر سے اُدھر جانا) back and forth across the paper. Inkjet printer ejects a thin stream (دھار) of ink.

2- Nozzle :

Ink is forced out of a small nozzle and breaks up into extremely small droplets.

3- Charging Electrode:

It charges the ink

droplets.

4- Deflection Plates: They divert charged droplets into a gutter.

5- Gutter:

It collects unused ink (diverted charged droplets).

6- Paper:

Paper is used to collect the uncharged droplets in the form of Print. Schematic diagram is shown in Fig.

Working:

An inkjet printhead ejects a steady flow of ink droplets. The charging electrode charges the droplets that are not needed on the paper. Charged droplets are deflected into a gutter by the deflection plates. The uncharged droplets fly off straight onto the paper to print the document.

Coloured Copies:

Inkjet printers also produce coloured copies.

Electric Flux

Definition:

"The number of electric field lines passing through a certain element of area is called electric flux through that area."

OR

"Scalar product of electric field intensity $\vec{E}$ and area vector $\vec{A}$ is called electric flux."

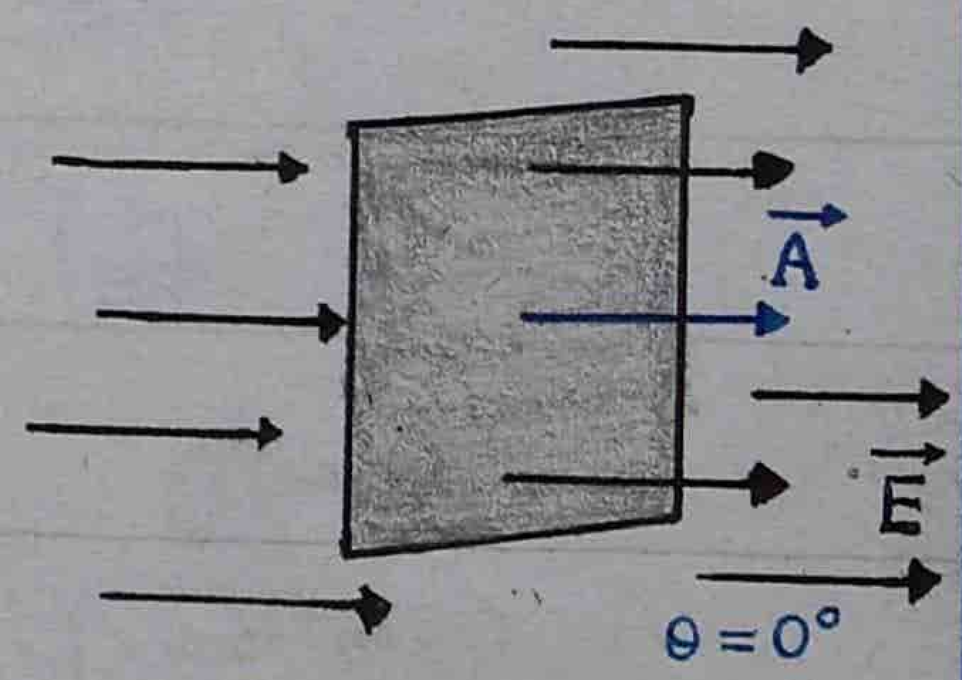
$$\boxed{\Phi_e = \vec{E} \cdot \vec{A} = EA\cos\theta}$$

Note:

Flux is scalar quantity.

Maximum Flux:

When area is held perpendicular to electric field lines, flux is maximum.



$$\Phi_e = \vec{E} \cdot \vec{A}$$

$$\Phi_e = EA\cos\theta$$

$$\Phi_e = EA\cos 0°$$

$$\Phi_e = EA(1)$$

$$\Phi_e = EA$$

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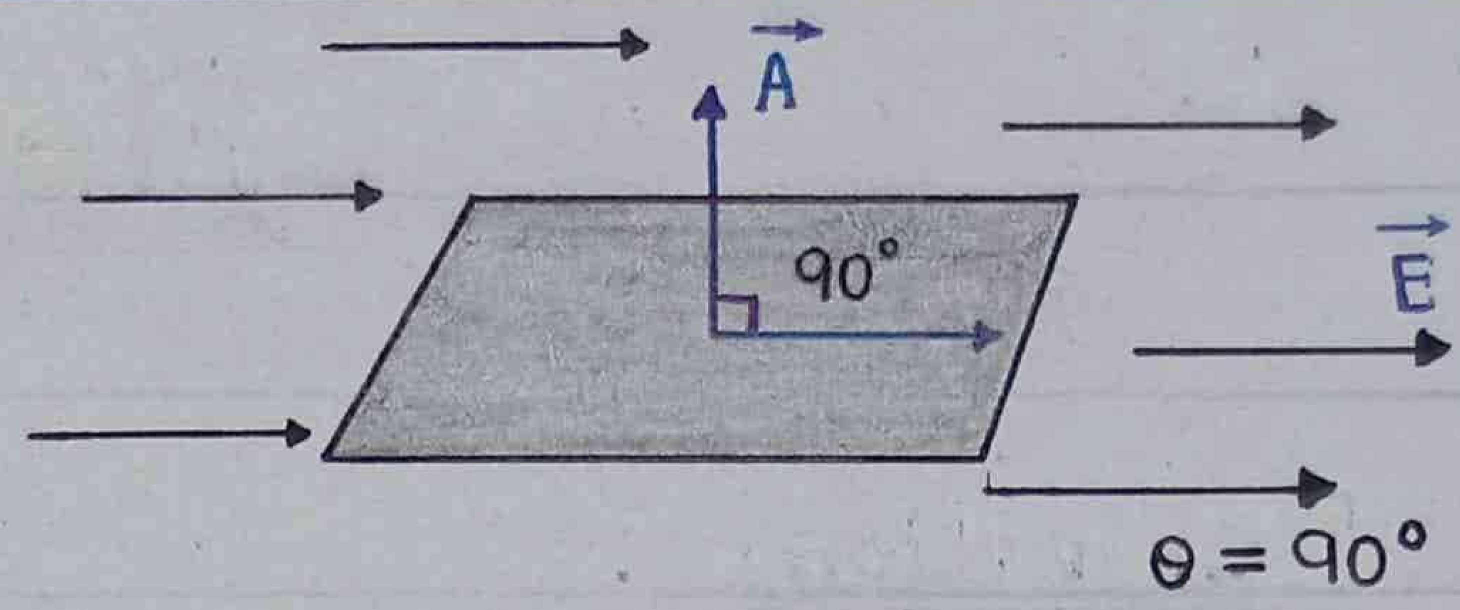
Minimum Flux:



When area is held parallel to the field lines, flux is minimum.

$$\Phi_e = \vec{E}\cdot\vec{A}$$

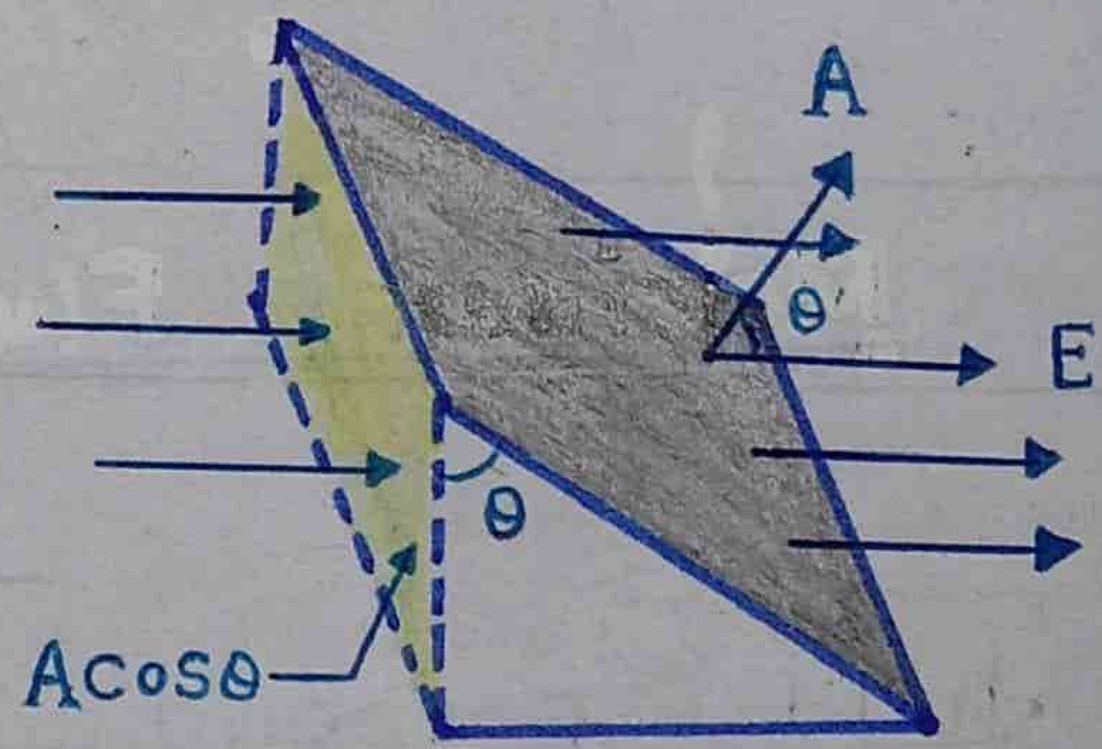
$$\Phi_e = EA\cos\theta$$

$$\Phi_e = EA\cos 90^\circ$$

$$\Phi_e = EA(0)$$

$$\Phi_e = 0$$

When area vector $\vec{A}$ makes an angle θ with $\vec{E}$.



$$\Phi_e = \vec{E}\cdot\vec{A} = EA\cos\theta$$

$$\Phi_e = E(A\cos\theta)$$

$A\cos\theta$ = Projection of area perpendicular to field lines.

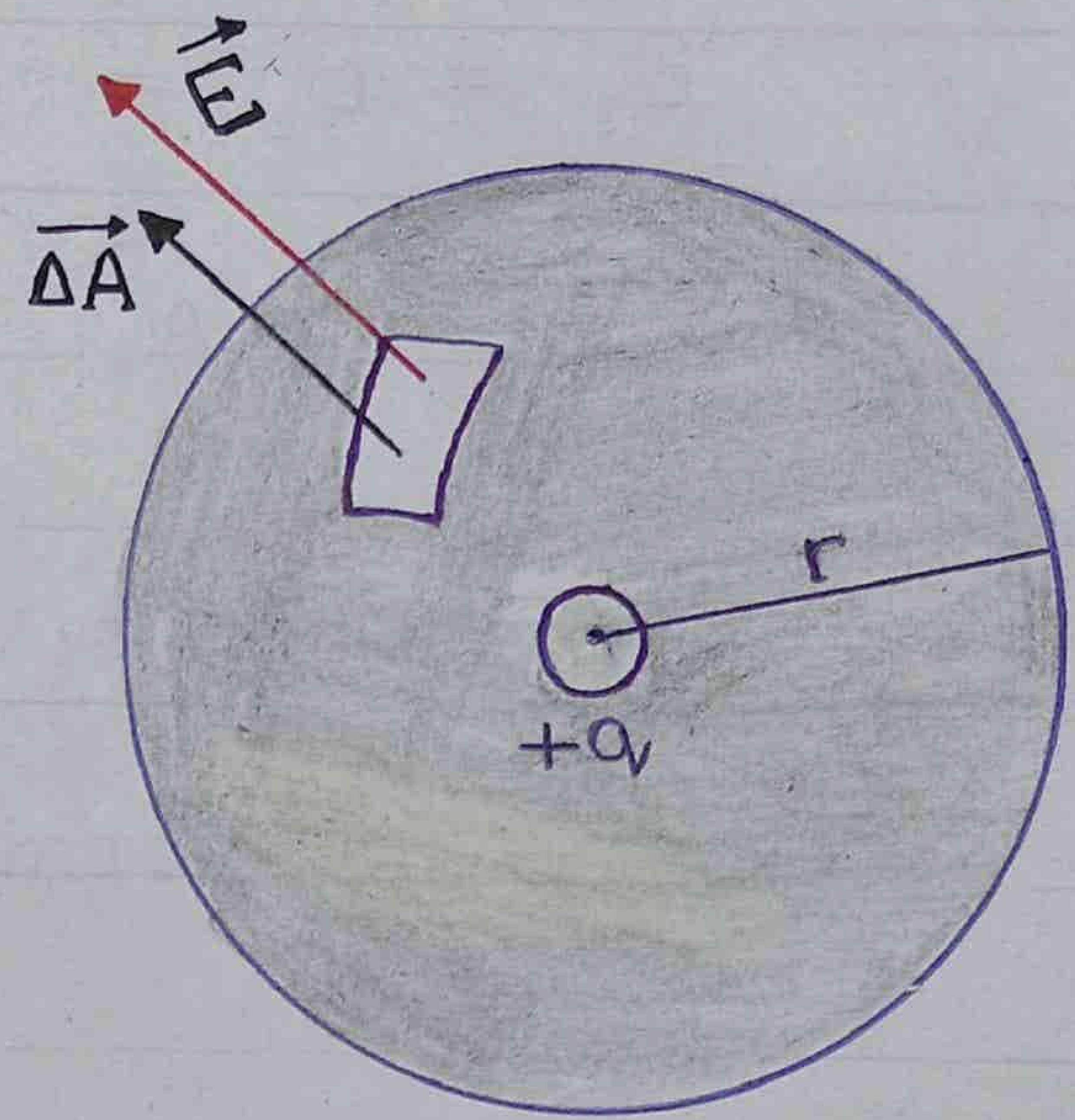
Unit of Φ_e:

$$\Phi_e = \vec{E}\cdot\vec{A}$$

$$= \frac{N}{C}\cdot m^2$$

$$\boxed{\Phi_e = N\,m\,C^{-1}}$$

12.6 Electric Flux through a surface enclosing a charge:

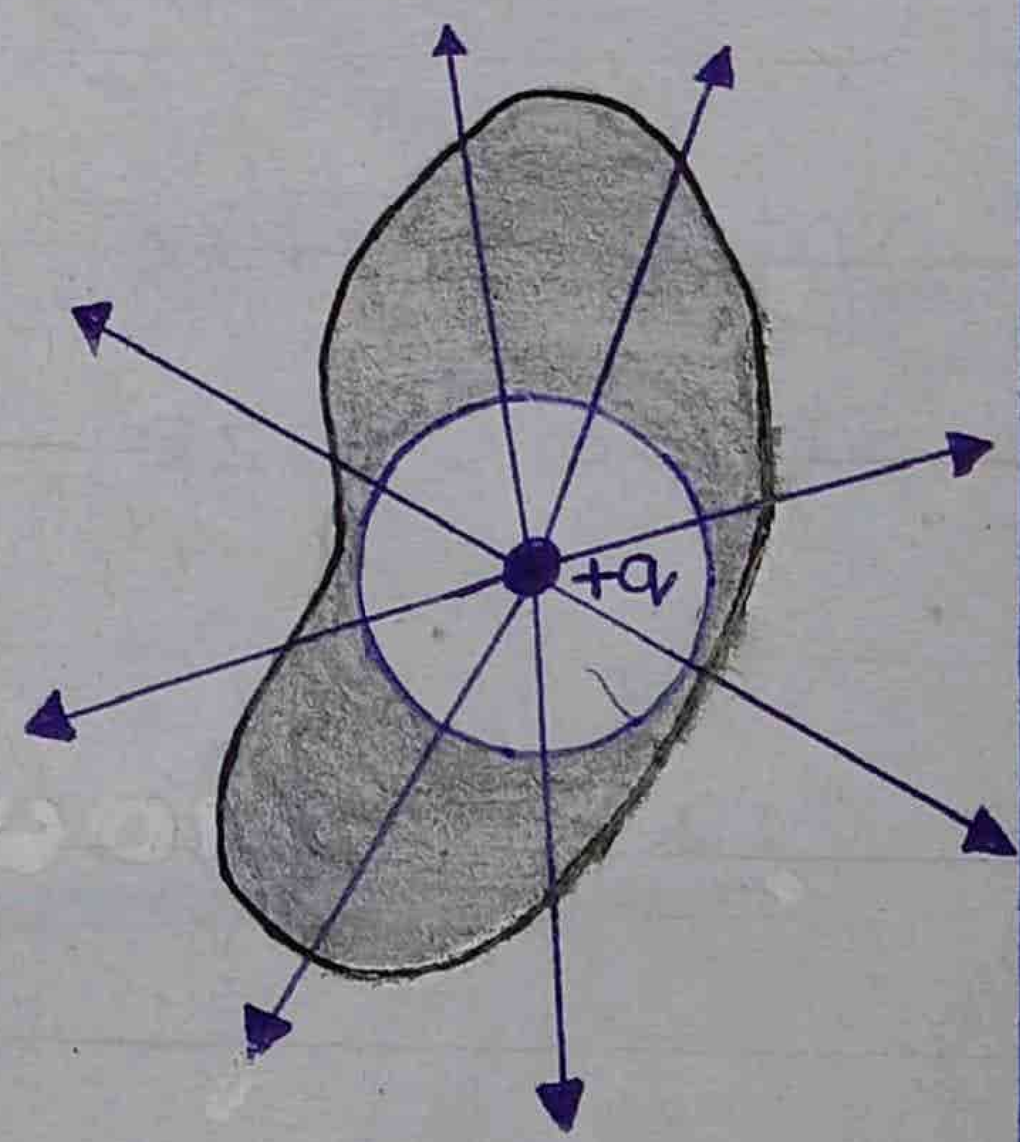


Consider a closed surface in the shape of a sphere of radius "r". A charge "q" is placed at the centre of the sphere.

To apply $\Phi_e = \vec{E}.\vec{A}$, the surface area should be flat.

So, surface area of sphere is divided into "n" small patches

$$\vec{\Delta A_1}, \vec{\Delta A_2}, \ldots, \Delta \vec{A_n}$$



Here electric intensities are

$$E_1, E_2, \ldots, E_n$$

Each $\vec{E}$ and $\vec{\Delta A}$ are parallel.

$$\Phi_e = \Phi_1 + \Phi_2 + \cdots + \Phi_n$$

$$\Phi_e = \vec{E_1}.\vec{\Delta A_1} + \vec{E_2}.\vec{\Delta A_2} + \cdots + \vec{E_n}.\vec{\Delta A_n}$$

$$\Phi_e = E_1 \Delta A_1 \cos 0^\circ + E_2 \Delta A_2 \cos 0^\circ + \cdots + E_n \Delta A_n \cos 0^\circ$$

$$\Phi_e = E_1 \Delta A_1 + E_2 \Delta A_2 + \cdots + E_n \Delta A_n$$

Due to spherical Symmetry

$$E_1 = E_2 = \cdots\cdots = E_n = E = \frac{1}{4\pi\epsilon_o} \cdot \frac{q}{r^2}$$

$$\Phi_e = E\Delta A_1 + E\Delta A_2 + \cdots\cdots + E\Delta A_n$$

$$\Phi_e = E\left[\Delta A_1 + \Delta A_2 + \cdots\cdots + \Delta A_n\right]$$

$$\Phi_e = E\left[\text{Total surface area of sphere}\right]$$

$$\Phi_e = \frac{1}{\cancel{4\pi}\epsilon_o} \cdot \frac{q}{\cancel{r^2}}\left[\cancel{4\pi r^2}\right]$$

$$\Phi_e = \frac{q}{\epsilon_o}$$

$$\boxed{\Phi_e = \frac{1}{\epsilon_o} \times q}$$

Note: Flux depends on q (charge); not on shape, size of closed surface.

12.7 Gauss's Law

Statement:

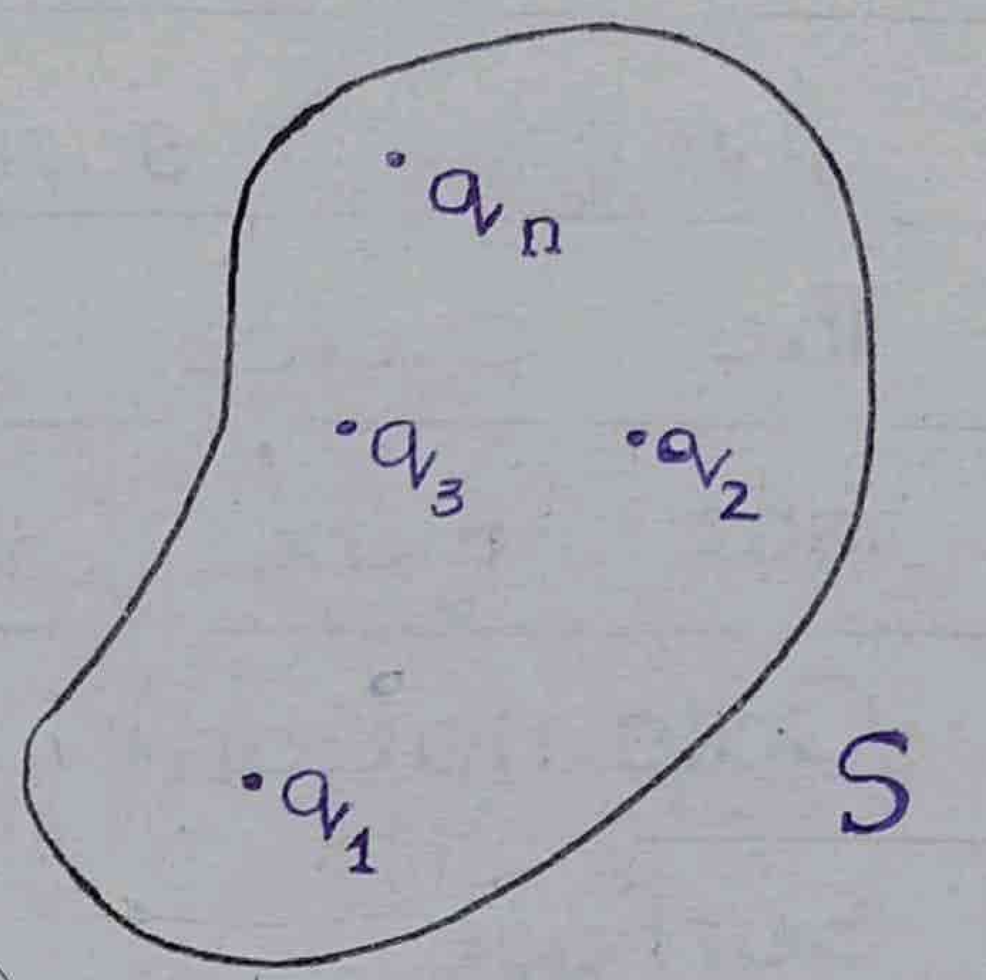
"Flux through any closed surface is $\frac{1}{\epsilon_o}$ times the total charge enclosed in it."

$$\boxed{\Phi_e = \frac{1}{\epsilon_o} \times Q}$$

$$\boxed{\Phi_e = \frac{Q}{\epsilon_o}}$$

Proof:

Consider charges $q_1, q_2, \ldots, q_n$ are present in a closed surface S, as shown in fig.



Flux through the closed surface is:

$$\Phi_e = \Phi_1 + \Phi_2 + \ldots\ldots + \Phi_n$$

$$\Phi_e = \frac{q_1}{\epsilon_o} + \frac{q_2}{\epsilon_o} + \ldots\ldots + \frac{q_n}{\epsilon_o}$$

$$\Phi_e = \frac{1}{\epsilon_o}\left[q_1 + q_2 + \ldots\ldots + q_n\right]$$

$$\Phi_e = \frac{1}{\epsilon_o}\left[\text{Total charge enclosed by the closed surface}\right]$$

$$\Phi_e = \frac{1}{\epsilon_o} \times Q$$

$Q = q_1 + q_2 + \cdots + q_n$

Q = total charge enclosed

$$\boxed{\Phi_e = \frac{Q}{\epsilon_o}}$$

12.8 Applications of Gauss's Law

"Gauss's Law is applied to calculate $\vec{E}$"

1. We imagine a closed surface Gaussion Surface surrounding the charge.
2- The choice of Gaussian Surface is such that flux through it can easily calculated.
3- Calculation of charge enclosed in Gaussian Surface.

Find

(i) Flux by Gauss Law:

$$\Phi_e = \frac{Q}{\epsilon_o} \quad \text{------} \quad (i)$$

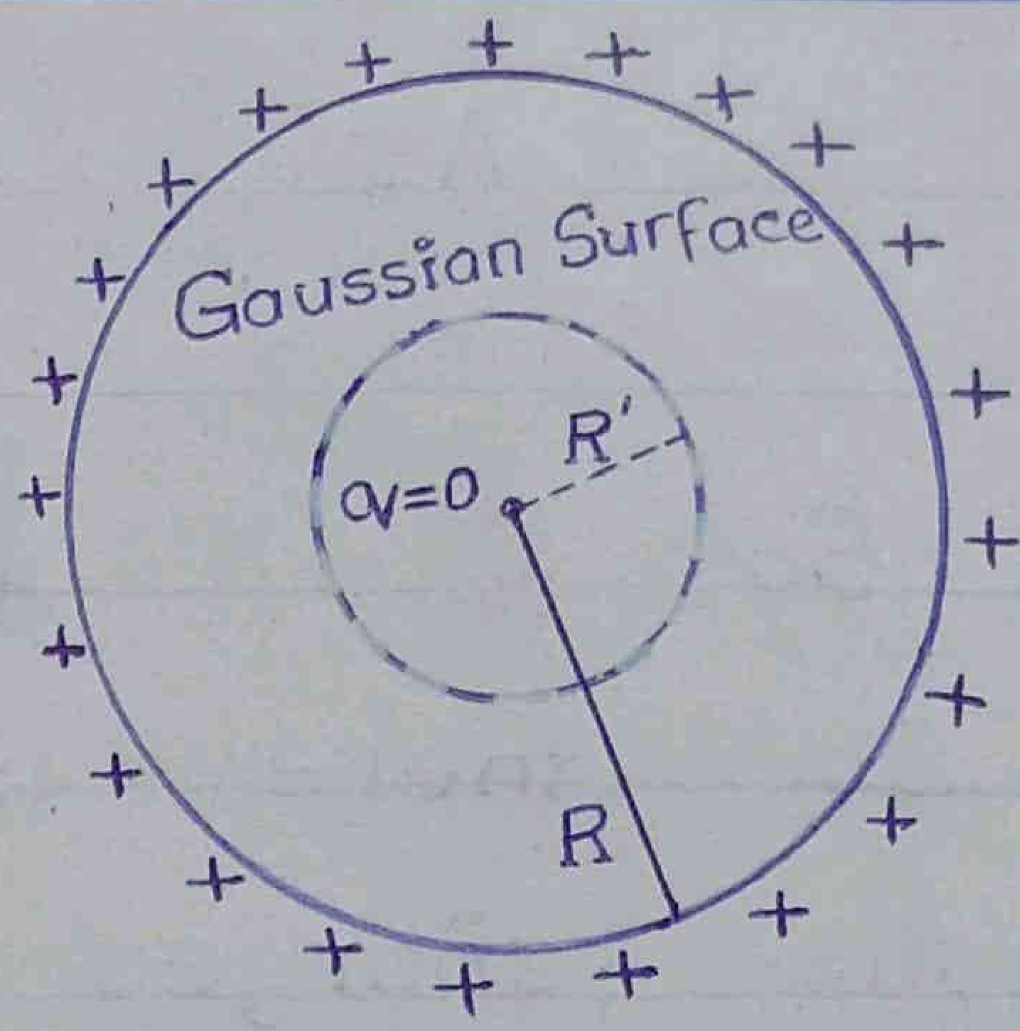
(ii) Flux by definition:

$$\Phi_e = \vec{E} \cdot \vec{A} \quad \text{------} \quad (ii)$$

$$\frac{Q}{\epsilon_o} = \vec{E} \cdot \vec{A}$$

1- Electric Field Intensity inside a Hollow Charged Sphere.

Consider a hollow conducting sphere



of radius R. It is given a charge +Q.

Now imagine a sphere of radius $R' < R$ within the hollow charged sphere.

This is <u>Gaussian Surface</u>.

Φ_e = Flux through the Gaussian Surface.

Charge enclosed in the Gaussian Surface is zero.

$$\boxed{q = 0}$$

(i) By Gauss's Law:

$$\Phi_e = \frac{q}{\epsilon_o}$$

$$\Phi_e = \frac{0}{\epsilon_o}$$

$$\Phi_e = 0 \quad \text{———} \quad (1)$$

(ii) By definition:

$$\Phi_e = \vec{E} \cdot \vec{A} \quad \text{———} \quad (2)$$

Comparing equation (1) and (2)

$$\vec{E} \cdot \vec{A} = 0$$

As

$$\vec{A} \neq 0$$

So,

$$\boxed{\vec{E} = 0}$$

So there is no electic Field within the charged metal sphere.

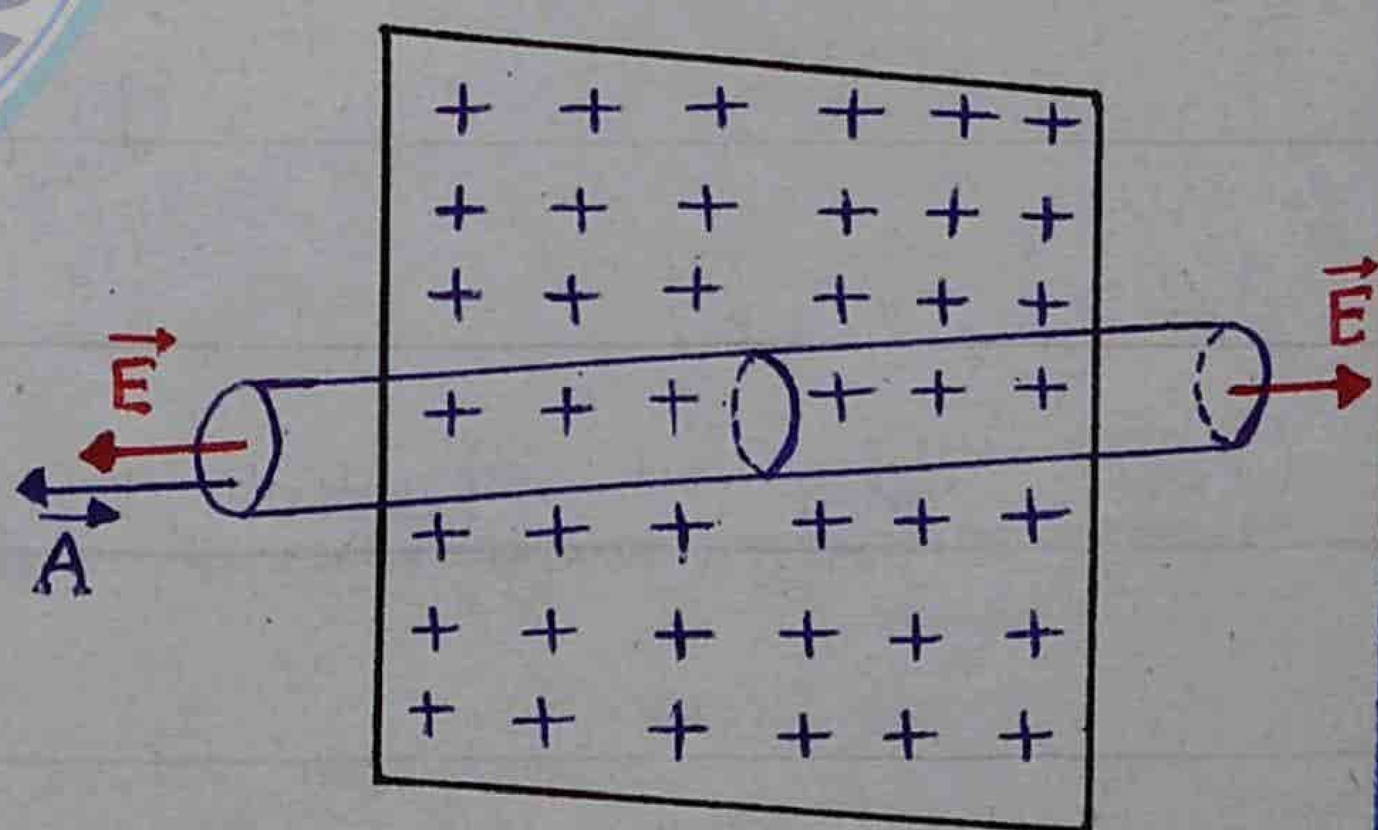
Results:

(i) The interior of a hollow metal charged sphere is field free region.

(ii) Any apparatus placed within a metal enclosure is Shielded from electric Fields.

2- Electric Field Intensity due to an infinite sheet of charge.

Consider a plane sheet of infinite extent(لامحدود وسعت). Positive charges are uniformly distributed on it.



Surface charge density = σ = Charge per unit area

$$\sigma = \frac{\text{charge}}{\text{Area}}$$

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

$$Q = \sigma A$$

Derivation of $\vec{E}$:

Consider a Gaussian Surface in the Form of a cylinder passing through the sheet.

1- $\vec{E}$ is parallel to curved surface of the cylinder. ($\theta = 90^\circ$).

2- $\vec{E}$ is perpendicular to the two Flat end Faces. ($\theta = 0^\circ$).

(i) Flux through the Curved Surface:

$$\Phi_1 = \vec{E}\cdot\vec{A}$$

$$\Phi_1 = EA\cos\theta$$

$$\Phi_1 = EA\cos 90^\circ$$

$$\Phi_1 = EA(0)$$

$$\boxed{\Phi_1 = 0}$$

(ii) Flux through the right end Face:

$$\Phi_2 = \vec{E} \cdot \vec{A}$$

$$\Phi_2 = EA\cos\theta$$

$$\Phi_2 = EA\cos 0^\circ$$

$$\Phi_2 = EA(1)$$

$$\boxed{\Phi_2 = EA}$$

(iii) Flux through the left end Face:

$$\Phi_3 = \vec{E} \cdot \vec{A}$$

$$\Phi_3 = EA\cos\theta$$

$$\Phi_3 = EA\cos 0^\circ$$

$$\Phi_3 = EA(1)$$

$$\boxed{\Phi_3 = EA}$$

Total Flux

$$\Phi_e = \Phi_1 + \Phi_2 + \Phi_3$$

$$= 0 + EA + EA$$

$$\Phi_e = 2EA \quad \text{———— (I)}$$

By Gauss's Law:

$$\Phi_e = \frac{Q}{\epsilon_o}$$

$$\Phi_e = \frac{\sigma A}{\epsilon_o} \quad \text{———} \quad (ii)$$

Comparing equation (i) and (ii)

$$2E\cancel{A} = \frac{\sigma \cancel{A}}{\epsilon_o}$$

$$\boxed{E = \frac{\sigma}{2\epsilon_o}}$$

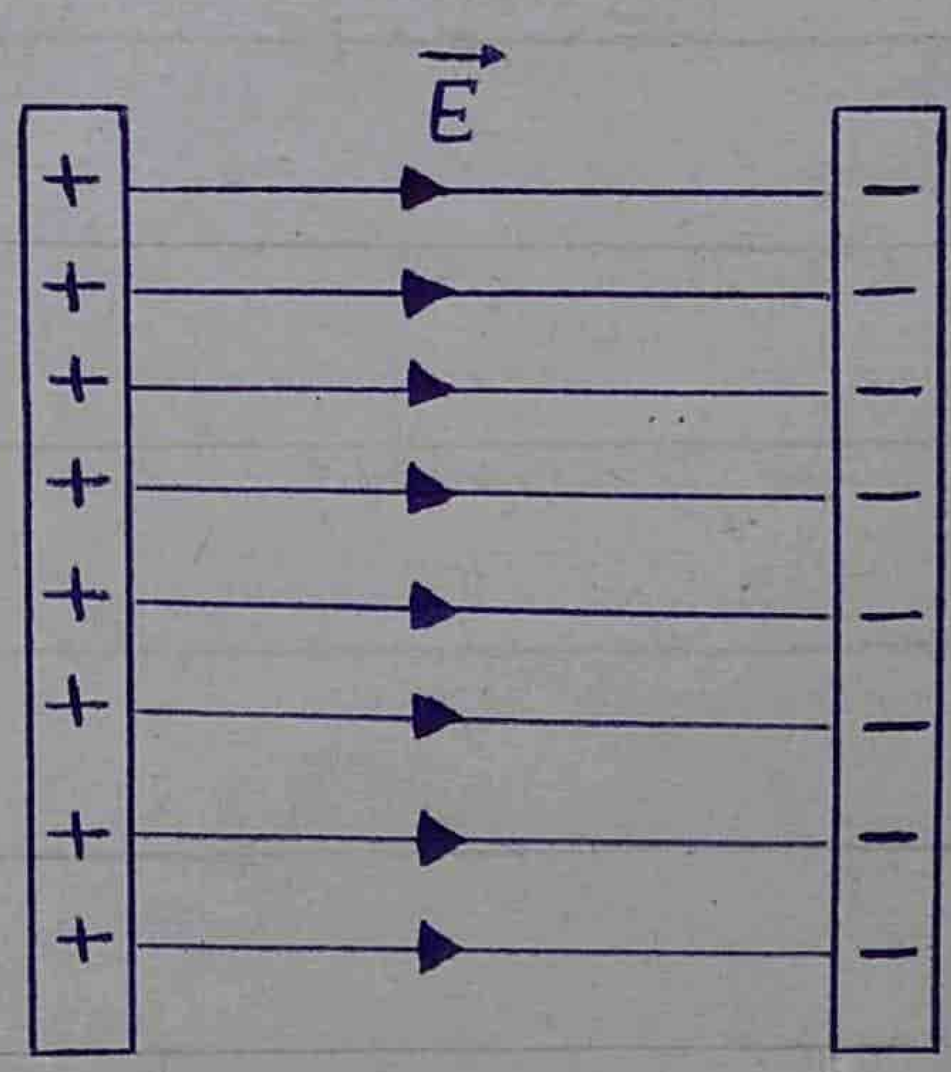
Vector Form:

$$\boxed{\vec{E} = \frac{\sigma}{2\epsilon_o}\hat{r}}$$

Where $\hat{r}$ is a unit vector normal to the sheet directed away from it.

3- Electric Field Intensity between two oppositely charged metal plates.

Consider two oppositely charged metal plates of infinite extent.



Distance between them is very small.

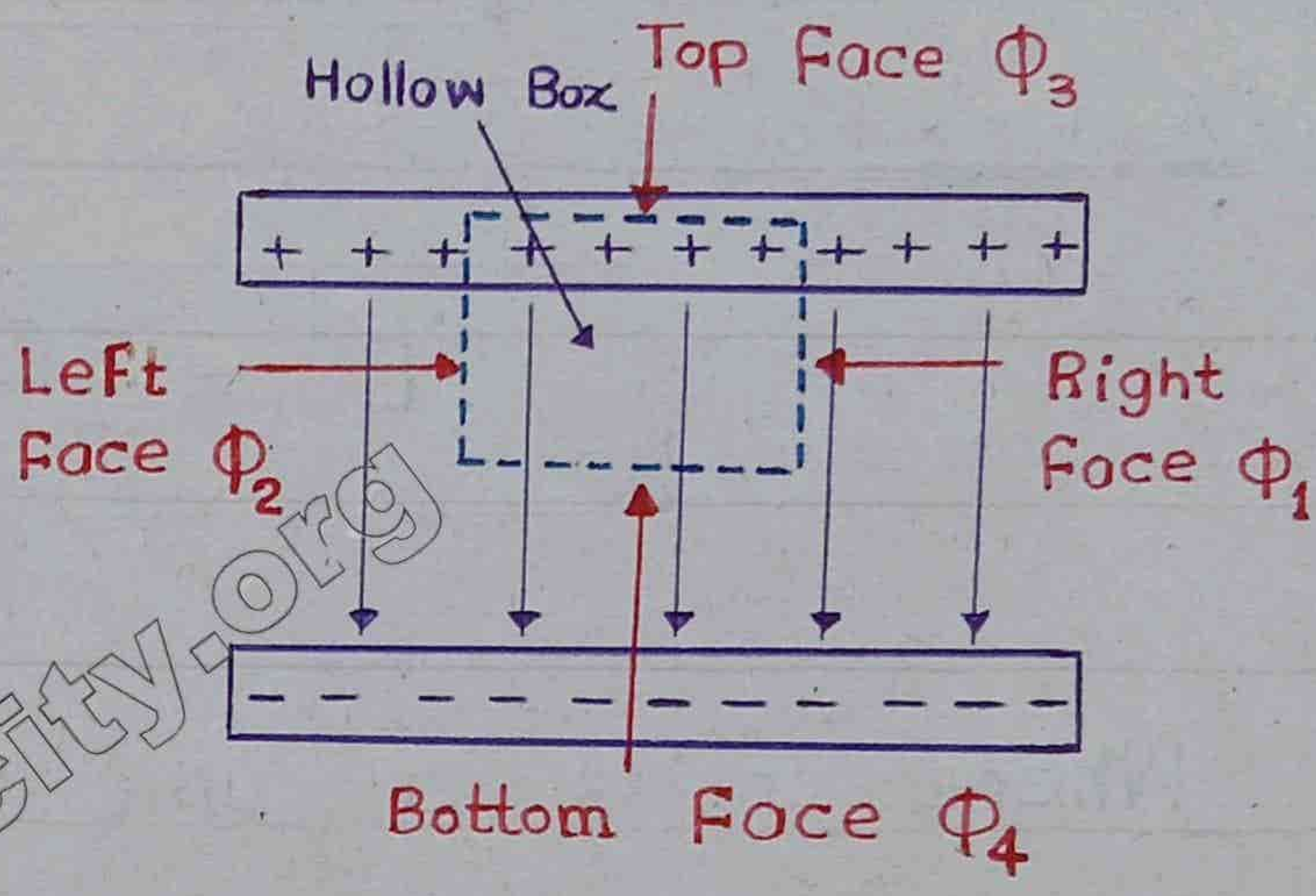
Charges are concentrated on the inner surfaces of the plates.

Electric Field lines are directed from positive to negative plate.

Surface charge density $= \sigma = \frac{\text{charge}}{\text{Area}}$

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

$$Q = \sigma A$$



Imagine a Gaussian Surface in the form of a hollow box. Its top is inside the upper metal plate.

1- Flux through right or left faces of the box is zero:

because they are parallel to $\vec{E}$.

$$\Phi_1 = \vec{E}\cdot\vec{A}$$

$$\Phi_1 = EA\cos 90^\circ$$

$$\Phi_1 = EA(0)$$

$$\Phi_1 = 0$$

Similarly

$$\Phi_2 = 0$$

2- Flux through the top face is zero, because this face is inside the metal plate. $\vec{E}$ inside the metal plate is zero.

$$\Phi_3 = \vec{E}\cdot\vec{A}$$

$$\Phi_3 = 0\cdot\vec{A} \qquad \therefore \vec{E} = 0$$

$$\Phi_3 = 0$$

3- Flux through the bottom face is:

$$\Phi_4 = \vec{E}\cdot\vec{A}$$

$$\Phi_4 = EA\cos\theta$$

$$\Phi_4 = EA\cos 0^\circ \qquad \therefore \cos 0^\circ = 1$$

$$\Phi_4 = EA(1)$$

$$\Phi_4 = EA$$

Net Flux:

$$\Phi_e = \Phi_1 + \Phi_2 + \Phi_3 + \Phi_4$$

$$\Phi_e = 0 + 0 + 0 + EA$$

$$\Phi_e = EA \qquad \text{———} \quad (i)$$

By Gauss's Law

$$\Phi_e = \frac{Q}{\epsilon_o} = \frac{\sigma A}{\epsilon_o} \qquad \text{———} \quad (ii)$$

Comparing (i) and (ii)

$$E\cancel{A} = \frac{\sigma \cancel{A}}{\epsilon_o}$$

$$\boxed{E = \frac{\sigma}{\epsilon_o}}$$

Vector Form:

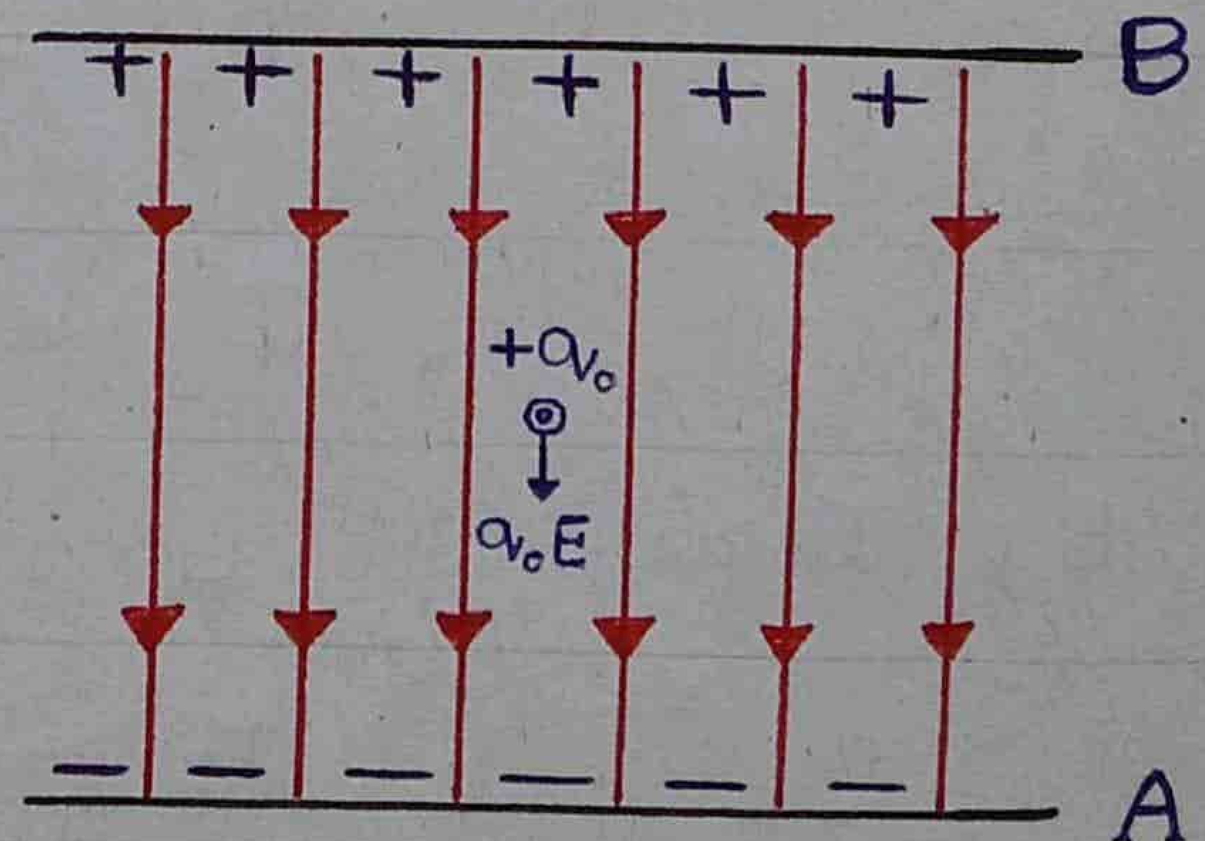
$$\boxed{\vec{E} = \frac{\sigma}{\epsilon_o}\hat{r}}$$

$\hat{r}$ = Unit vector form positive to negative plate.

12.9 Electric Potential

Relation between Electric Potential Energy "ΔU" and Potential difference "ΔV".

Consider two oppositely charged plates A and B. A test charge $+q_o$ will move from positive plate towards the negative plate A due to electric force

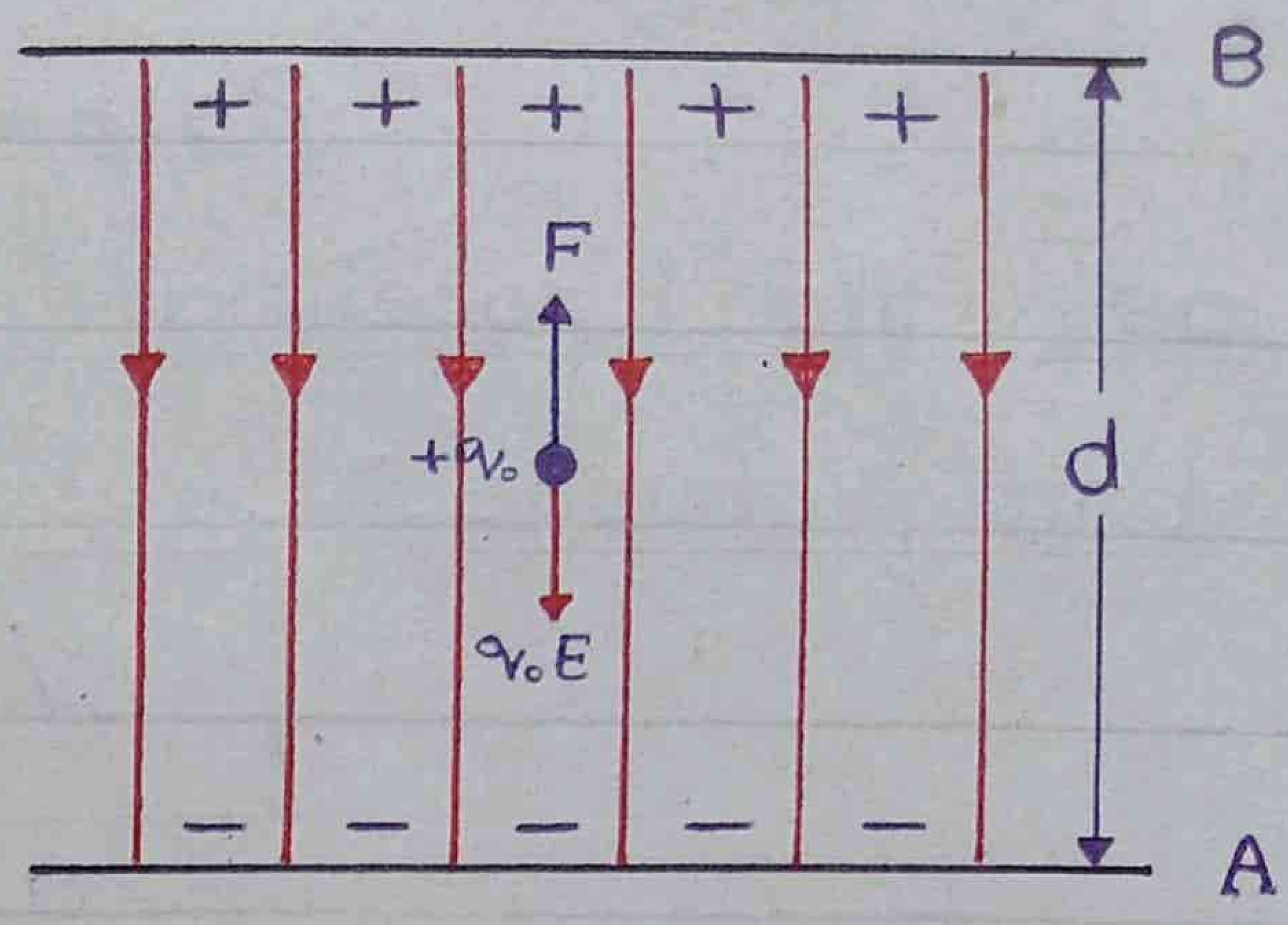


$$\vec{F} = q_o\vec{E}$$

as shown in Fig.

It will gain K.E.

If we apply a Force $\vec{F}$ equal and opposite to $q_o\vec{E}$, the charge will move from plate A towards plate B with constant velocity.



i.e in electrostatic equilibrium.

It will gain electrostatic P.E.

The work done in moving the charge from plate A to B appears as the increase in P.E.

$$\text{Change in PE} = \text{Work done from A to B.}$$

$$U_B - U_A = W_{AB}$$

$$\Delta U = W_{AB}$$

Potential Difference ΔV:

It is defined as the amount of work done in moving a unit positive charge from A to B, while keeping the charge in electrostatic equilibrium.

$$\Delta V = \frac{W_{AB}}{q_o}$$

$$\Delta V = \frac{\Delta U}{q_o}$$

Definition:

"Potential difference is defined as the potential energy difference per unit charge."

$$\boxed{\Delta V = \frac{\Delta U}{q_o}}$$

$\Delta U = \Delta V q_o$ or $W_{AB} = q_o \Delta V$

Unit of Potential difference is Volt.

$$\Delta V = \frac{W_{AB}}{q_o}$$

$$1\,\text{Volt} = \frac{1\,\text{Joule}}{1\,\text{Coulomb}} \qquad V = \frac{J}{C} = JC^{-1}$$

volt = Joule per Coulomb

Volt:

"Potential difference between two points is one volt when work done in moving a positive one coulomb charge (unit +ve charge) is one joule."

Electric Potential or Absolute Potential "V"

"Electric Potential or absolute potential at a point is the amount of work done in moving a unit positive charge from infinity to that point, keeping the charge in equilibrium."

$$\Delta V = \frac{W_{AB}}{q_o}$$

If we take A at infinity

$V_A = 0$, $V_B = 0$

$W_{AB} = W$

$$V_B - V_A = \frac{W_{AB}}{q_o}$$

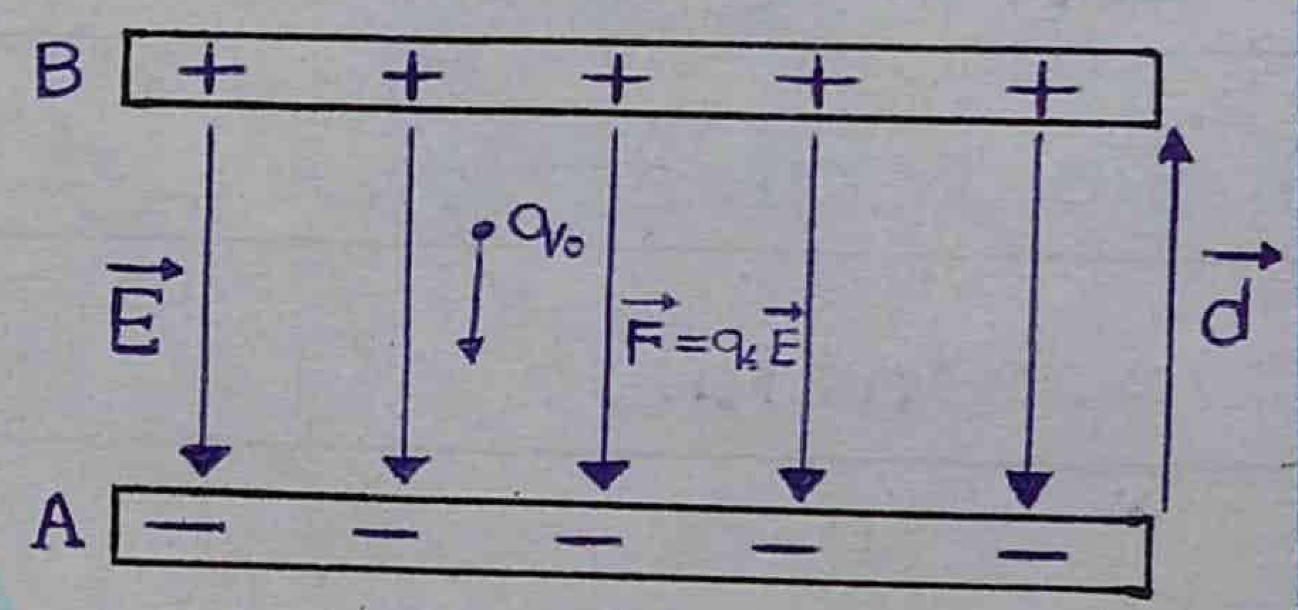
$$V - 0 = \frac{W}{q_o}$$

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

Potential = Work done per unit charge

Electric Field $\vec{E}$ as Potential Gradient:

Consider $\vec{E}$ between two oppositely charged plates as shown in Fig.



$$\Delta V = V_B - V_A = \frac{W_{AB}}{q_o} \quad \text{——— (i)}$$

$$W_{AB} = \vec{F} \cdot \vec{d}$$

$$W_{AB} = F d \cos\theta$$

$$W_{AB} = F d \cos 180^\circ$$

$$W_{AB} = F d (-1)$$

$$W_{AB} = -F d \qquad \because F = q_o E$$

$$W_{AB} = -(q_o E) d$$

$$W_{AB} = -q_o Ed \quad \text{(ii)}$$

Put equation (ii) in (i), we get

$$\Delta V = \frac{-\cancel{q_o} Ed}{\cancel{q_o}}$$

$$\Delta V = -Ed$$

$$E = -\frac{\Delta V}{d}$$

If the distance "d" is small $d = \Delta r$

$$\boxed{E = -\frac{\Delta V}{\Delta r}}$$

$\frac{\Delta V}{\Delta r}$ = gradient of potential

Electric Field Intensity = −ve of gradient of potential

In $E = -\frac{\Delta V}{\Delta r}$, the −ve sign shows that the direction of $\vec{E}$ is along the decreasing potential.

Potential Gradient $= \frac{\Delta V}{\Delta r}$

Definition:

"The quantity which gives the maximum value of rate of change of potential with distance is known as potential gradient."

Unit of potential gradiant is

NC^{-1} or Vm^{-1}

Question: Prove that

$$\frac{\text{Volt}}{\text{meter}} = \frac{\text{Newton}}{\text{Coulomb}}$$

Proof:

$$L.H.S = \frac{\text{Volt}}{\text{meter}}$$

As

$$\Delta V = \frac{W}{q_o}$$

$$\text{Volt} = \frac{\text{Joule}}{\text{Coulomb}}$$

$$L.H.S = \frac{\text{Joule}}{\text{Coulomb} \times \text{meter}}$$

$$W = \vec{F}.\vec{d}$$

$$\text{Joule} = \text{Newton}.\text{meter}$$

$$L.H.S = \frac{\text{Newton} \times \cancel{\text{meter}}}{\text{coulomb} \times \cancel{\text{meter}}}$$

$$L.H.S = \frac{\text{Newton}}{\text{Coulomb}}$$

$$L.H.S = R.H.S$$

So

$$\boxed{\frac{\text{Volt}}{\text{meter}} = \frac{\text{Newton}}{\text{Coulomb}}}$$

Just information

As

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

units of $E = \frac{\text{Newton}}{\text{Coulomb}}$

As $\Delta V = -Ed$

or $\boxed{V = Ed}$ Magnitude

But $E = -\frac{\Delta V}{\Delta r}$

units of $E = \frac{\text{Volt}}{\text{meter}}$

So

$\frac{\text{Newton}}{\text{Coulomb}}$ is equivalent to $\frac{\text{Volt}}{\text{meter}}$

12.10 Electric Potential at a point due to a point charge

Definition:

"Electric potential at a point due to a point charge is defined as the amount of work done in moving a unit positive charge from infinity to that point, keeping the charge in equilibrium."

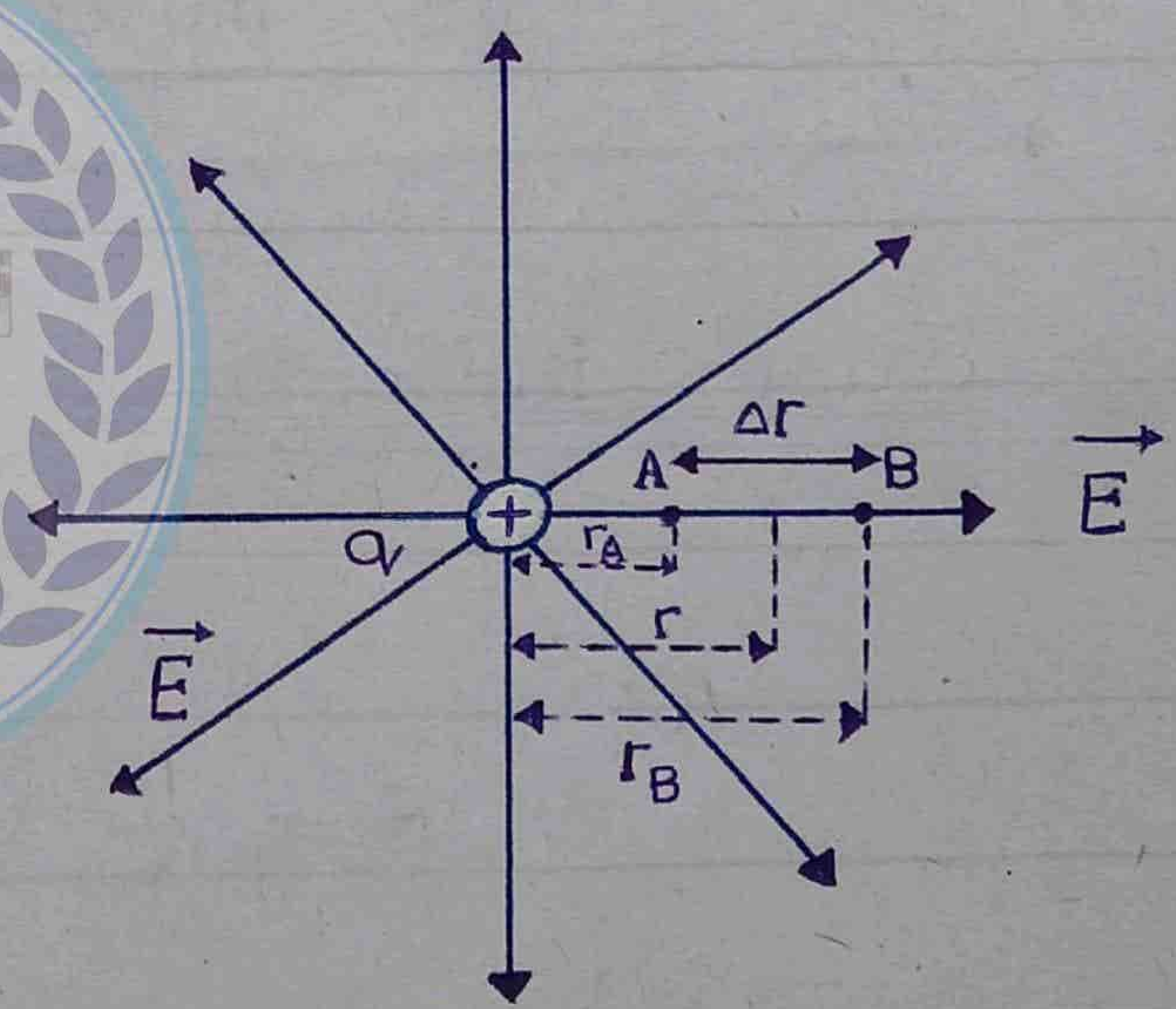
$$\boxed{V = \frac{1}{4\pi\epsilon_o}\frac{q}{r}}$$

Proof:

Consider a charge q whose electric field is shown in Fig.

This field is radical.

Take two points A and B very close to each other, so that the electric field intensity $\vec{E}$ remains constant.



The distances of the points A and B from the charge q are r_A, r_B.

r = Distance of the charge q from the mid point between A and B.

Δr = Distance between the points A and B.

As
$$E = -\frac{\Delta V}{\Delta r}$$

$$\Delta V = -E\Delta r \qquad \text{(i)}$$

According to the Fig.

$$r_B = r_A + \Delta r$$

$$\Delta r = r_B - r_A \qquad \text{(ii)}$$

The magnitude of electric intensity at this point is

$$E = \frac{1}{4\pi\epsilon_o}\frac{q}{r^2} \qquad \text{(iii)}$$

As the points A and B are very close to each other.

$$r_A \simeq r_B \simeq r$$

$$r^2 = rr$$

$$r^2 = r_A r_B$$ putting in eq (iii)

$$E = \frac{1}{4\pi\epsilon_o}\frac{q}{r_A r_B}$$

Put the value of E and Δr in equation (i)

$$\Delta V = -\frac{1}{4\pi\epsilon_o}\frac{q}{r_A r_B}(r_B - r_A)$$

$$V_B - V_A = -\frac{q}{4\pi\epsilon_o}\frac{r_B - r_A}{r_A r_B}$$

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$$V_B - V_A = -\frac{q}{4\pi\epsilon_o}\left(\frac{\cancel{r_B}}{r_A \cancel{r_B}} - \frac{\cancel{r_A}}{\cancel{r_A} r_B}\right)$$

$$V_B - V_A = -\frac{q}{4\pi\epsilon_o}\left(\frac{1}{r_A} - \frac{1}{r_B}\right)$$

Multiply both sides by "-1".

$$-(V_B - V_A) = -1\left[-\frac{q}{4\pi\epsilon_o}\left(\frac{1}{r_A} - \frac{1}{r_B}\right)\right]$$

$$V_A - V_B = \frac{q}{4\pi\epsilon_o}\left(\frac{1}{r_A} - \frac{1}{r_B}\right)$$

To find absolute potential at A, the point B is at infinity. So

$$V_B = 0 \; ; \; r_B = \infty$$

$$\frac{1}{r_B} = \frac{1}{\infty} = 0$$

$$V_A - 0 = \frac{q}{4\pi\epsilon_o}\left(\frac{1}{r_A} - 0\right)$$

$$V_A = \frac{q}{4\pi\epsilon_o} \cdot \frac{1}{r_A}$$

The general formula for the electric potential "V" at a distance "r" from the charge q is:

$$\boxed{V = \frac{1}{4\pi\epsilon_o} \cdot \frac{q}{r}}$$

Electron Volt (eV):

It is a unit of energy.

Definition:

"One electron volt is the amount of energy gained or lost by an electron as it moves through a potential difference of one volt."

Question:

Prove that $1eV = 1.6 \times 10^{-19}$ Joule.

Proof:

As $$\Delta V = \frac{\Delta U}{q}$$

But $\text{volt} = \frac{\text{Joule}}{\text{Coulomb}}$

$$\Delta U = q \Delta V$$

$$\Delta K.E = e \Delta V$$

$$\Delta K.E = (1.6 \times 10^{-19} \text{ Coulomb}) \times 1 \text{ volt}$$

$$\Delta K.E = (1.6 \times 10^{-19} \cancel{\text{Coulomb}}) \times \frac{\text{Joule}}{\cancel{\text{Coulomb}}}$$

$$\Delta K.E = 1.6 \times 10^{-19} \text{ Joule}$$

So

$$\boxed{1 eV = 1.6 \times 10^{-19} \text{ Joule}}$$

Important Formula: $\boxed{K.E = qV}$

12.11 Comparison of Electric and Gravitational Forces:

Similarities:

1) Gravitational Force $F_g = G\frac{m_1 m_2}{r^2}$ is a conservative force. Work done in the gravitational field is independent of path followed by the body.

The electric force (Coulomb's Force) $F_e = k\frac{q_1 q_2}{r^2}$ is also a conservative force.

2) As $F_g \propto \frac{1}{r^2}$; $F_e \propto \frac{1}{r^2}$
Both forces are inverse square forces. They are inversely proportional to the square of distance.

Dissimilarities:

1) The value of gravitational constant $G = 6.67 \times 10^{-11}\ N\,m^2\,kg^{-2}$ is very small. So, gravitational force F_g is very weak. Whereas, the value of electric constant $k = 9 \times 10^9\ N\,m^2\,C^{-2}$ is large.

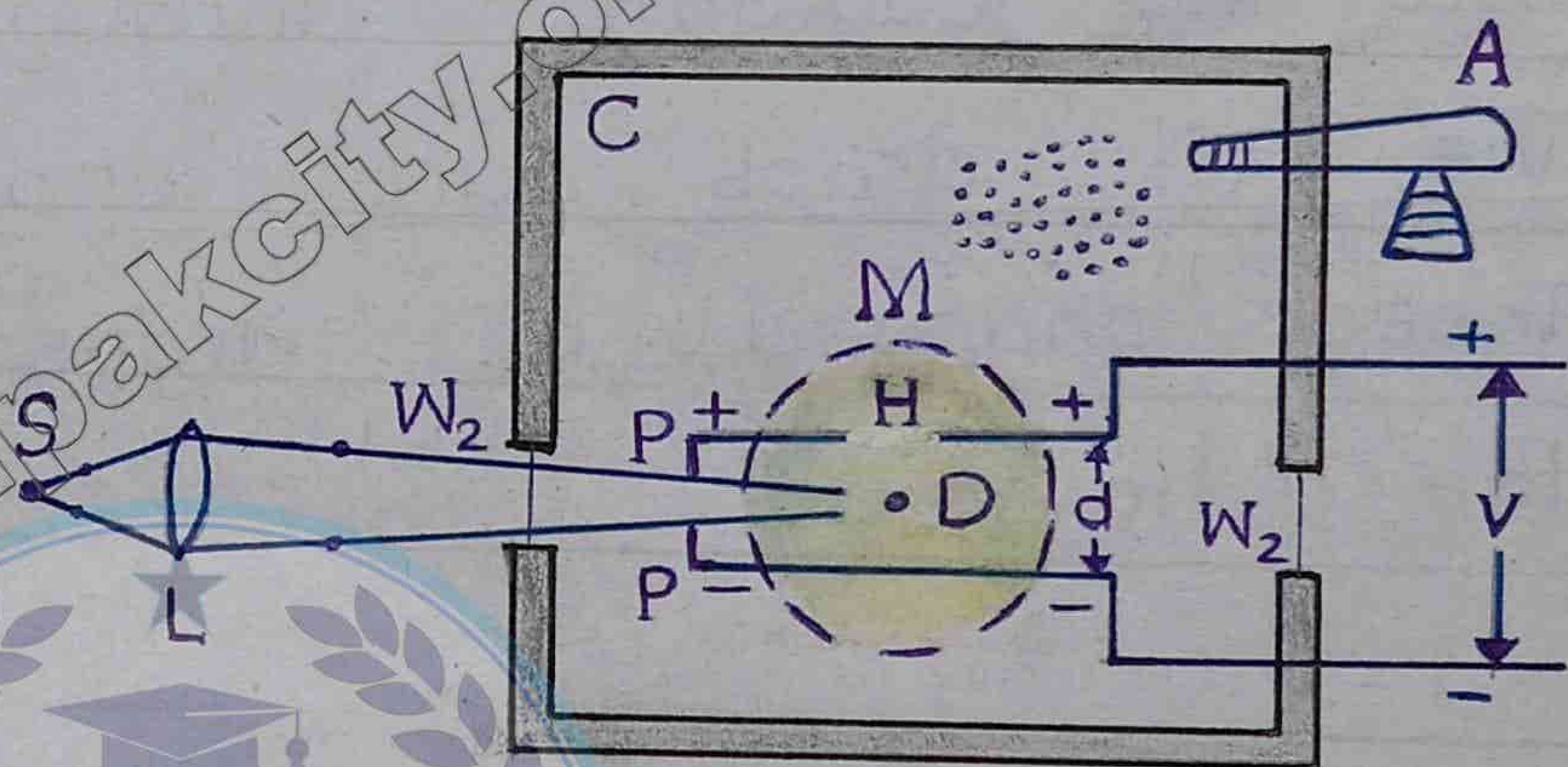
2) Electrostatic force can be attractive or repulsive. Whereas the

gravitational Force is only attractive.

3) The electric Force depends upon the medium and can be shielded (روکنا). The gravitational Force cannot be shielded.

12.12 Charge of an electron by Millikan's method

In 1909 R.A. Millikan Found the charge of an electron. The schematic diagram is shown in Fig.



Construction:

1- Container C:

It contains the parallel plates PP' and it saves oil drop From the air disturbance.

2- Parallel Plates PP':

A voltage "V" is applied between the plates.

An electric Field E is produced. The upper plate has a small hole "H".
d = distance between the plates.

3- Power Supply:

The voltage V is applied and controlled by the battery $V = Ed$.

4- Atomizer A:

Atomizer sprays oil drops into the container through the nozzle. The oil drops are charged due to Friction. These charged oil drops pass through the hole "H".

5- Microscope M:

The path of the motion of the oil drops is observed by the microscope.

6- Source of Light S:

It makes the drops visible.

Working:

By adjusting the voltage V and hence E ($V = Ed$), the droplet is made to suspend between the plates PP'.

In this situation;

Gravitational Force = Electric Force

$$F_g = F_e$$

$$mg = qE$$

$$mg = q\frac{V}{d}$$

$F_g = w = mg$

But $V = Ed$

$E = \frac{V}{d}$

$$\boxed{q = \frac{mgd}{V}} \qquad \text{———} \quad (i)$$

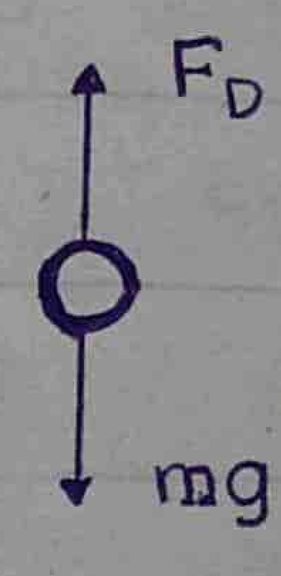
Knowing the value of m, g, d, V, the value of charge "q" can be

<u>Mass "m" is still unknown.</u>

<u>Mass of Droplet:</u>

The voltage V i.e battery is switched off. The droplet falls with constant velocity called <u>terminal velocity V_t.</u> Here, the weight "mg" is balanced by the Drag Force F_D.

$$mg = F_D$$



<u>By Stokes Law</u>

$$F_D = 6\pi\eta r v_t$$

Where "r" is the radius of the droplet,

" η " is the coefficient of viscosity , " v_t " is the terminal velocity .

$$mg = F_D$$

$$mg = 6\pi\eta r v_t \quad \text{———} \quad (ii)$$

$$\rho = \frac{mass}{Volume} = \frac{m}{\frac{4}{3}\pi r^3}$$

$$m = \frac{4}{3}\pi r^3 \times \rho \quad \text{———} \quad (iii)$$

Put the value of equation (iii) in (ii)

$$\frac{\cancel{4}^{2}}{3}\cancel{\pi} r^{\cancel{3}} \rho . g = \cancel{6}\cancel{\pi}\eta \cancel{r} v_t$$

$$2r^2 \rho . g = 9\eta v_t$$

$$r^2 = \frac{9\eta v_t}{2\rho g}$$

$$r = \sqrt{\frac{9\eta v_t}{2\rho g}}$$

Knowing " r " the mass " m " can be found by equation (iii) .

This value of " m " is used in equation (i), So , the change on the droplet is calculated by equation (i) .

Determination of charge on the droplet:

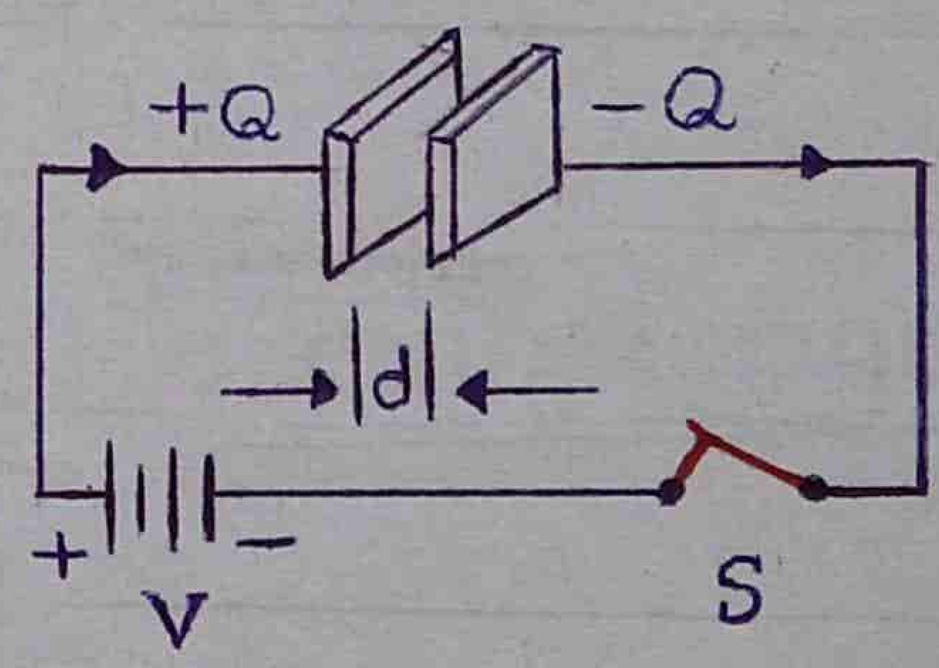
Millikan measured charge on many droplets. He Found that each charge was on integral multiple of minimum charge 1.6×10^{-19} Coulomb.

This minimum charge is the charge of an electron $\boxed{e = 1.6 \times 10^{-19}\ C}$.

12.13 Capacitor

"Capacitor is a device which is used to store electric charge or electric energy."

Construction:



A capacitor consists of two conductors placed very close to each other.

The insulating medium between the conductors (plates) is called Dielectric.

When the conductors are in the Form of parallel plates, then the capacitor is called Parallel Plate Capacitor.

Working:

When the plates of the capacitor are connected to the battery of voltage V, a potential drop V appears across the plates.

(i) The plate connected with the +ve terminal of the battery gets +Q charge.

(ii) The plate connected with the −ve terminal of the battery gets −Q charge.

Q = Magnitude of charge on either plate.

$$Q \propto V$$

$$Q = CV$$

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

C = Capacitance of the capacitor.

Capacitance:

"Capacitance is the ability of a capacitor to store charge."

Capacitance C depends on:

(i) Shape, geometry (distance between the plates, area of a plate of the capacitor).

(ii) Medium between the plates.

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

Unit of capacitance is "Farad".

$$1\ \text{Farad} = \frac{1\ \text{Coulomb}}{1\ \text{volt}}$$

$$\boxed{\text{Farad} = \text{Coulomb per volt}}$$

Farad:

"Capacitance of a capacitor is one Farad if a charge of one coulomb given to one of the plates of a parallel plate capacitor produces a potential difference of one volt between them."

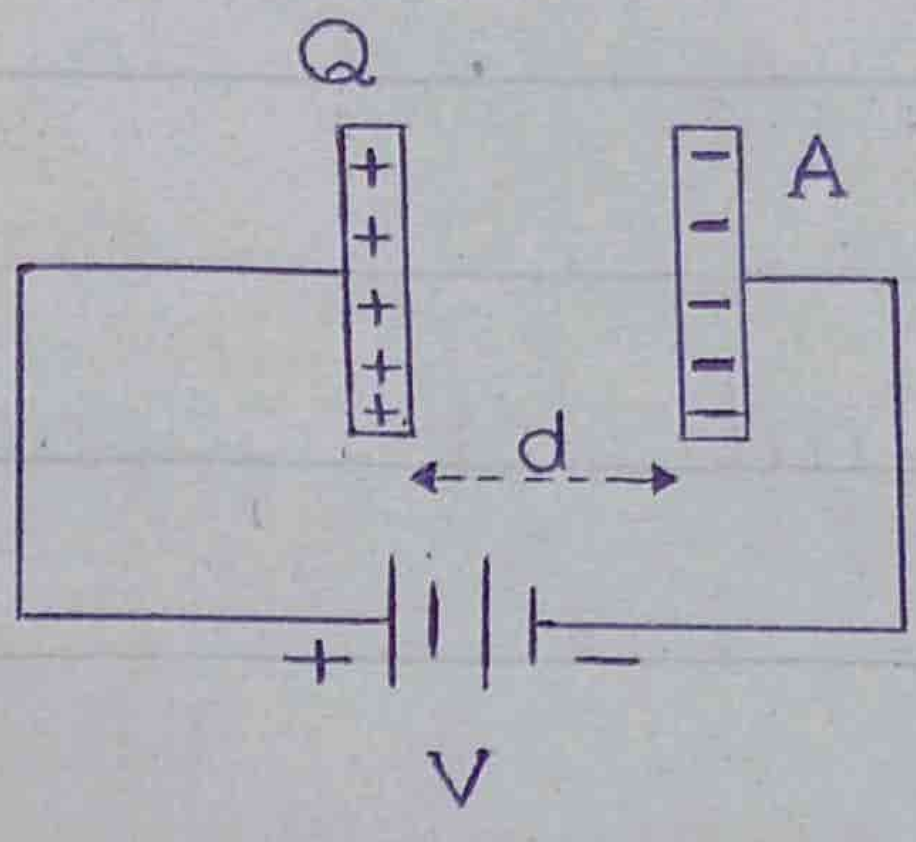
Note:

1 Farad is a very big unit. Hence we use its sub multiple units.

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

$1\ pF = 10^{-12}\ F = 1$ pico Farad.

12.14 Capacitance of a Parallel Plate Capacitor



Consider a parallel plate capacitor.

"Q" is the charge and "A" is the area of each plate.

d = distance between the plates.

E = Electric field between the plates.

V = Potential difference between the plates.

Case-1: When vacuum between the plates:

As $Q = CV$

$$C_{vac} = \frac{Q}{V}$$

Surface charge density

$$\sigma = \frac{\text{Charge}}{\text{Area}} = \frac{Q}{A}$$

$$Q = \sigma A$$

$$C_{vac} = \frac{\sigma A}{V} \qquad \text{But} \quad V = Ed$$

$$C_{vac} = \frac{\sigma A}{Ed} \quad \text{———} \quad (1)$$

The electric field intensity E, between oppositely charged plates of the capacitor is

$$E = \frac{\sigma}{\epsilon_o}$$ put in equation (1)

$$C_{vac} = \frac{\cancel{\sigma} A}{\frac{\cancel{\sigma}}{\epsilon_o} d}$$

$$\boxed{C_{vac} = \frac{\epsilon_o A}{d}}$$

Case-2 Effect of Dielectric Medium:

$$C_{med} = \frac{\epsilon_o \epsilon_r A}{d}$$

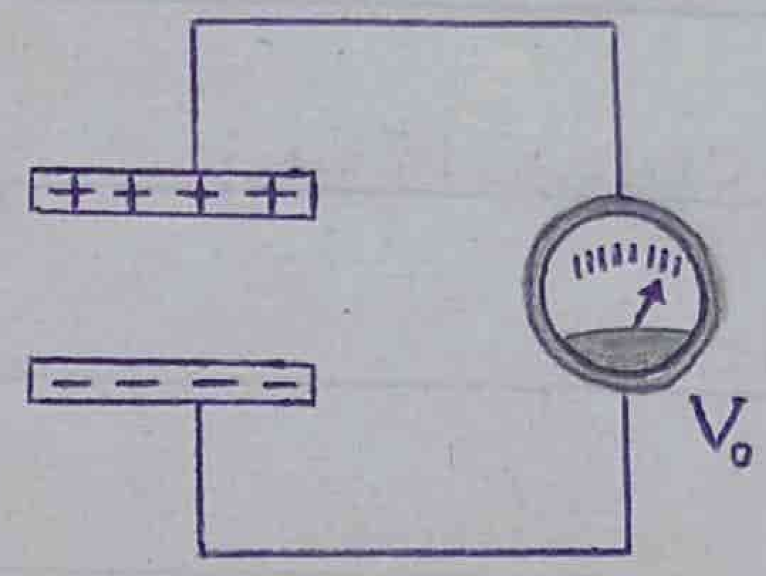
When an insulator called "Dielectric" is placed between the plates of the capacitor its capacitance increases by a factor ϵ_r.

ϵ_r = It is called relative permittivity of the medium.
ϵ_r = Its value is different for different materials
ϵ_r = It is also called Dielectric Constant.

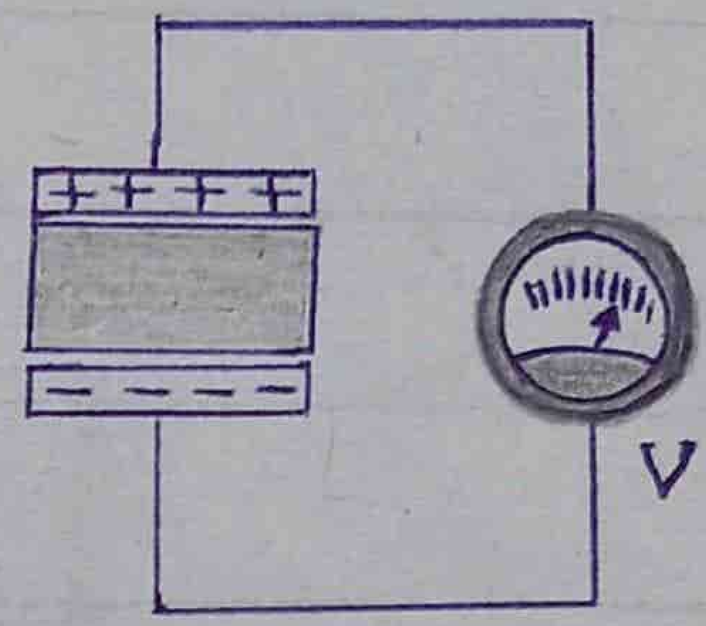
Explanation:

Figure show a charged

capacitor whose plates are connected to a voltmeter. The potential difference between the plates is V_o.



Now a dielectric medium is inserted(داخل کرنا) between the plates. The potential difference decreases from V_o to V.



$$V < V_o$$

The charge Q = remains same.

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

As V decreases capacitance C increases.

$$C_{med} = \frac{\epsilon_o \epsilon_r A}{d} = \epsilon_r \left(\frac{\epsilon_o A}{d}\right) = \epsilon_r C_{vac}$$

$$C_{med} = \epsilon_r C_{vac}$$

As $\epsilon_r > 1$ So, $C_{med} > C_{vac}$

$$\boxed{\epsilon_r = \frac{C_{med}}{C_{vac}}}$$

Definition of dielectric constant: ϵ_r

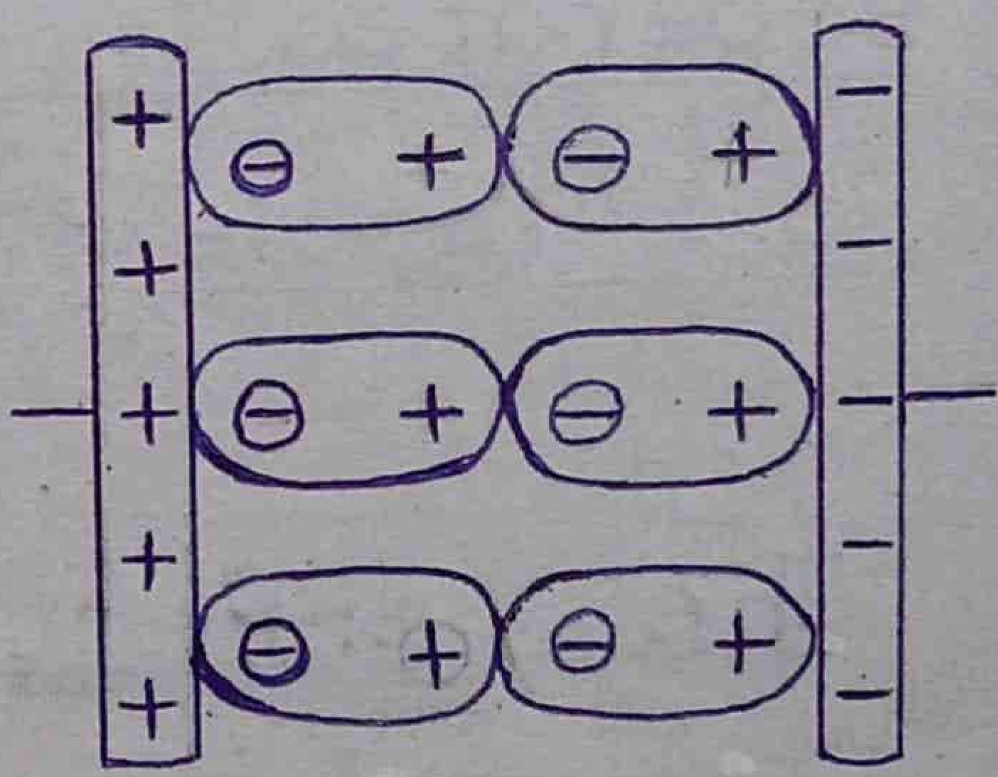
" The ratio of the capacitance of a parallel plate capacitor with an insulating substance as medium between the plates to its capacitance with vacuum (or air) as medium between them."

12.15 Electric Polization of Dielectrics

"In the presence of electric field, the molecules of a dielectric becomes dipoles. This process is called Polarization."

Polarization of dielectric increases the capacitance of a capacitor.

Explanation:



A dielectric consists of molecules and atoms which are electrically neutral. They contain equal amounts of +ve and −ve charges. The centre of +ve and −ve charges is same.

When the molecules of the dielectric are placed in the electric field of a capacitor. The negative charge (electrons) are displaced towards the positively charged plate, and the positive charge (nuclei) towards the negatively charged plate.

Now the centre of +ve and −ve charges is not same.

One end of the molecule shows a −ve charge and the other end shows an equal amount of +ve charge. But the molecules are still neutral. It acts as a dipole.

Dipole:

"Two equal and opposite charges seperated by a small distance is called a dipole."

The effect of Polarization on the Capacitance

As shown in Fig.

1- Positive plate attracts negative end of dipole.

2- Negative plate attracts positive end of dipole.

σ = Surface charge density on the plate decreases.

As $E = \frac{\sigma}{\epsilon_o}$; E = decreases.

As $V = Ed$; V = decreases.

As $C = \frac{Q}{V}$; C = Increases.

Result:

Decrease in V increases the Capacitance C.

12.16 Energy Stored in a Capacitor

A capacitor stores electric energy. This energy is stored in the electric field between the plates of the capacitor.

Explanation:

The charge on the plates of the capacitor posses electrical energy, because some work has to be done to deposit charge on the plates.

(i) Initially, when there is no charge on the capacitor, potential difference between the plates is zero.

$$V = 0$$

(ii) Finally, when charge Q is stored on the capacitor, the potential difference is V.

Average Potential difference

$$\Delta V = \frac{0 + V}{2} = \frac{V}{2}$$

As $\Delta V = \frac{\Delta U}{Q}$

$$\frac{1}{2} V = \frac{P.E}{Q}$$

$$P.E = \frac{1}{2} QV$$

$$\boxed{\text{Energy} = \frac{1}{2} QV}$$

But $Q = CV$

$$\text{Energy} = \frac{1}{2} CV.V$$

$$\boxed{\text{Energy} = \frac{1}{2} CV^2}$$

As

$$Q = CV \quad ; \quad V = \frac{Q}{C}$$

$$\text{Energy} = \frac{1}{2} Q.V$$

$$\text{Energy} = \frac{1}{2} Q \cdot \frac{Q}{C}$$

$$\boxed{\text{Energy} = \frac{1}{2} \frac{Q^2}{C}}$$

$$\text{Energy} = \frac{1}{2} QV = \frac{1}{2} CV^2 = \frac{1}{2} C\left(\frac{Q}{C}\right)^2$$

$$\boxed{\text{Energy} = \frac{1}{2} \frac{Q^2}{C}}$$

Energy Stored in terms of Electric Field E

$$\text{Energy} = \frac{1}{2} C.V^2$$

As

$$C = \frac{\epsilon_o \epsilon_r A}{d} \quad \text{and} \quad V = Ed$$

$$\text{Energy} = \frac{1}{2}\left(\frac{\epsilon_o \epsilon_r A}{d}\right)(Ed)^2$$

$$\text{Energy} = \frac{1}{2}\frac{\epsilon_o \epsilon_r A}{\cancel{d}} . E^2 d^{\cancel{2}}$$

$$\text{Energy} = \frac{1}{2}\epsilon_o \epsilon_r A E^2 d$$

$$\boxed{\text{Energy} = \frac{1}{2}\epsilon_o \epsilon_r E^2 Ad}$$

$$\frac{\text{Energy}}{Ad} = \frac{1}{2}\epsilon_o \epsilon_r E^2$$

But $Ad = \text{Volume}$

$$\frac{\text{Energy}}{\text{Volume}} = \frac{1}{2}\epsilon_o \epsilon_r E^2$$

Result:

$$\boxed{\text{Energy Density} = \frac{1}{2}\epsilon_o \epsilon_r E^2}$$

Energy Density:

"Energy stored per unit volume is called energy density."

$$\text{Energy density} = \frac{\text{Energy}}{\text{Volume}}$$

Units of Energy density is Jm^{-3}.

12.17 Charging and discharging of a Capacitor

1- Charging of a Capacitor:

Many electric circuits consists of both capacitor C and resistor R. Fig (1) shows a circuit called RC-Circuit.

When the switch S is set at terminal A, the battery of voltage V_o starts charging the capacitor C through the resistor R.

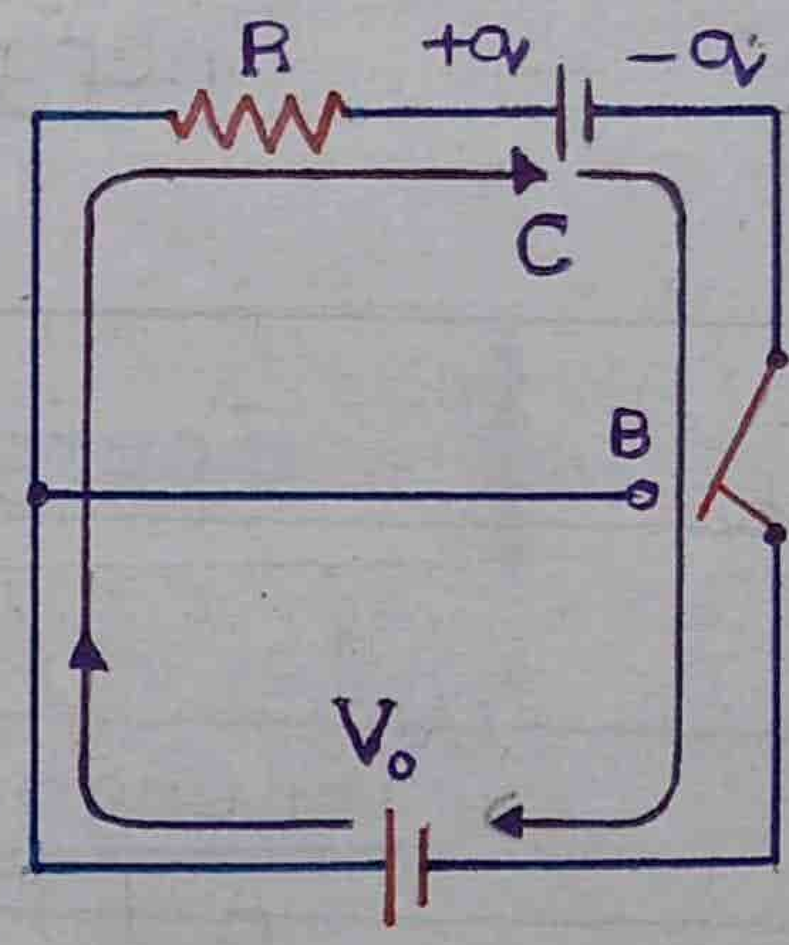
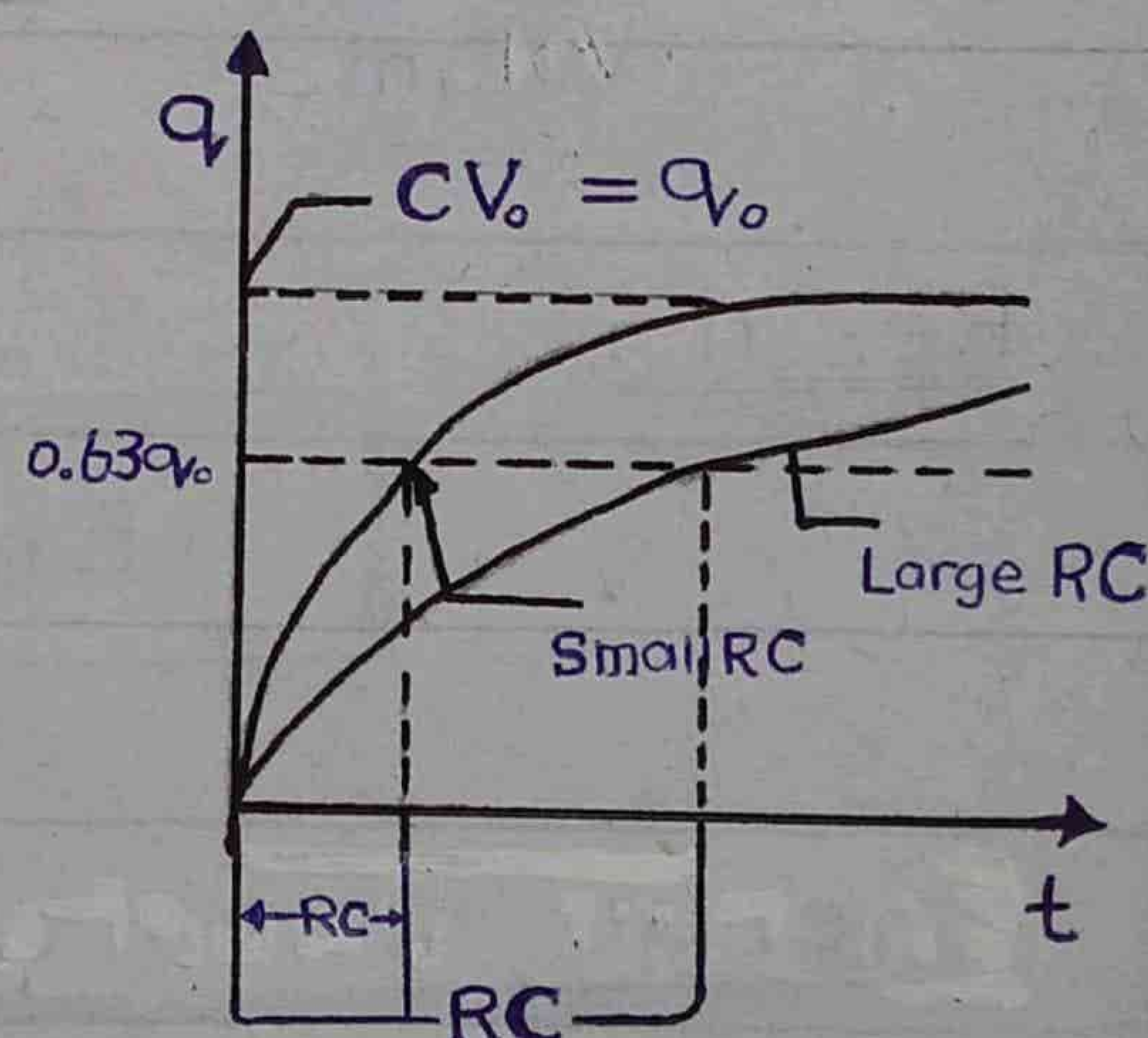


Fig (1)
Charging a capacitor

The charge on the capacitor builds up gradually from zero to final equilibrium value $q_o = CV_o$. This growth of charge with time is shown in the graph.



The time of charging or discharging of a capacitor depends on the product RC.

$$\boxed{RC = \text{Time Constant}}$$

$$\boxed{t = RC}$$

Time Constant:

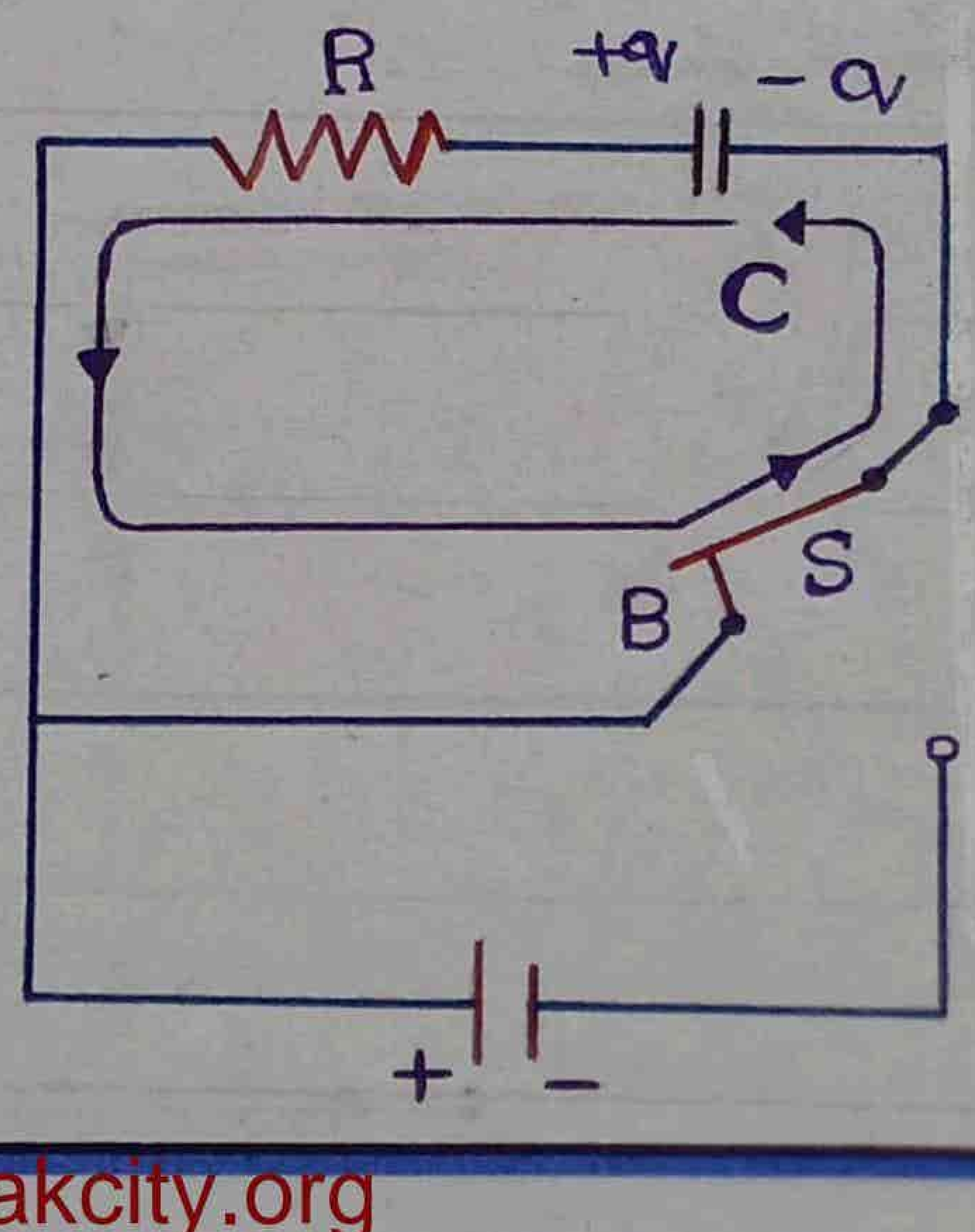
"The time required by the capacitor to deposit 0.63 times the equilibrium charge q_0."

$$q = 0.63\, q_0$$

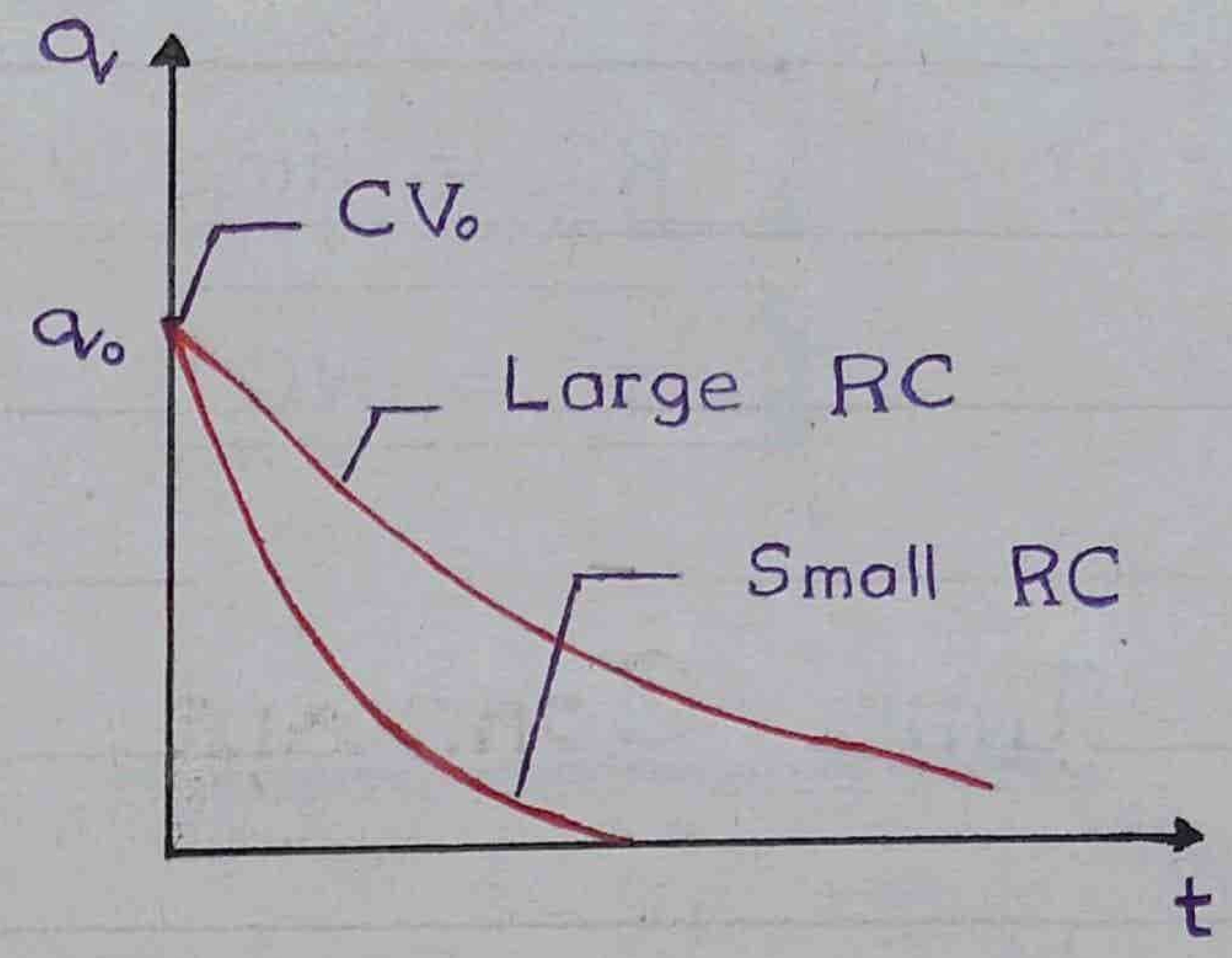
Note:

Graph shows that the capacitor charges rapidly when the time constant RC is small.

2- Discharging of the Capacitor:



When the switch S is set at the point B, the charge +q on the left plate will flow anti-clockwise through the resistance and neutralize the charge $-q$ on the right plate, as shown in Fig. Graph shows that the discharging begins at $t = 0$ when $q_o = CV_o$. The charge decreases gradually to zero.



Dicharging a Capacitor

Note:

When the time constant RC is smaller, capacitor discharges rapidly.

As $RC = t$

ohm x Farad = Second

Example:

IF $R = 10\ k\Omega$

$C = 10\ \mu F$

$t = RC = 10 \times 10^{3} \times 10 \times 10^{-6}$

$t = 1 \times 10^{-1}\ s$

$t = 0.1$ seconds

Answers of the Short Questions

12.1 The potential is constant throughout a given region of space. Is the electrical field zero or non-zero in this region? Explain.

12.2 Suppose that you follow an electric field line to positive point charge. Do electric field and the potential increase or decrease?

12.3 How can you identify that which plate of a capacitor is positively charged?

12.4 Describe the force and forces on a positive point charge when placed between parallel plates

(a) with similar and equal charges (b) with opposite and equal charges

12.5 Electric lines of force never cross. why?

12.6 If a point charge **q** of mass **m** is released in a non-uniform electric field with field lines pointing in the same direction, will it make a rectilinear motion?

12.7 Is **E** necessarily zero inside a charged rubber balloon if balloon is spherical? Assume that charge is distributed uniformly over the surface.

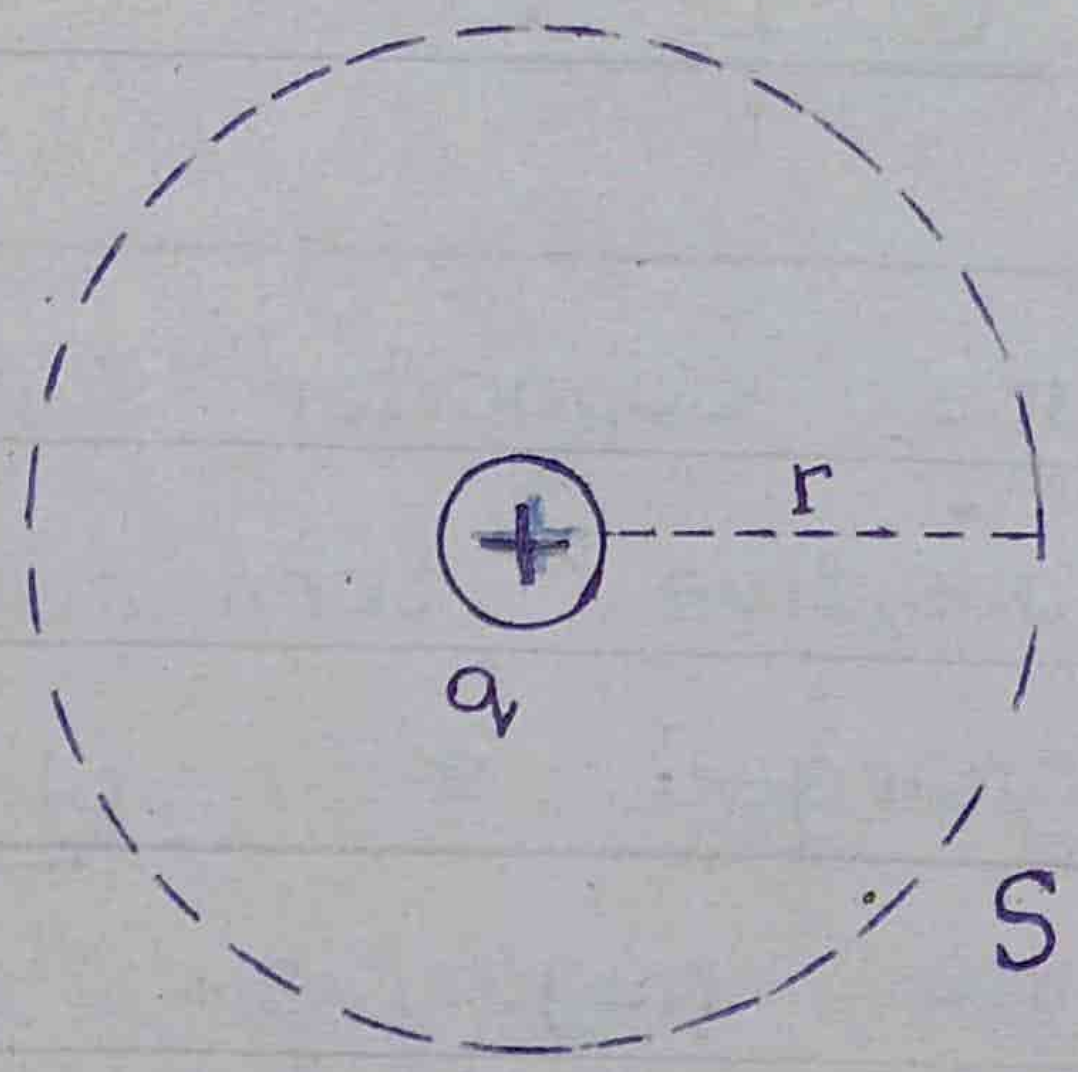
12.8 Is it true that Gauss's law states that the total number of lines of forces crossing any closed surface in the outward direction is proportional to the net positive charge enclosed within surface?

12.9 Do electrons tend to go to region of high potential or of low potential?

Answers of Short Questions

Q-12.1

Answer



The region at which potential is constant is called equipotential surface. Such a surface S is shown in Fig.
At every point on this surface, potential $V = \frac{1}{4\pi\epsilon_o}\frac{q}{r}$ is same. i.e constant. It is not zero.

So at this surface the magnitude of electric field "E" is constant. Electric field "E" is non-zero.

$$E = \frac{1}{4\pi\epsilon_o}\frac{q}{r^2} \qquad E \neq 0$$

Q-12.2

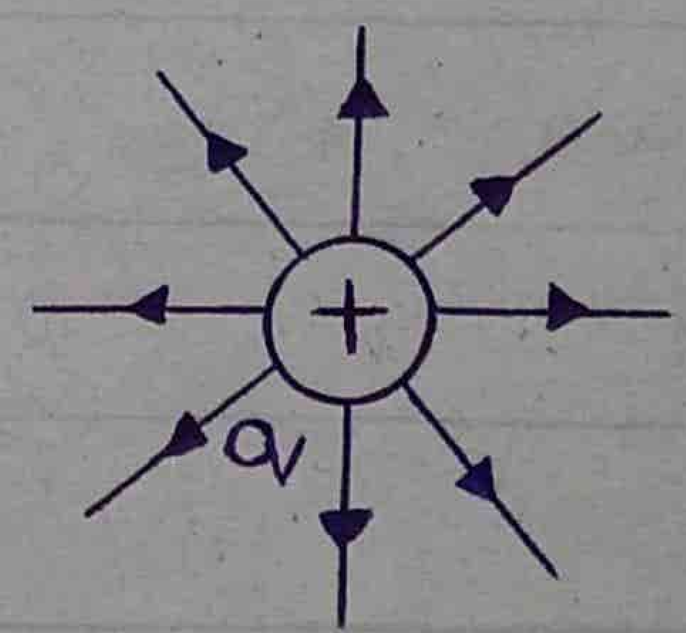
Answer

As

$$E = \frac{1}{4\pi\epsilon_o}\frac{q}{r^2} \; ; \qquad E \propto \frac{1}{r^2}$$

$$V = \frac{1}{4\pi\epsilon_o}\frac{q}{r} \; ; \qquad V \propto \frac{1}{r}$$

The relations for "E" and "V" show that as you follow an electric field line due to a +ve point charge, the distance "r" increase.



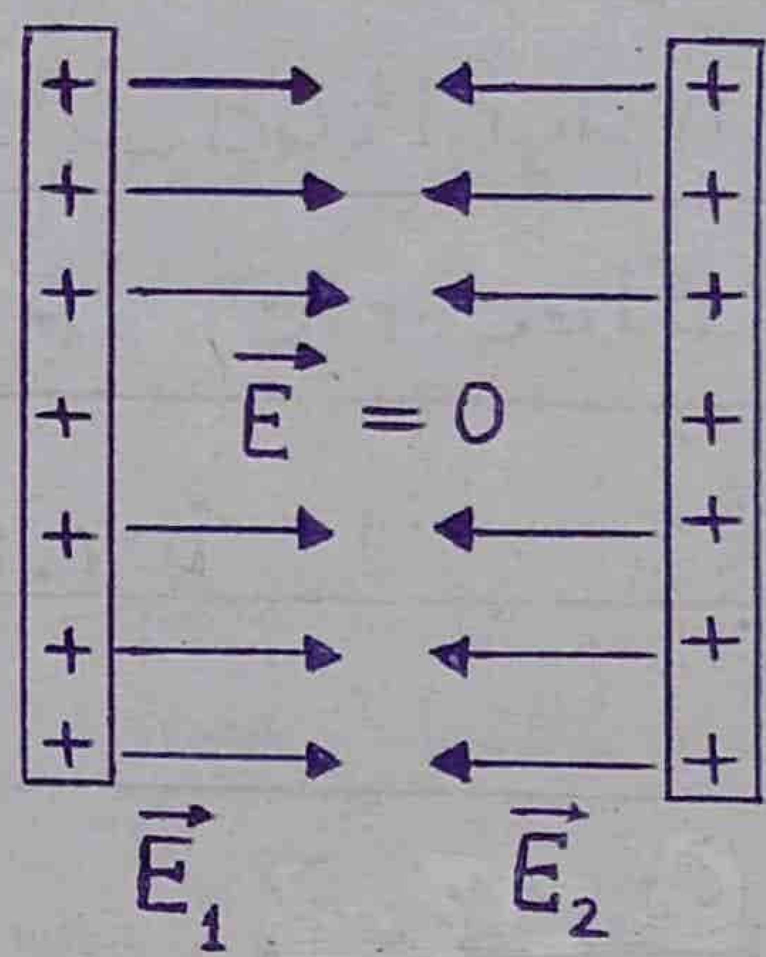
As a result both "E" and "V" decrease.

Q-12.3 Answer

The plate of the capacitor which is connected with the positive terminal of the battery is positively charged. The plate which is connected to the negative terminal of the battery is negatively charged.

Q-12.4 Answer

(a)



As shown in Figure $\vec{E}_1$ and $\vec{E}_2$ are equal but in opposite direction. So

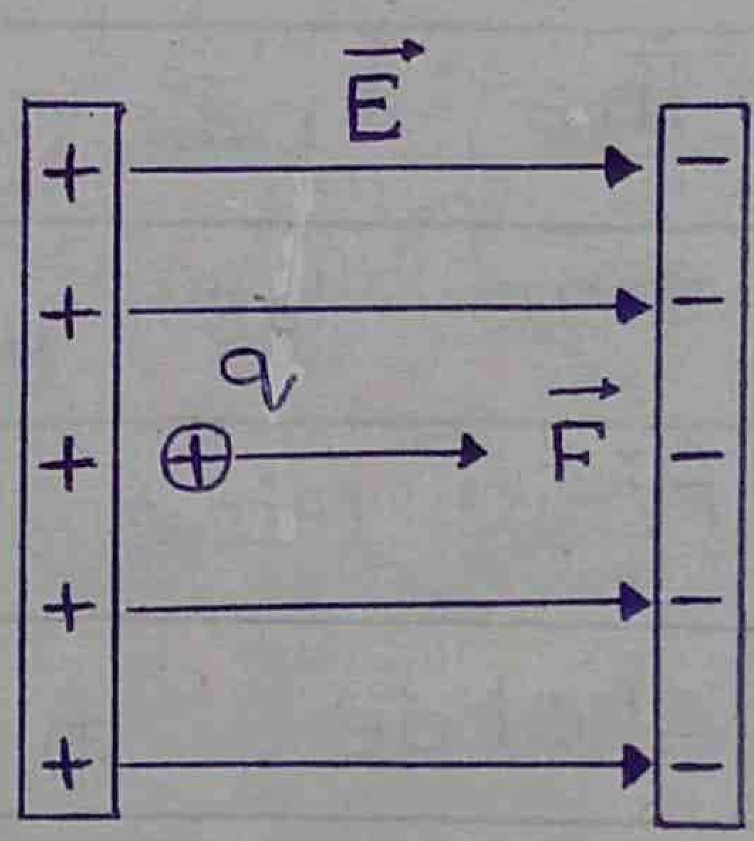
$$\vec{E} = \vec{E}_1 - \vec{E}_2 = 0$$

$$\vec{F} = q\vec{E} = q(0) = 0$$

$$\vec{F} = 0$$

No net Force will act on the charge.

(b)



$\vec{E} = \vec{E}_1 + \vec{E}_2$

As shown in Figure $\vec{E}$ is From +ve to −ve plate $\vec{E} \neq 0$

As

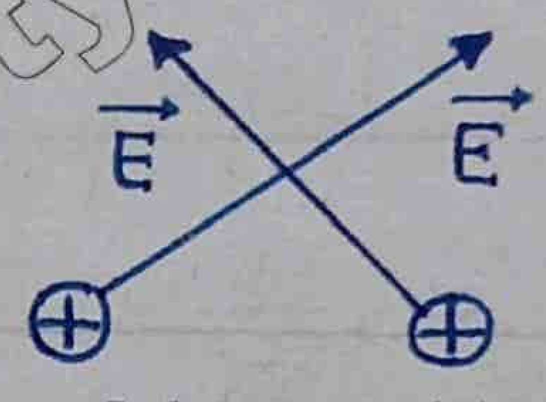
$$\vec{F} = q\vec{E} \quad ; \quad \vec{F} \neq 0$$

Due to this Force the charge "q" will move From +ve towards −ve plate.

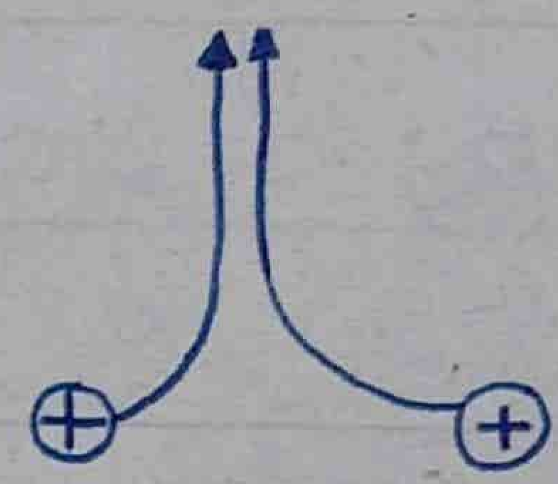
Q-12.5 Answer

No two electric Field lines cross each other. This is so, because $\vec{E}$ has only one direction at any given point.

If the lines cross eachother, $\vec{E}$ could have more than one direction, which is not possible. So electric Field lines do not cross each other.



Not possible



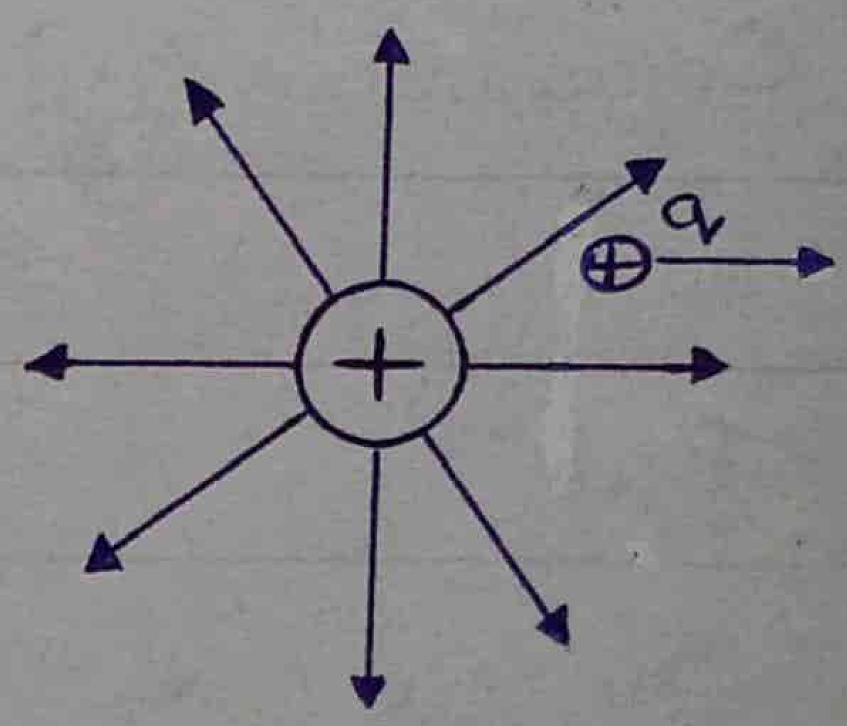
possible

Q-12.6 Answer

In non-uniform electric Field $\vec{E}$, the motion of the charge "q" may or may not be rectilinear (straight line).

Case-1:

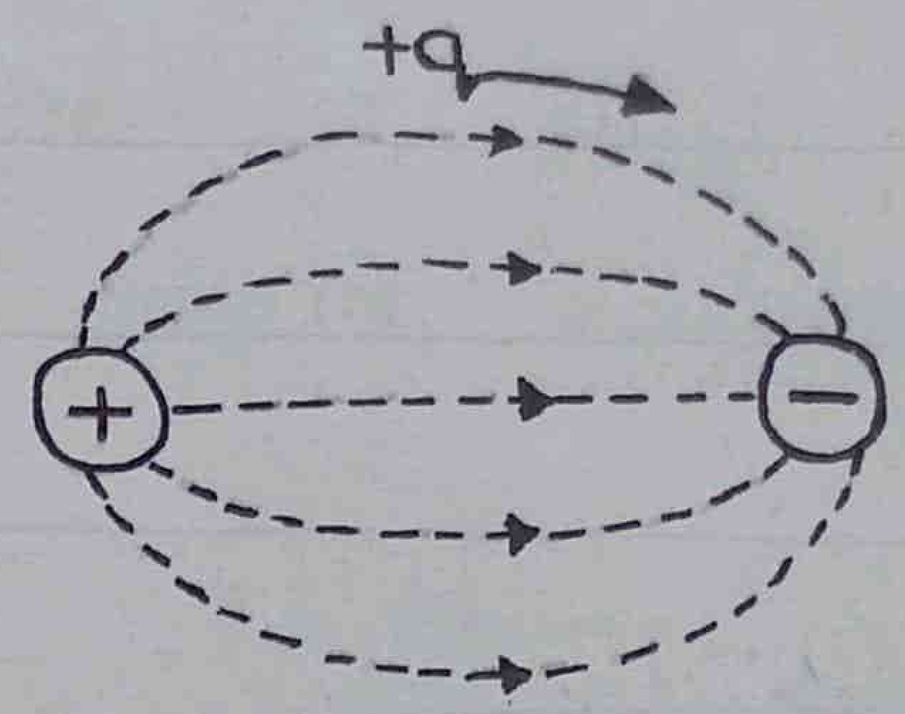
Due to a single point charge or a spherical charged body. The given point charge +q will make a straight line motion. Fig (a).



(a)

Case - 2:

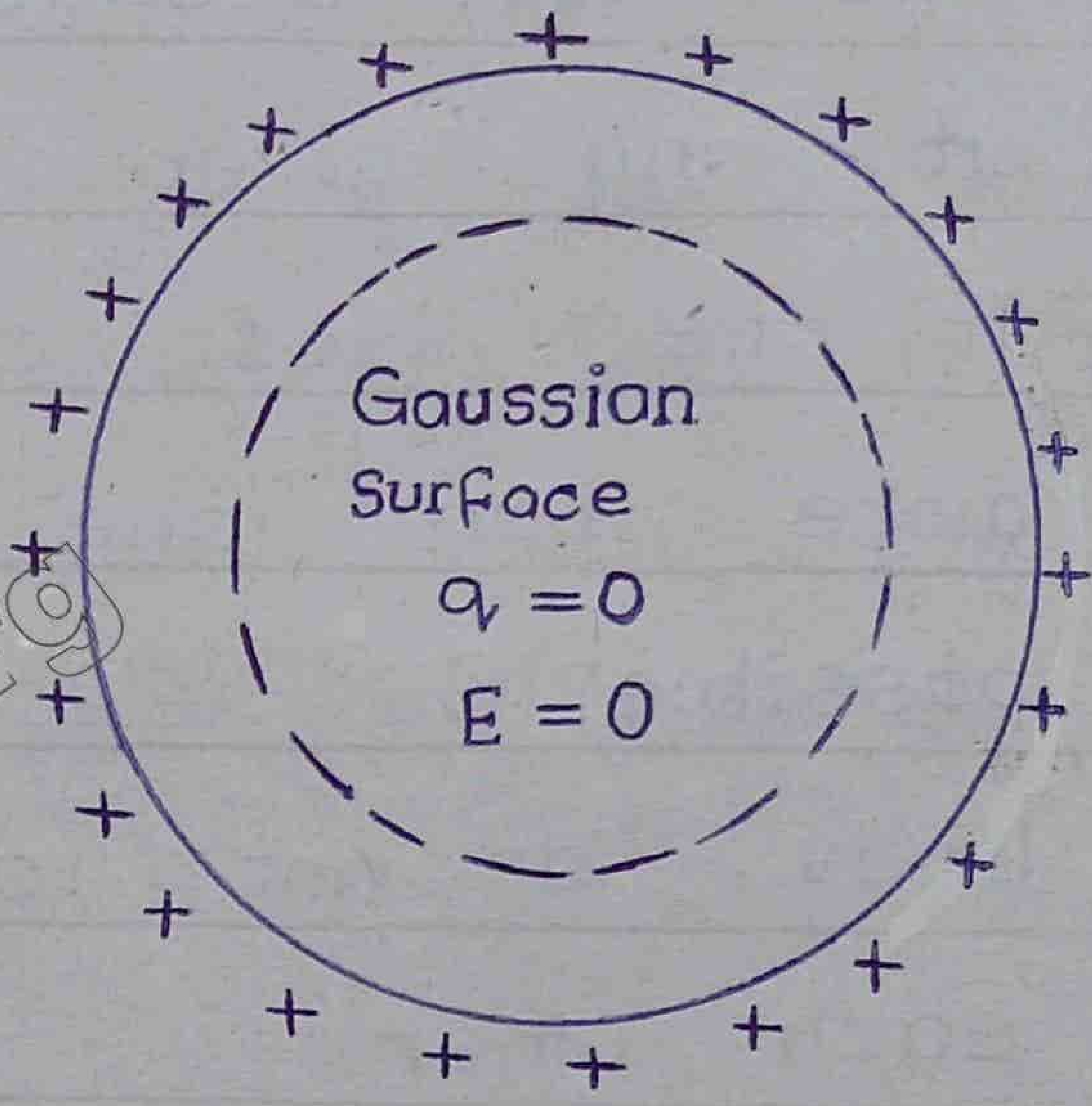
If there are two or more charges, the charge $+q$ may move along a curved path. Fig (b).



(b)

Q-12.7

Answer



Consider a Gaussian Surface inside the balloon. charge $q = 0$ inside it.

By Gauss's Law

$$\Phi_e = \frac{q}{\epsilon_o}$$

$$\Phi_e = \frac{0}{\epsilon_o}$$

$$\Phi_e = 0 \quad \text{———} \quad (1)$$

By definition of electric flux

$$\Phi_e = \vec{E} \cdot \vec{A} \quad \text{———} \quad (2)$$

Comparing (1) and (2)

$$\vec{E} \cdot \vec{A} = 0$$

But $\vec{A} \neq 0$

So

$$\vec{E} = 0$$

Hence electric Field is zero inside the charged rubber balloon.

Q-12.8 Answer

By Gauss's Law

$$\Phi_e = \frac{1}{\epsilon_o} \cdot Q$$

$$\Phi_e \propto Q$$

Φ_e = Flux = Number of lines passing perpendicularly through an area.

Yes.

It is true that the total number of lines of Force crossing any closed surface in the outward direction is proportional to the net +ve charge enclosed within the surface.

Q-12.9 Answer

As the electron is negatively charged. So, the electron will move From

a region of low potential towards the region of heigh potential.
Electrons will move in $-\vec{E}$ direction.

High Potential

Low Potential