ELECTROSTATICS

1

Electrostatics Lecture#1

- detection of charge
- polarity of charge
- nature of charge

measured by Gold Leaf Electroscope

Electrostatics → Basic info.
→ Coulomb's force & G.F
→ Electric field → $E = \frac{Fe}{q}$
→ Electric potential & p.d
→ Capacitors

Type of Questions ?

i) Knowledge → information
ii) Concepts → easy, → medium, → hard
Graphical ?
iii) Numerical ⟹ Formula ✓ + concepts ✓
calculation ⟹ approximation
iv) Formula + Graphs
v) Data → Table

$T = 2\pi\sqrt{\frac{m}{k}}$

slope $= k = \frac{F}{x}$

$k = 2000\ N/m$
$m = 50\ g$
$T = ?$

$4.45 \to 4.5$, 4.4

$\frac{4.4}{4}$ $\frac{4.5}{5}$

$g = 9.8\ m/s^2 \implies 10\ m/s^2$

$\sqrt{g} = \pi$ $\quad T = 2\pi\sqrt{\frac{l}{g}} = 2\sqrt{l}$

Numericals ↓

① branch of physics in which we study about charges at rest.

(Electrostatics) → charges at rest.
↓ charge ↓ rest

Types of charges — −Q, +Q

② only electric field is present — when charge is at rest.

acc to maxwell changing electric flux produces $\vec{B}$.

$\Delta\phi_e = 0 \to B = 0$, $E \neq 0$

no magnetic field

ϕ_e = electric flux = const.

$\Delta\phi_e = 0$

when electric flux changes magnetic field is produced i.e when charge is in motion.

③ Detection of charge → Electroscope (Gold Leaf electroscope)

Measurement of charge → Electrometer

Neutral: N.C, $Q = 0$

④ How bodies get charge ?

Electrification

conduction (permanent) — direct contact — transfer of electrons

gain electrons → -ive charge ⊖Q

lose electrons → +ive charge ⊕Q

induction: Electrostatic induction (temporary) → no direct contact.

charge body (+) → Neutral body (net Q = 0)

Quantization

→ like → repel

• Electrostatic Induction :- rearrangement of charges in a neutral body when a charged body is brought near it.

- to Millikens the charge Quantisation of charge
-ed on a body is the
-gral multiple of charge $e = 1.6 \times 10^{-19}$ C
$\bar{e}$.

$Q = \pm Ne$

Q) charge on a
-4 = charge of $\bar{e}$ =
$\times 10^{-19}$ C ($\therefore N = 1$)

$Q = +25\,\mu C$ $Q = Ne$
$N = ?$ $N = \frac{Q}{e}$

$N = \frac{25 \times 10^{-6}}{1.6 \times 10^{-19}}$

Scientific notation

$N = \frac{\cancel{25} \times 10^{-6}}{\cancel{16} \times 10^{-20}}$

$= 1.5 \times 10^{-6+20}$

$= 1.5 \times 10^{14}$ electrons true

→ $1\,e = 1.6 \times 10^{-19}$ C

→ $1\,C = 6.25 \times 10^{18}$ e

$1\,C = \left(\frac{1}{1.6 \times 10^{-19}}\right)$

→ $1C = 6.25 \times 10^{18}$ e

$25\,\mu C = 6.25 \times 10^{18} \times 25 \times 10^{-6}$
$= 156.25 \times 10^{12}$
$= 1.56 \times 10^{14}$

6.25 × 25 = 3125 + 12500 = 156.25

⑥ Principle of electrostatics
→ like charges → repel
→ unlike charges → attract

Redistribution of charges → electrostatic induction (no conduction, direct contact)

F_e → attractive (strong) / repulsive (weak) } Net force → attractive

⊕ Neutral body → charge = ? ⊕ ← away

Ground / earth → removed

→ charges store in the capacitor by means of conduction.
→ charge is an intrinsic property

$F_c = F_c$ of attraction
charge in motion → magnetic field F_m ?
Mag. of charge → very small → $F_m \approx 0$

⑦ Properties of charge

i) Nature a) +ive b) -ive
ii) ←⊕ ⊕→ repulsion; ⊕→ ←⊖ attraction
iii) Scalar Quantity → additive in nature
Neutral body $Q = 0$ → $Q = +Q + (-Q) = 0$
iv) independent of speed
v) Quantisation of charge $Q = \pm Ne$
vi) Isolated system → Q = constant
Law of cons. of charge
Radioactivity ⟹ (U) → (Th + He)
$Q_U = Q_{Th} + Q_{He}$

Note: Mass is the analogue of charge → iv)
- charge may not exist without mass
- Mass can exist without net charge

1.6×10^{-19} C 0.0....... 16

(1)

coloumb's Law Application : dist b/w charges $> 10^{-15} m$

Electrostatics Lecture#2

Coulomb's law of electrostatics $\longrightarrow$ limitations (7) $\rightarrow$ static charges; $\rightarrow$ point charges (charges having size less than the dist. b/w them)

$\leftarrow r \rightarrow$

q_1 (+) $\qquad$ q_2 (+)

$F_e \Leftarrow$ (+) $\qquad$ (+) $\Rightarrow F_e$

$\leftarrow r \rightarrow$

Fe depends upon the product of the charge not the individual charge

(3) $\boxed{F_e \propto q_1 q_2}$ $\quad$ $\boxed{F_e \propto \frac{1}{r^2}}$ } inverse square law $\downarrow$ graph is exponential curve.

↓

therefore the ratio of force exerted by both charges on each other (Q) will always be equal to 1.

(4) $\boxed{F_e = k\frac{q_1 q_2}{r^2}}$

K = coulomb's const.

(2) ε_0 = permitivity of free space / (absolute permittivity)

$\varepsilon_0 = 8.85 \times 10^{-12} \frac{C^2}{Nm^2}$

(5) $K = \frac{1}{4\pi\varepsilon_0} = 9\times 10^9 \frac{Nm^2}{C^2}$

(6) $\boxed{F_e = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}}$

↳ tells us about the effect of dielectric

(8) (+) proton $\quad$ (+) proton $\quad$ $r = 4\times10^{-15}$ m

$\leftarrow r \rightarrow$ $\quad$ $F_e = ?$

$$1.6 \times 1.6 = 2.56$$

$$F_e = k\frac{q_1 q_2}{r^2} = \frac{9\times10^9(1.6\times10^{-19})(1.6\times10^{-19})}{(4\times10^{-15})^2} = \frac{9\times10^9\times2.56\times10^{-38}}{16\times10^{-30}}$$

$$= \frac{\cancel{9}^{4.5}\times10^9\times \cancel{25.6}^{6.3}\times10^{-39}}{\cancel{2}\cancel{4}\,\cancel{16}\times10^{-30}} = 13.5\times 10^{9}\times10^{-39}\times10^{30}$$

$$= 13.5 \text{ N}$$

(9) Dependence of (K) $\rightarrow$ system of units; $\rightarrow$ medium b/w charges (dielectric)

when medium is introduced b/w the charges, Fe dec ↓.

(10) 1 N = 10^5 dyne

$1\, kg\frac{m}{s^2} = 10^5\, g\frac{cm}{s^2}$

MKS $\longrightarrow$ CGS

Vector form $\vec{F_e} \longrightarrow$ unit vector $\hat{r}$

along $\hat{r}$ (the line connecting the charges)

$$\vec{F_e} = \pm k\frac{q_1 q_2}{r^2}\hat{r} \qquad \because \hat{r} = \frac{\vec{r}}{r}$$

$$\vec{F_e} = \pm k\frac{q_1 q_2}{r^2}\frac{\vec{r}}{r} = \pm k\frac{q_1 q_2}{r^3}\vec{r}$$

(11) Nature of F_e

attractive: -ive sign

repulsive: +ive sign

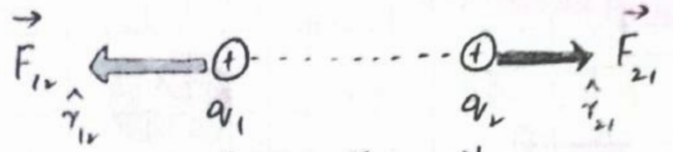
Coulomb's force

Fe or colomb's force dec↓ by the introduction of medium but the gravitational force only depends upon sys. of units it b/z gravitational force can't be shielded.

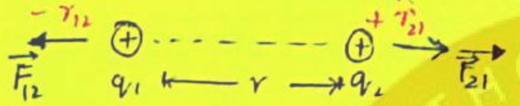
forces equal in magnitude but opposite in direction

(12) Coulomb's force is a mutual force — magnitude = equal; direction = opposite } obeys 3rd law of motion

attractive



$\vec{F}_{12} = \left[k\frac{q_1 q_2}{r^2}\right]\hat{r}_{12}$ $\qquad$ $\vec{F}_{21} = \left[k\frac{q_1 q_2}{r^2}\right]\hat{r}_{21}$



$\vec{F}_{12} = k\frac{q_1 q_2}{r^2}(\hat{r}_{12})$ $\qquad$ $\vec{F}_{21} = k\frac{q_1 q_2}{r^2}(\hat{r}_{21})$

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

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

$\vec{F}_{21} = -\left[k\frac{q_1 q_2}{r^2}\hat{r}_{12}\right]$

$\boxed{\vec{F}_{21} = -\vec{F}_{12}}$ equal in magnitude, opp in direction.

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

$\frac{|\vec{F}_{12}|}{|\vec{F}_{21}|} = 1:1$

→ No matter how bigger / smaller the charge is the ratio of both these forces will always be equal to 1 : 1.

(13) Effect of dielectric on F_e / (effect of medium) } F_e dec. by $\frac{1}{\varepsilon_r}$ times in the presence of dielectric

insulating medium

in the absence of dielectric → $F = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}$ $\qquad$ $\underbrace{\varepsilon_r = 1}_{\text{free space}}$

ε_r = relative permittivity of dielectric.

in the presence of dielectric → $\boxed{F_{med.} = \frac{1}{4\pi\varepsilon_0\varepsilon_r}\frac{q_1 q_2}{r^2}}$

ε_r of vacuum = 1

of air = 1·0006

of metal = ∞

$\boxed{F_{med} = \frac{1}{\varepsilon_r}\left(\frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}\right) = \frac{1}{\varepsilon_r}F}$

(that's why electric field in metals doesn't develop inside but on the surface.)

$\boxed{\varepsilon_r = \frac{F_{vac}}{F_{med}}}$ $\boxed{\geq 1}$

$$F_{med} = \frac{1}{\varepsilon_r}\left(\frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}\right) = \frac{1}{\varepsilon_r} F$$

Hence ε_r, can be defined as ; ratio of force in the absence of medium to force in the presence of medium.

$$F_{med} = \frac{1}{\varepsilon_r} F$$

ε_r = Relative perm of dielectric

$\boxed{\varepsilon_r \geq 1}$

$\varepsilon_r = 1 \rightarrow$ free space

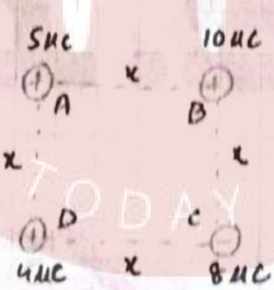
$\varepsilon_r = 1.0006 \rightarrow$ air

$\varepsilon_r = \frac{F}{F_{med}}$

Note : Metal $\Rightarrow \varepsilon_r = \infty$ $\quad F_{metal} = \left(\frac{1}{\infty}\right) F = 0$

(9) Nature of F_e
- basic force of nature
- obeys 3rd law of motion
- central force ⊕——⊖
- conservative force
- medium dependent (shielding)
- long range → inverse square law

(15) Q) ✓



$F_e \rightarrow$ attraction → max. / min.

$F_e \rightarrow$ repulsion → max. / min.

Q) ✓ proton $\xleftrightarrow{r}$ proton $\qquad$ electron $\xleftrightarrow{r}$ electron

$\frac{F_e}{F_g} = ?$ $\qquad$ $m_e = 9.1 \times 10^{-31}$ kg, $m_p = 1.67 \times 10^{-27}$ kg, $q = 1.6 \times 10^{-19}$ C $\qquad \frac{F_e}{F_g} = ?$

$F_e = \frac{K q_1 q_2}{r^2}$

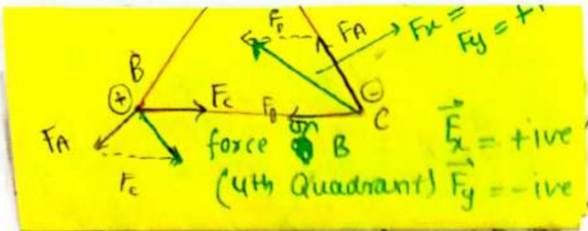
$F_g = \frac{G m m}{r^2}$

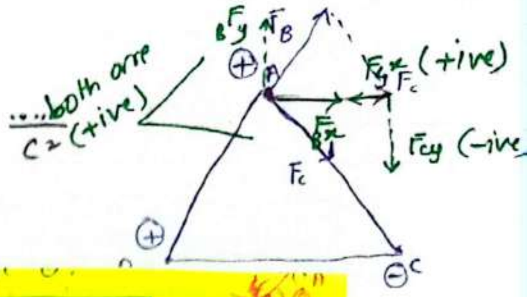
$G = 6.67 \times 10^{-11} \frac{Nm^2}{kg^2}$

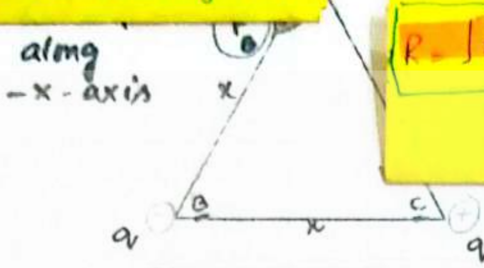
$K = 9 \times 10^9 \frac{Nm^2}{C^2}$

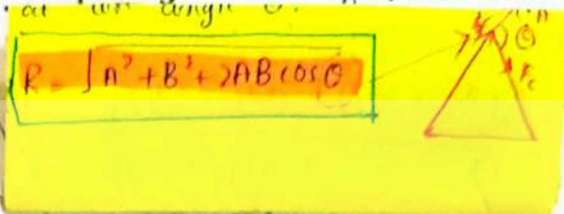
F_e

MCQ # 02

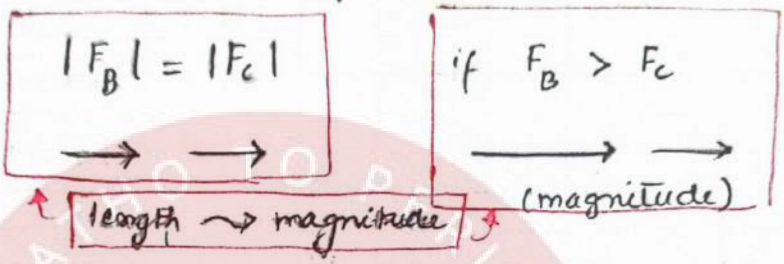


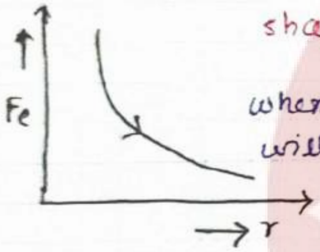






force on;



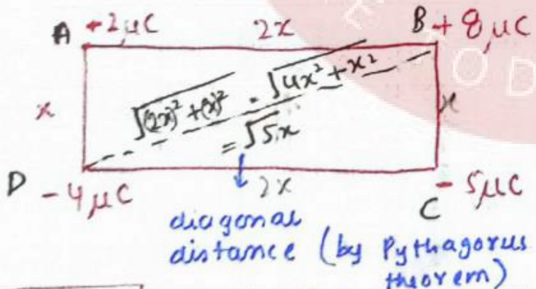


shape of graph = curved (Reason: inverse square law)

whenever any physical Q is plotted against 'd' the graph will be an exponential curve (inverse square law)

→ SI base Unit of Coloumb's const. $k = \frac{Nm^2}{C^2} = \frac{kg\,ms^{-2}\,m^2}{A^2 s^{+2}} = \boxed{kg\,m^3 s^{-4} A^{-2}}$

→ SI base Unit of $\varepsilon_0 = \boxed{kg^{-1}\, m^{-3} s^4 A^2}$



i) Fe of attraction is min. b/w wcf two charges?

ii) Fe of repulsion is min. b/w wcf two charges?

AB → $\boxed{\text{repulsive}}$ → $F = k\frac{q_1 q_2}{r^2} = k\frac{(2)(8)}{(2x)^2} = k\frac{16}{4x^2} \pm \left(\frac{k}{4x^2}\right) = 4\frac{k}{x^2}$ (min)

BC → $\boxed{\text{attractive}}$ → $F = k\frac{(8)(-5)}{(x)^2} = -\left(k\frac{40}{x^2}\right) = -40\frac{k}{x^2}$ (max) (Fe max (overall))

CD → $\boxed{\text{repulsive}}$ → $F = k\frac{(-5)(-4)}{(2x)^2} = +k\frac{20^5}{4x^2} = +k\frac{5}{x^2}$ (max)

DA → attractive → $F = k\frac{(-4)(2)}{x^2} = -8\frac{k}{x^2}$

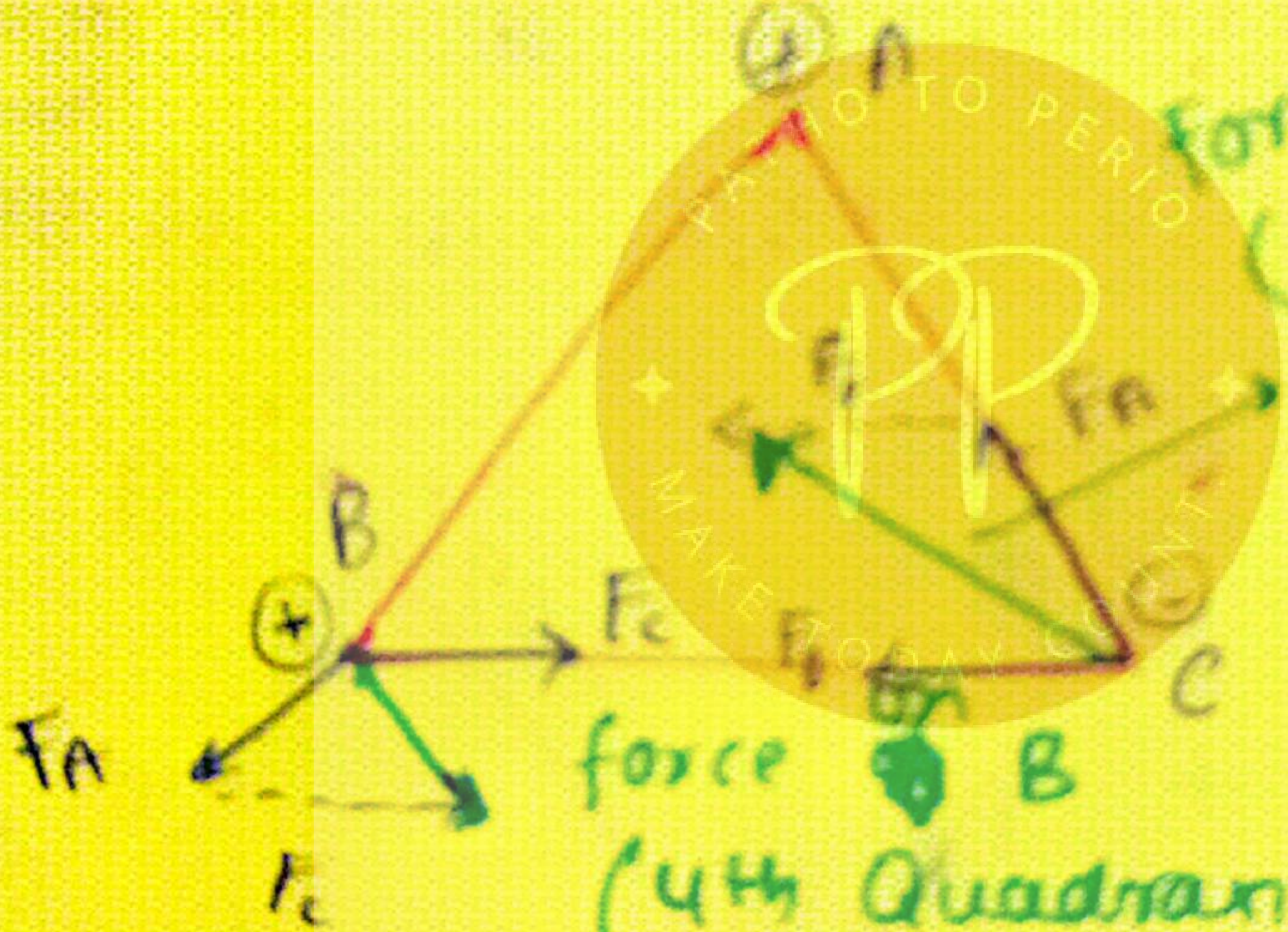
repulsive (vector) → outwards
attractive (vector) → inwards

MCQ

01

charges are placed at the corners of an equilateral triangle. What is direction of resultant force acting on point A?

Direction of resultant force acting on B and C.



force on C
(2nd Quadrant)
$F_x = -ive$
$F_y = +ive$

force on B
(4th Quadrant) $\vec{F_x} = +ive$
$\vec{F_y} = -ive$

MCQ 02 if $q_A = 2\mu C$, $q_B = 4\mu C$ and $q_C = 5\mu C$ and $x = 10cm$. Then what is the magnitude of F_R on charge q_A?

$$F = \sqrt{F_x^2 + F_y^2}$$

$$F = \sqrt{(F_{Bx} + \cancel{F_{By}})^2 + (F_{By} + F_{cy})^2}$$

$= \_\_\_\_\_\_ N$ (magnitude)

- $F_{Bx} = k \frac{q_A q_B}{r^2} \cos\theta$
- $F_{By} = k \frac{q_A q_B}{r^2} \sin\theta$

$\phi = \tan^{-1}\left(\frac{F_y}{F_x}\right)$ (Direction)

$$\phi = \tan^{-1}\left(\frac{F_y}{F_x}\right) = \tan^{-1}\left(\frac{F_{cy} + F_{By}}{F_{cx} + F_{Bx}}\right)$$

method # 02

Resultant b/w two vectors $\vec{A}$ & $\vec{B}$ at an angle θ.

$$\boxed{R = \sqrt{A^2 + B^2 + 2AB\cos\theta}}$$

$AC \rightarrow \boxed{\text{attractive}} \rightarrow F = \frac{k(+2)(-5)}{(\sqrt{5}x)^2}$

$= -\frac{10k}{\cancel{5}x^2} = -\frac{2k}{x^2}$ (min) (F_e min) (overall)

$BD \Rightarrow$ attractive $\rightarrow F = \frac{k(8 \times -4)}{(\sqrt{5}x)^2}$

$= \frac{-32k}{5x^2} = -6.4\frac{k}{x^2}$

In Coulomb's Law;

-ive sign (attraction)

+ive sign (repulsion)

force b/w charges is

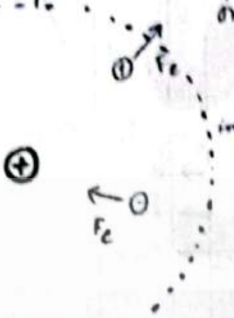
attractive / repulsive } will be a mutual force

repulsive (vector) → outwards

attractive (vector) → inwards

Electric field

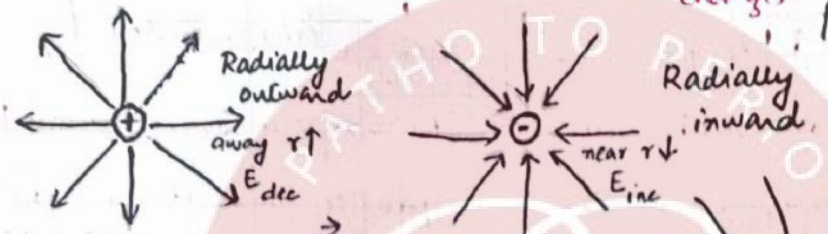
① " region around a charge in which it can produce electrostatic effect, (F_e of attraction or repulsion) " on any other charge.
(space)

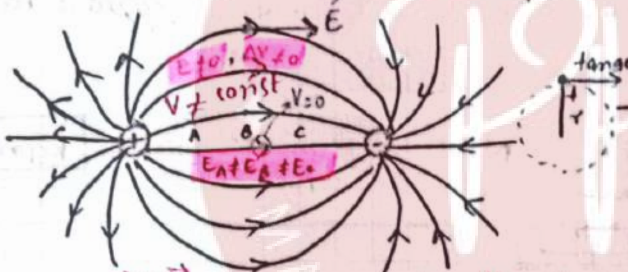


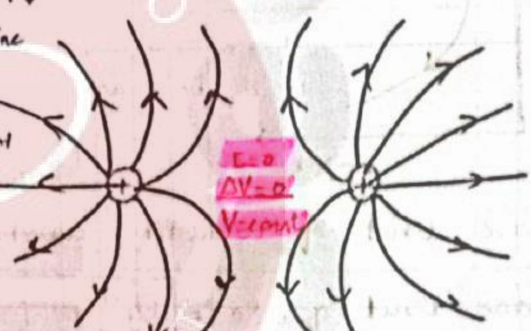
② Dependence → magnitude of charge q
→ distance from charge r
→ medium around the charge ε

③ Representation of electric field } Electric field lines → imaginary lines (magnitude ≠ 0)
→ path followed by unit +ive charge in an electric field
(test charge) doesn't influence the $\vec{E}$ of source charge

$\boxed{\Delta V = Ed}$

④


⑤


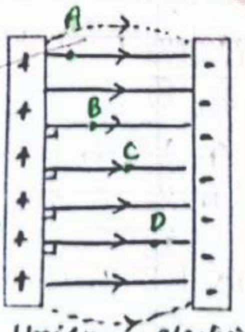


$\rightarrow \vec{E}$ dec↓ ← → b/w the lines do not join each other

Non-uniform electric field (fringing)

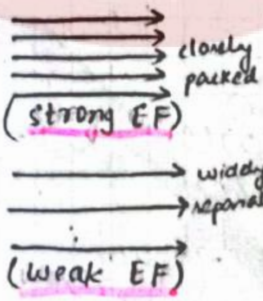
Note: diff. = 0 ⇒ const

⑥
(at the ends) $E \neq 0$
$\Delta V \neq 0$
$V \neq 0$



$E_A = E_B = E_C = E_D$

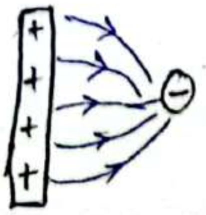
Uniform electric field → parallel field lines



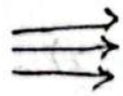
⑧ Characteristics of electric field lines

- Generally not closed curves / loops
- tangent to electric field lines at any point → direction of electric field intensity
- never intersect each other

- "curved path"

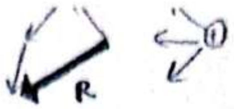
⑦


(non-uniform $\vec{E}$ field)

-  (parallel) → uniform $\vec{E}$

 (non-parallel) → non-uniform $\vec{E}$ fringing field

field → parallel field lines



① Unique path"

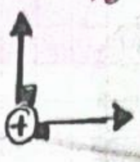
①

+ ——→ −

V_{high} V_{low}

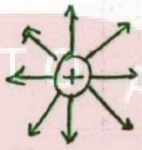
follow the electric field lines } V_{dec}

● Number of lines per unit cross-sectional area is prop. to electric field
$\phi_e = EA\cos\theta \rightarrow \phi_e \propto E$



● Electric field lines are always normal to the surface

- Conductor (Metal) $\varepsilon_r = \infty$ } no electric field inside
- Insulator (dielectric) $\varepsilon_r \geq 1$ } electric field will pass



- line drawn on surface of charge (electric field lines)
- tangent drawn at any point on electric field lines represent the direction of $\vec{E}$.

Electric field intensity / Electric field strength / Electric flux density

strength of $\vec{E}$. E

Unit :- NC^{-1} and Vm^{-1} (SI unit)

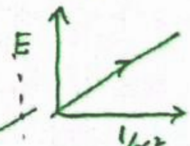
SI - Base Unit :- $\frac{N}{C} = \frac{kgms^{-2}}{As^{-1}} = kgms^{-3}A^{-1}$

① "Electrostatic force per unit charge in an electric field"

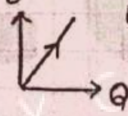
F_e, q, small charge (test charge), Q

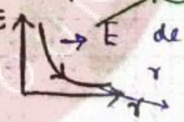
② $\boxed{E = \frac{F_e}{q} \left(\frac{N}{C}\right)}$; $\boxed{F_e = \frac{kQq}{r^2}}$

q, F_e, Q, E



③ $E = \lim_{q \to 0} \frac{F_e}{q}$





→ E dec by power 2 when r inc. at ∞, this line touches the x-axis and E = 0.

④ $\boxed{E = k\frac{Q}{r^2} = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2}}$

- $E \propto Q$
- $E \propto \frac{1}{r^2}$ (inverse square law)
- $E \propto \frac{1}{\varepsilon \text{ (medium)}}$

in the presence of dielectric $\boxed{E = \frac{1}{4\pi\varepsilon_0\varepsilon_r}\frac{Q}{r^2}}$ $\boxed{E_{med} = \frac{E_{vac}}{\varepsilon_r}}$

$\boxed{E_{med} < E_{vac}}$

Direction of $\vec{F_e}$ = Direction of $\vec{E}$

vector form : $\vec{E} = \frac{kQ}{r^2}\hat{r} = \frac{kQ}{r^2}\frac{\vec{r}}{r}$ ∵ $\hat{r} = \frac{\vec{r}}{r}$

⑤ Direction of Electric field Intensity :- along the direction of electric field lines.

OR

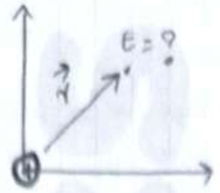
electric field intensity is in the direction of coulomb force.

$\boxed{\vec{E} = \left(\frac{kQ}{r^3}\right)\vec{r}}$

unit vector :- a vector divided by its magnitude

⑥ Q) Imp' for MCQ

$E = \left(\frac{Kq}{r^3}\right) r$



$Q = +4\,\mu C \longrightarrow$ origin

$\vec{r} = 3\hat{i} + 4\hat{j}$ cm $\Longrightarrow$ position vector

$E = ?$ → vector form

$r = \sqrt{(3)^2 + (4)^2}$

$r = 5$ cm $= 5 \times 10^{-2}$

when the ans is required in vector form.

Note

$$\boxed{\vec{E} = \left(\frac{Kq}{r^3}\right)\vec{r}} = \left(\frac{9\times10^9 \times 4\times10^{-6}}{(5\times10^{-2})^3}\right)(3\hat{i}+4\hat{j})$$

$(10^x)^y = 10^{xy}$

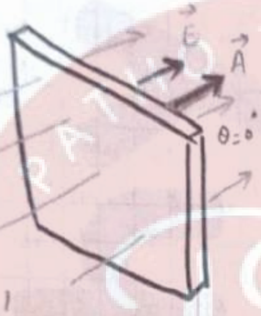
$(10^{-2})^3 = 10^{-6}$

$$= \frac{36\times10^3}{125\times10^{-6}}(3\hat{i}+4\hat{j}) = (288\times10^6)(3\hat{i}+4\hat{j})$$

$$= (864\hat{i} + 1152\hat{j})\,10^6 \text{ NC}$$

⑦ Electric flux:-

the number of lines passing through a surface is called electric flux.



$\boxed{\phi_e = \vec{E}.\vec{A}}$

$\boxed{\phi_e = EA\cos\theta}$

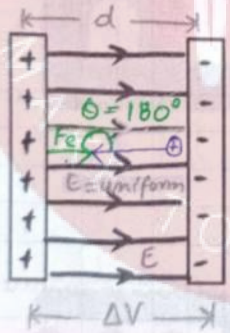
$\boxed{\phi_e = EA}$ when $\theta = 0°$ b/w $\vec{E}$ and $\vec{A}$

$\boxed{E = \frac{\phi_e}{A}}$ Electric flux density

$\cos 0° = 1$

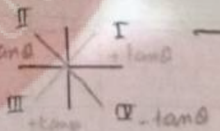
$\sin 0° = 0$

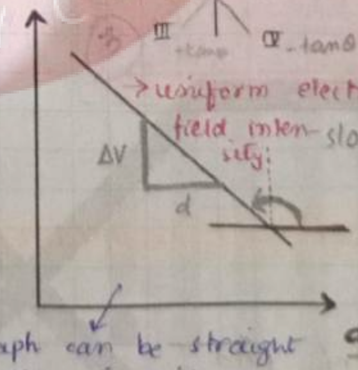
Electric field intensity as negative potential gradient



② $E = -\frac{\Delta V}{d}$

physical quantity / distance (linear dimension)





→ uniform electric field intensity.

slope = tanθ = perpendicular / base

$= \ominus\frac{\Delta V}{d} = -(E)$

= uniform

$\Delta V = 50$ V $\quad d = 25$ cm

$E = ?$ $\quad E = -\frac{\Delta V}{d} = -\frac{50}{25\times10^{-2}}$

$E = \ominus 2\times10^2$ NC^{-1}

inverse graph can be straight line when slope is uniform

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

↓

electric field intensity when potential gradient (ΔV) is given. (difference)

V ↑

formed in case of oppositely charged plates.

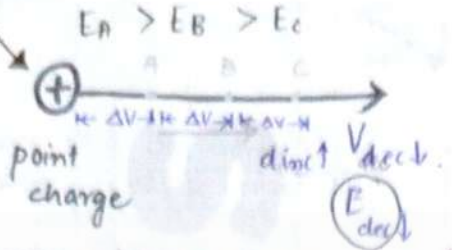
-ive sign shows work done against electrostatic force.

~~formed in case of oppositely charged~~

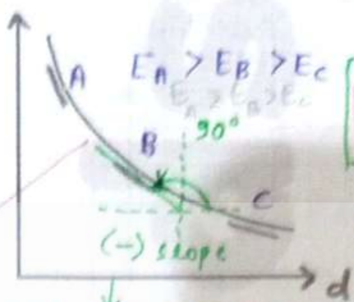
applied when the distance b/w two points isn't but the electric field intensity is uniform

→ uniform E = straight line (in case of opp. charged plates)
↓
(b/c b/w the opp. charged plates 'E' is uniform)

→ non-uniform E = curved line. (in case of moving away from a point charge)



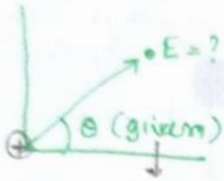
non-uniform electric field intensity.



$$\boxed{V = \frac{kQ}{r}}$$ point charge

slope = ⊖E = non-unif.

graph used when E = non-uniform



θ given instead of vector (r)

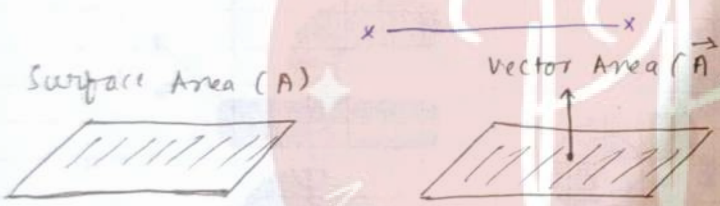
then $\vec{E} = E_x\hat{i} + E_y\hat{j} = E\cos\theta\,\hat{i} + E\sin\theta\,\hat{j}$

$\vec{E} = E(\cos\theta\,\hat{i} + \sin\theta\,\hat{j}) = \frac{kq}{r}(\cos\theta\,\hat{i} + \sin\theta\,\hat{j})$

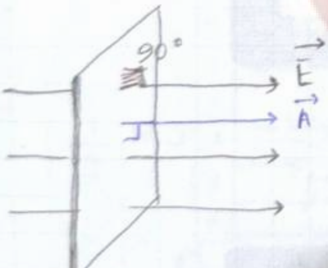
formula for finding θ of electric field intensity:

$\theta = \tan^{-1}\left(\frac{E_y}{E_x}\right)$ (direction)

(extra :- $\cos^2\theta + \sin^2\theta = 1$)

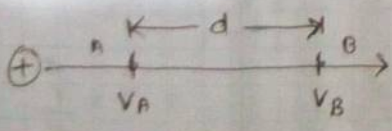


the angle b/w surface area and vector area is 90°.



θ b/w $\vec{E}$ and surface area = 90°

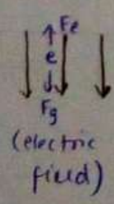
θ b/w $\vec{E}$ and vector area = 0°



In the given situation the formula used is;

$$\boxed{E = \frac{\Delta V}{d} = \frac{V_A - V_B}{d}}$$

→ Electric field intensity of suspended charged particle in an electric field:-



$|F_e| = |F_g|$

$Eq = mg$

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

→ a proton can't be suspended bcz the Fe as well as Fg will be acting downward. (talking about the given field).

↳ electric field required for a ~~proton~~ electron/proton to suspend)

Electric field required for a proton to suspend :- $g = 9.8 m/s^2$

electron

$$E = \frac{mg}{q} = \frac{9.1 \times 10^{-31} \times 10^{1}}{1.6 \times 10^{-19} C}$$

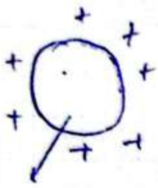
$$\boxed{E = 6 \times 10^{-11} NC^{-1}}$$

→ For the suspension of proton the direction of electric field is to reversed :

$$E = \frac{mg}{q} = \frac{1.67 \times 10^{-27} \times 10^{1}}{1.6 \times 10^{-19} C}$$

$$\boxed{E = 10^{-7} NC^{-1}}$$

Gauss's Law :-

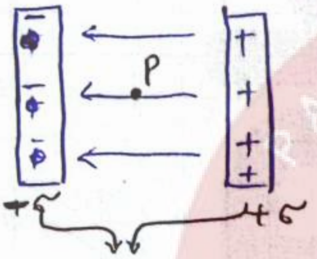


→ electric field intensity due to a hollow charged sphere.

→ if ~~inside~~ outside / at the surface the potential is 10V then inside at every point the potential will be 10V.

→ moving away from the surface E↓ so V also decr↓.

→ Electric field intensity at any point on an infinite large sheet.



→ two opp. charged plates

- both are uniformly charged.

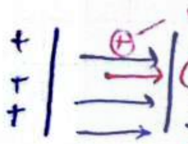
Electric field intensity at point 'P' wrt to both the plates is given as ;

$$E = \frac{\sigma}{2\varepsilon_0}$$

$\vec{E}$ is independent of the size of the plate.

- $E \propto \sigma$ and $E \propto \frac{1}{\varepsilon_r}$ (medium/dielectric decr E)

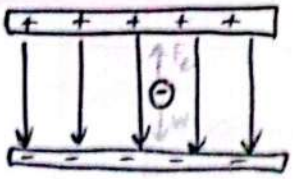
③ Electric field intensity b/w the oppositely charged parallel plates :-



(F of attraction + repulsion)

↓

(both forces same direction, $\vec{E}$ is const.)



"Suspended charge particle in an electric field

$|F_e| = |W|$

$Eq = mg \longrightarrow \boxed{E = \frac{mg}{q}}$

if electron is suspended } $E = ?$

$$E = \frac{mg}{q} = \frac{9.1 \times 10^{-31} \times 10^{1}}{1.6 \times 10^{-19}}$$

$$= 6 \times 10^{-30+19}$$

$$= 6 \times 10^{-11}\ NC^{-1}$$

Practice exercise → proton q

→ α-particle, $q = 2e$, $m = 4m$

Applications of Gauss's Law → tells us about electric field intensity.

Gauss's law ⟶ irregular/regular closed body $\phi_e = ?$

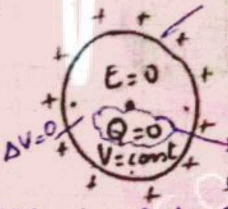
$$\boxed{\phi_e = \frac{1}{\varepsilon_o} Q} \qquad \boxed{\phi_{med} = \frac{1}{\varepsilon_o \varepsilon_r} Q}$$

$Q = q_1 + q_2 + \dots q_5$

"indep. of size, shape & geometry"

① Electric field intensity inside a (hollow charge sphere) is equal to zero.

can be any closed body



outside $E \neq 0$

but inside $E = 0$.

$$\boxed{\phi_e = \frac{1}{\varepsilon_o} Q} \Rightarrow \boxed{\phi_e = 0}$$

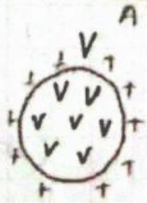
$\rightarrow Q = 0$

so $\phi_e = 0$. $\quad \phi_e = EA \Rightarrow E = \frac{\phi_e}{A}$

$E = 0$

$E = \frac{\Delta V}{d} \rightarrow$ if $E = 0 \Rightarrow \Delta V = 0 \Rightarrow V = const$

diff. = 0



② Electric field intensity at any point on a infinite large charge sheet (uniformly charge)

$$\boxed{E = \frac{\sigma}{2\varepsilon_o}} \qquad \boxed{E_{die} = \frac{\sigma}{2\varepsilon_o \varepsilon_r}}$$

$$\boxed{k = \frac{1}{4\pi\varepsilon_o} \longrightarrow \varepsilon_o = \frac{1}{4\pi k}}$$

surface charge density = uniform

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

Unit : C/m^2

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

sigma

$E = \frac{\sigma}{2\varepsilon_0}$

$4\pi\varepsilon_0$

• $\boxed{E = 2\pi k \sigma}$

F = 0, E = 0

(2) Electric field intensity between two opposite charge plates

(capacitor plate concept)

$\vec{E}$ is independent of size of the plates.

• $E = E_+ + E_-$

$E = \frac{\sigma}{2\varepsilon_0} + \frac{\sigma}{2\varepsilon_0}$

• $\boxed{E = \frac{\sigma}{\varepsilon_0}}$; ε_0 =

• $\boxed{E = 4\pi k \sigma}$

→ b/w the two opp. charged plates, the electric field is uniform.

$E_{\text{opp. charge plates}} = 2\, E_{\text{single plate}} = 2\left(\frac{\sigma}{2\varepsilon_0}\right) = \frac{\sigma}{\varepsilon_0}$

10N ← ▨ → 10N $F_{net} =$

Zero field location / Neutral Zone E = 0

(net force) = 0 ... value of E = 0 ... region is neutral zone ... field loca-

if E = 0 → $E_{net} = 0$ (electric field intensity)

$E_1 + (-E_2) = 0$ ➡ $|E_1| = |E_2|$

b/w similar charges

E = 0 b/w the charges & closer to smaller charge

b/w opposite charges

E = ... on ext. side & closer to smaller ...

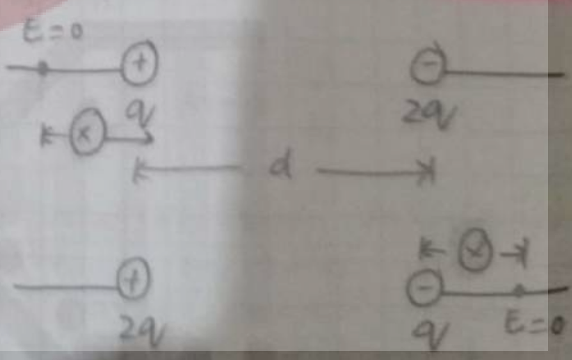
(d − x)

+q ← x → E = 0 ← d → +2q

−q ← x → E = 0 −2q

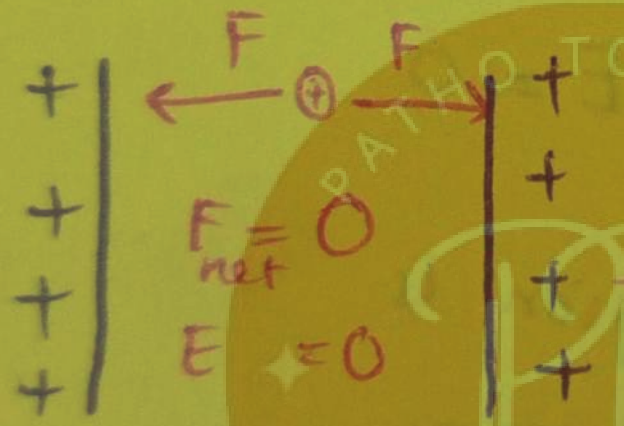
E = 0, x, +q, d, −2q

+2q, −q, x, E = 0



q_1 x = ? q_2 ← d →

MCQ what is the electric field intensity b/w the two same charged plates.



a unit +ive charge placed b/w the plates. both will repel it with equal but opp. force

→ So $F_{net} = 0$ and E b/w the plates is also zero

جہاں پر Fe-net

(net electrostatic force)

کی zero-value ہوگی وہاں

E = 0 ہوگی۔

↓

and that region is called neutral zone or zero field location.

(b/w similar charges)

$$\boxed{x = \frac{d}{\sqrt{\frac{q_B}{q_S}} + 1}}$$

(b/w the opposite charges)

$$\boxed{x = \frac{d}{\sqrt{\frac{q_B}{q_S}} - 1}}$$

Q) $+2\,\mu C$ (q_s) & $+6\,\mu C$ (q_B)

$d = 3$ cm

find zero field location

$x = ?$

$$x = \frac{3}{\sqrt{\frac{\cancel{6}^{3} \times \cancel{10^{-6}}}{\cancel{2} \times \cancel{10^{-6}}}} + 1}$$

$\because \sqrt{2} = 1.4$

$\sqrt{3} = 1.7$

$\sqrt{5} = 2.2$

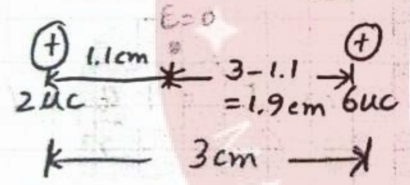
$\sqrt{10} = 3.2 = \pi$

$$x = \frac{3}{\sqrt{3} + 1}$$

$$= \frac{3}{1.7 + 1} = \frac{3}{2.7} = \frac{1\cancel{3}}{\cancel{27}_{9} \times 10^{-1}}$$

$$= 0.11 \times 10^{1} = 1.1\ \text{cm}$$

$9\overline{)10}$ → $.11$, $\frac{9}{10}$



Q) $+1\,\mu C$ & $-4\,\mu C$

$d = 5$ cm

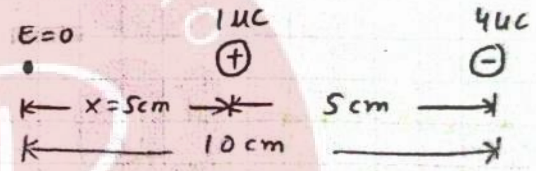
find zero field location

$x = ?$

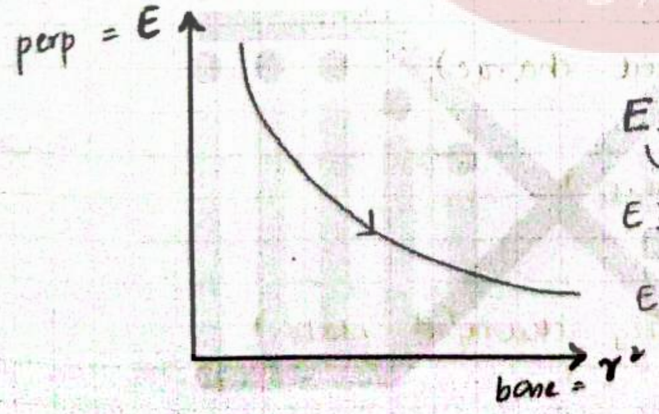
$$x = \frac{5}{\sqrt{\frac{4 \times \cancel{10^{-6}}}{1 \times \cancel{10^{-6}}}} - 1}$$

$$= \frac{5}{2 - 1} = \frac{5}{1}$$

$x = 5$ cm



Graphical Representation

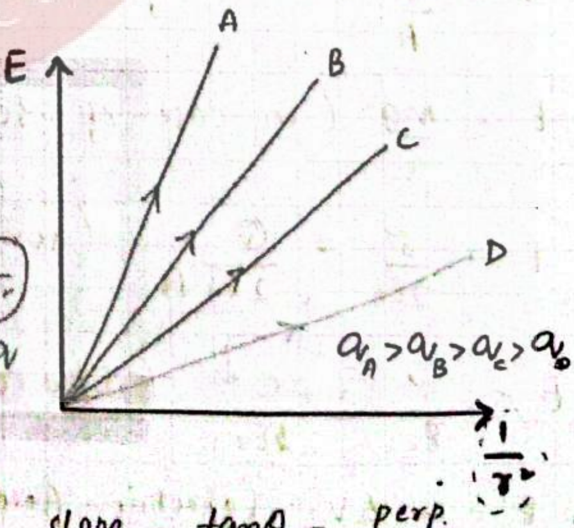


$E = \frac{kq}{r^2}$

$E = kq\left(\frac{1}{r^2}\right)$

$Er^2 = kq$

slope = $\tan\theta$ = $\frac{\text{perp}}{\ }$

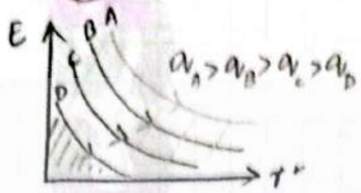


$q_A > q_B > q_C > q_D$

slope = $\tan\theta$ = $\frac{\text{perp.}}{\ }$

slope $= \tan\theta = \dfrac{\text{perp}}{\text{base}}$

$= \dfrac{E}{r^2} \longrightarrow$ no info.



Area $=$ perp $\times$ base

$= E \times r^2$

Area $= kq$

Area $\propto q$

slope $= \tan\theta = \dfrac{\text{perp}}{\text{base}}$

$= \dfrac{E}{1/r^2} = Er^2$

$= kq$

slope $\propto q$

Area $=$ perp $\times$ base

$= E \times \dfrac{1}{r^2}$

$= \dfrac{E}{r^2} \longrightarrow$ no

Units:
- SI unit $\rightarrow NC^{-1} = Vm^{-1}$
- SI base unit $\rightarrow kg\, m\, s^{-3} A^{-1}$

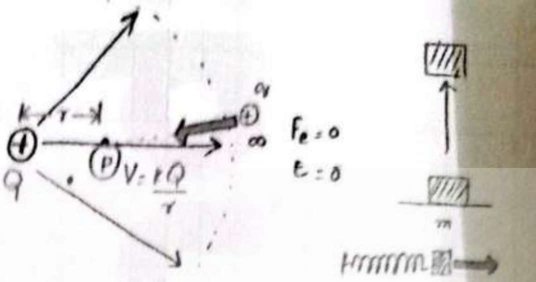
Summary of the Formulas :-

- $E = \dfrac{F}{q_0}$ (electric field)
- $E = k\dfrac{q}{r^2}$ or $\vec{E} = k\dfrac{q}{r^2}\hat{r}$ (vector form)
- $E = \dfrac{\phi}{A}$ (Electric field intensity in terms of flux).
- $E = \dfrac{mg}{q}$ (in case of suspended charge)
- $E = \dfrac{\sigma}{2\varepsilon_0} = \dfrac{Q}{2\varepsilon_0 A}$ (single plate)
- $E = \dfrac{\sigma}{\varepsilon_0}$ $\left(\sigma = \dfrac{Q}{A}\right)$ $\dfrac{Q}{A\varepsilon_0}$ (b/w oppositely charged plates)
- $E = -\dfrac{\Delta V}{d}$ (electric field intensity as negative potential gradient).

→ Electric field is a conservative field so the work done in an electric field is independent of the path followed. (and work done in a closed path is zero).

① Electric Potential V

" electrostatic potential energy work done (energy stored) per unit charge in moving it from infinity to point P, against the electric field"



- keeping electrostatic equilibrium
- without acceleration ($a=0$)

$F \Leftarrow\!\!\!\!=\!\!\!\!\Rightarrow F_e$ $\quad \because F = F_e,\ F_{net}=0,\ a=0$

$\boxed{V = \frac{W}{q} = \frac{F_e d}{q}}$ } point charge → $\boxed{V = \frac{kQ}{r} = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r}}$ potential due to a point charge

$\boxed{V = \frac{U}{q}}$ $\quad \because U =$ Electrostatic potential energy

Absolute electric potential

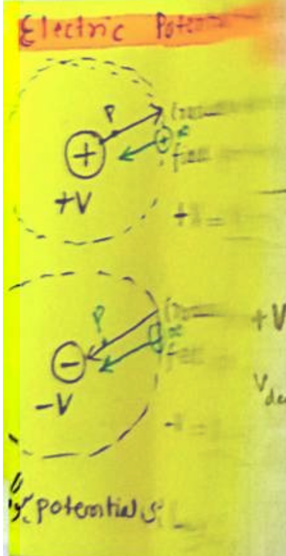
SI unit → volt $V = JC^{-1} = NmC^{-1}$

SI base unit → $kg\, m\, s^{-2}\, m\, A^{-1} s^{-1} = kg\, m^2 s^{-3} A^{-1}$

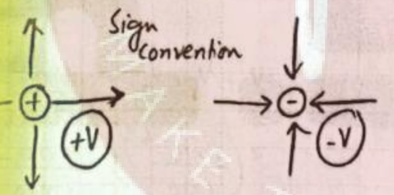
Note:
$P = VI$
$V = \frac{P}{I}$
$V = \frac{kg\,m^2 s^{-3}}{A}$
$P = I^2 R$
$R = \frac{P}{I^2}$

Electric Potential

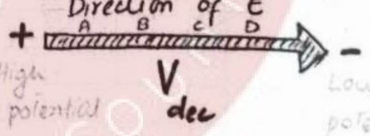
- Scalar Quantity



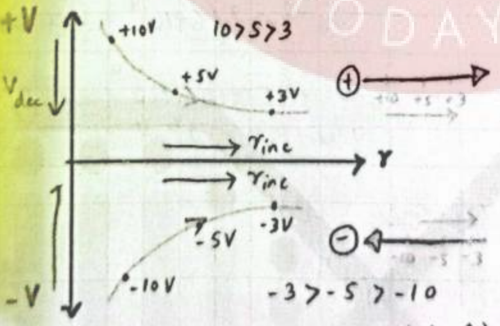
Sign convention



along the → Direction of $\vec{E}$



$V_A > V_B > V_C > V_D$

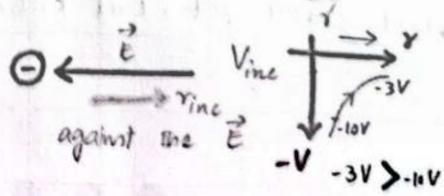


$10 > 5 > 3$

$-3 > -5 > -10$

(moving away from -ive charge → V inc↑)

$\downarrow V = \frac{kQ}{r\uparrow}$ $\quad +V = \frac{kQ}{r}$ $\quad -V = \frac{kQ}{r}$



against the $\vec{E}$

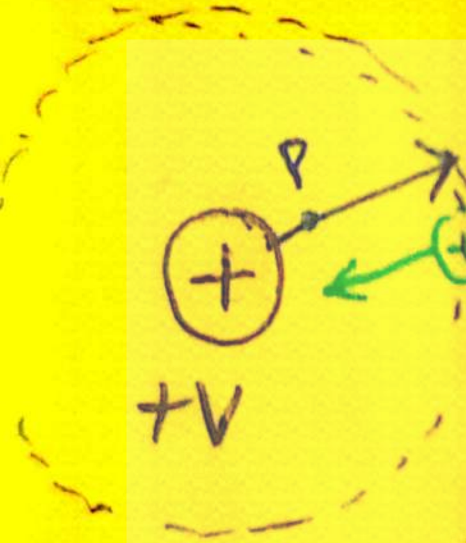
$-3V > -10V$

Note: $+V$ ⊕ $\quad -V$ ⊖ unlike (opp) charges

$V_{net} = 0$ (possible) • $V_{net} = V_+ + (-V) = V - V = 0$

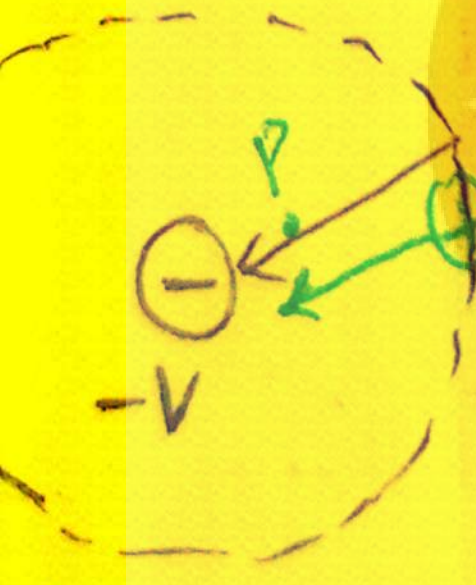
Electric potential b/w the opposite charges will be zero.

Electric Potential → Scalar Quantity



(radially outward Electric field for +ive charge)

$$+V = k\frac{(+q)}{r}$$



(radially inward electric field for -ive charge)

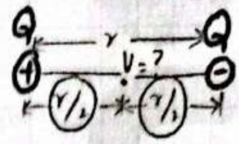
$$-V = k\frac{(-q)}{r}$$

جیسا charge ہو گا، ویسا ہی potential ہو گا

$V_{net} = 0$ (possible) • $V_{net} = V_+ + (-V) = V - V = 0$

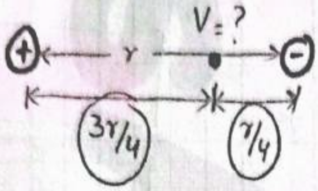
like (similar) charges • $V_{net} = V_+ + V_+ = V + V$

$V_{net} \neq 0$ $= -V + (-V) = -V - V$



"Electric potential at mid point between two equal & opposite charges is equal to zero."

$$V = V_+ + V_- = \frac{kQ}{r/2} + \left(-\frac{kQ}{r/2}\right) = 0$$



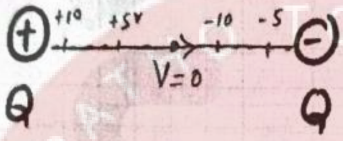
$$V = V_+ + V_- = \frac{kQ}{3r/4} + \left(-\frac{kQ}{r/4}\right)$$

$$= \left(\frac{4kQ}{3r}\right) - \left(\frac{4kQ}{r}\right)$$

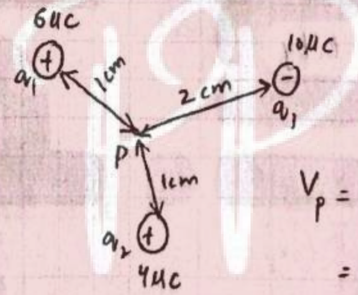
$$= 4kQ\left(\frac{1}{3r} - \frac{1}{r}\right)$$

$$= 4kQ\left(\frac{1-3}{3r}\right) = 4kQ($$

$$= -\frac{8kQ}{3r}$$



Q)



$V_p = ?$

$$V_p = V_1 + V_2 + V_3 = \frac{kq_1}{r_1} + \frac{kq_2}{r_2} - \frac{kq_3}{r_3}$$

$$= k\left(\frac{6\times10^{-6}}{1\times10^{-2}}\right) + \frac{4\times10^{-6}}{1\times10^{-2}} - \frac{\cancel{10}^{5}\times10^{-6}}{\cancel{2}\times10^{-2}}$$

$$= 9\times10^9\left(6\times10^{-4} + 4\times10^{-4} - 5\times10^{-4}\right)$$

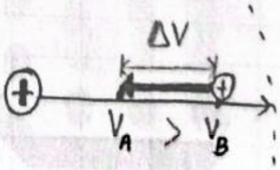
$$= +45\times10^9\times10^{-4} = +45\times10^5$$

$$= +4.5\times10^6 \text{ V}$$

Electric Potential Difference ΔV

electrostatic potential Energy

" work done (energy stored) per unit charge in moving it b/w any two points in an electric field"



- against electric field
- electrostatic equilibrium.

keeping electrostatic equilibrium means that the charge is moved slowly so that K.E = const. V = const. and a = 0.

A charge will be in electrostatic equilibrium when the external force applied on it is equal to Fe.

$(\Delta V = -Ed)$ in case of oppositely charged plates E = uniform so ΔV (potential difference) is also uniform. and d = same

$V \neq$ uniform

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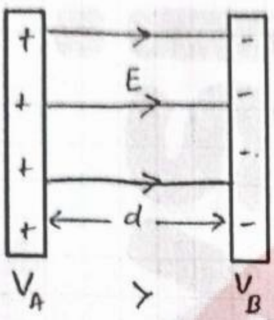
$V_A > V_B$

(keeping)
- against electric field
- electrostatic equilibrium
- without accelerating

} $F_{net} = 0$, $a = 0$

$$\boxed{\Delta V = \frac{W}{q} = \frac{U}{q}} \quad \text{or} \quad \boxed{V_A - V_B = \frac{W}{q} = \frac{U}{q}}$$

Note: Units of electric potential, electric p.d & emf are same. (Volt)



$$\boxed{\Delta V = -Ed} \quad \text{or} \quad \boxed{\Delta V = -\left(\frac{F_e}{q}\right)d}$$

-ive ⟹ -W

⟹ against electric field

$V_A > V_B$

1eV is the energy gained by an $\bar{e}$ while moving b/w two points having PD = 1V.

electron volt (eV) ⟶ smallest unit of electrical energy

used at sub-microscopic level.

K.E → inc or gain
P.E → dec or loss

K.E → dec or loss
P.E → inc or gain

ELECTRON VOLT (eV)

$\bar{e}$ moving against the electric field. $[-W = P.E\ (\text{loss})]$

$\bar{e}$ moving along the electric field $[+W = P.E\ (\text{gain})]$

(this is for negative charge)

1V ⟶ eV $\left\{ U_{gain} \text{ or } U_{loss} \text{ if } \Delta V = 1V \right\}$ $U = 1\ eV$

1 eV = 1.6×10^{-19} J ⟹ 1 J = 6.25×10^{18} eV

...rticle ...electric ... } $U_{gain} = ?$

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

$U = \Delta V q$

$U = (100)(2e) = 200\ eV$

$U = 2 \times 10^2 \times 1.6 \times 10^{-19}$ J

$= 3.2 \times 10^{-17}$ J

Electric Potential Energy

- $\boxed{U = \Delta V q_o}$
- $\boxed{U = V(q_o)}$

} P.E or K.E

$\boxed{U = ...}$

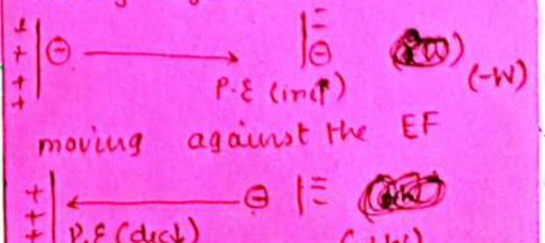
for -ive charge

moving along the EF

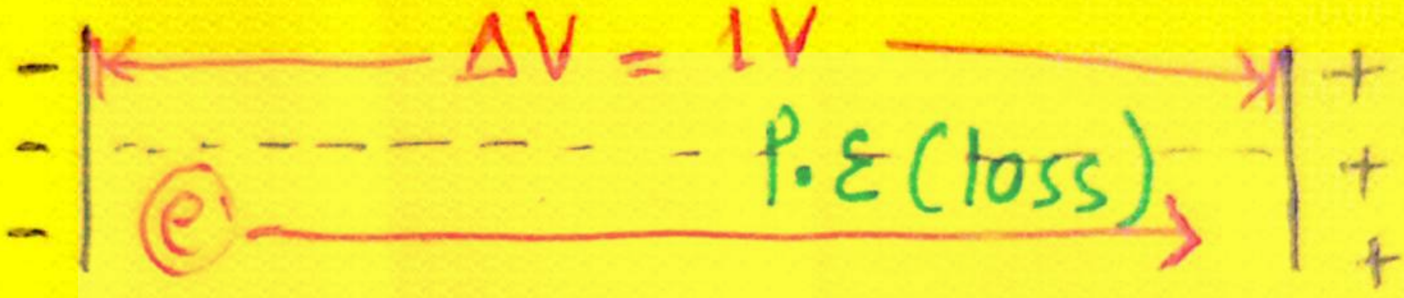
P.E (inc) (-W)

moving against the EF

P.E (dec) (+W)



ELECTRON VOLT (eV)



$\bar{e}$ moving against the electric field. [$-W$ = P.E (loss)]

$\bar{e}$ moving along the electric field [$+W$ = P.E (gain)]

(this is for negative charge)

Electrostatic Potential Energy :-

moving against the electric field.

$$\oplus \xrightarrow[\text{P.E inc}\uparrow]{\text{K.E dec}\downarrow} \qquad \oplus \quad (-W)$$

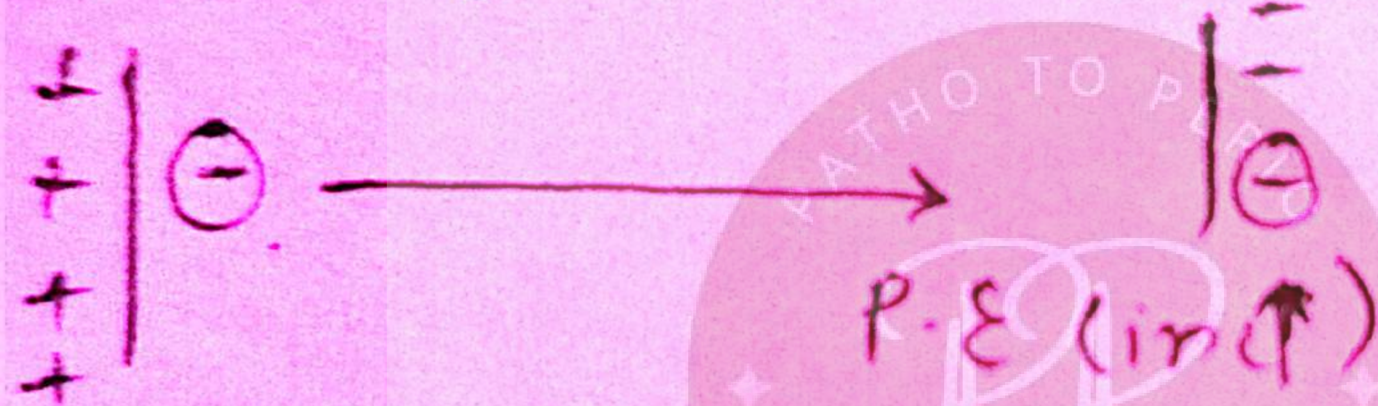
moving along the electric field.

$$\oplus \xrightarrow[\text{P.E dec}\downarrow]{\text{K.E inc}\uparrow} \qquad \ominus \quad (+W)$$

(this is for +ive charge)

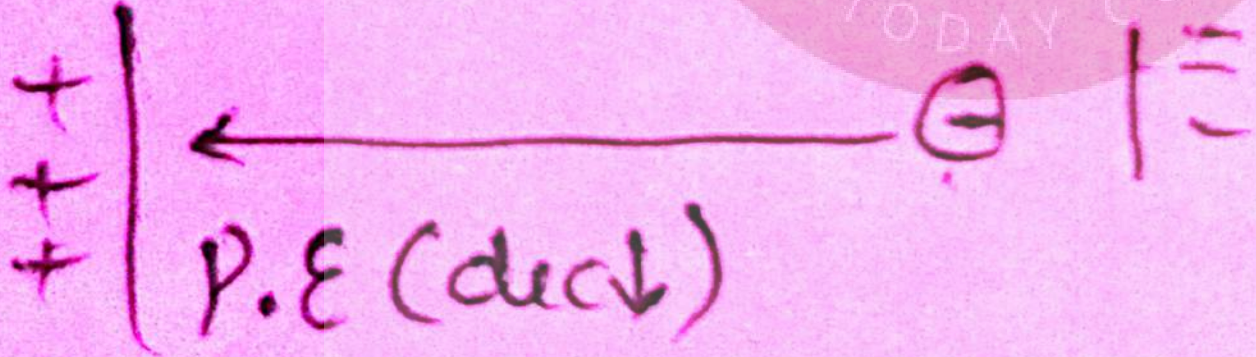
for -ive charge

moving along ~~against~~ the EF



(-W)

moving against the EF



(+W)

$U = \frac{kQq}{r} = \frac{ke \cdot e}{r} = \frac{ke^2}{r}$

- $V = V(q)$ r   Q

Hydrogen atom → in any orbit ⟹ $E_n = P.E.$ ...

$E_n = -\frac{E_0}{n^2} = -\frac{13.6}{n^2}$ if $E_n = -E$

$\boxed{P.E = -2E}$

$\boxed{K.E = +E}$ (−13.6eV)

- $P.E = -\frac{Ke^2}{r_n}$
- $K.E.$ ...
- $E_n = -\frac{Ke^2}{2r}$ ...

P.E in an orbit

$U = \frac{kQ}{r} q$

Q = charge of nucleus

q = e

r = orbit radius

$\boxed{E_0 = 13.6eV}$

if n = 1 (ground state) $E_n = -13.6eV$ $P.E_n = -27.2$ ... $K.E_n = +13.6$ ...

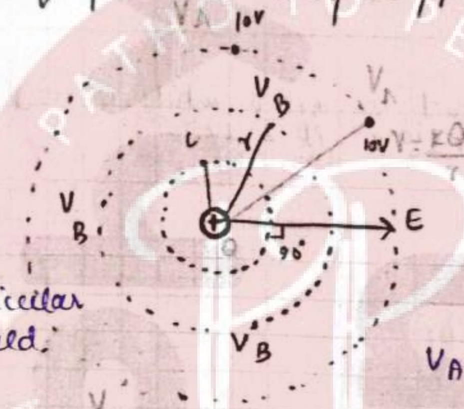
$\boxed{r_1 = 0.53A^\circ}$

if n = 2 (1st excited state) $E_n = -3.4eV$ $P.E_n = -6.8$ ... $K.E_n = +3.4$ ...

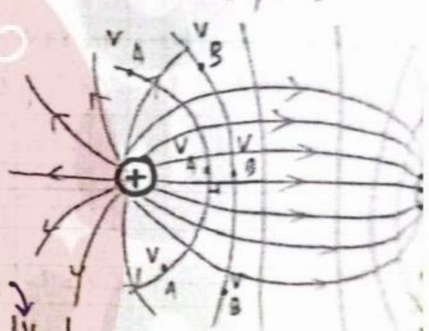
$\boxed{r_2 = n^2 r_1 \rightarrow r_1 = 0.53A^\circ}$

for any nucleus $\}$ $\boxed{Q = Ze}$

Equipotential surface / plane



dipoles



always perpendicular to the electric field.

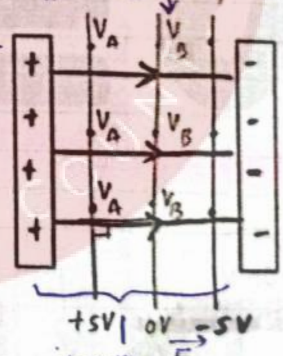
equipotential surfaces also exist b/w oppositely charged parallel plates.

(parallel surfaces)

Equipotential surface V = equal $\Delta V = 0$

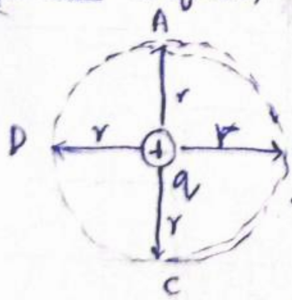
$W = 0$
$U = 0$ $\}$ $E \neq 0$

$V_A > V_B$



uniform $\vec{E}$

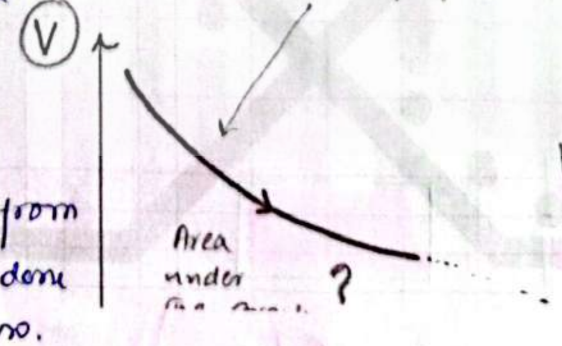
" The ... electric ... are at ... electric ...



← equipotential surface

$\Delta V = 0$ V = const.

Area = perp × base = Vr = KQ



$V = \frac{kQ}{r'}$

if a charge is moved from A to B the work done will be equal to zero.

(bcz both the points are at same potential.

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P.E + K.E

$K.E = \frac{ke^2}{2r_n}$

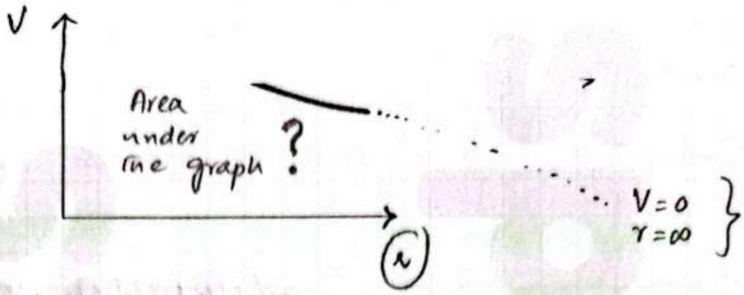
$= -\frac{ke^2}{2r_n}$

27.2 eV

13.6 eV

6.8 eV

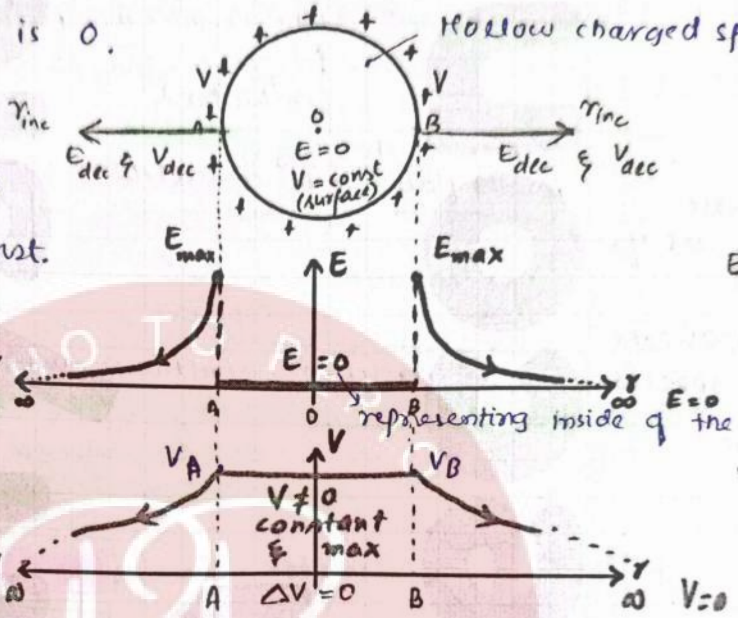
3.4 eV



→ the electric field intensity inside the hollow charged sphere is 0.

→ inside the sphere of r_{inc}

$\vec{E} = 0$ then $\Delta V = 0$ and $V = const.$ and non-zero.



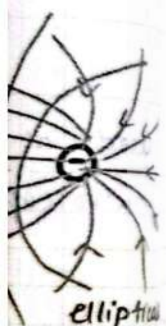
$E = \frac{kQ}{r^2}$

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

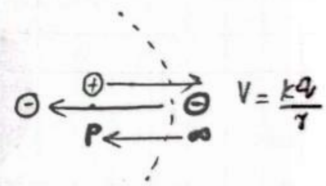
$V = \frac{kQ}{r}$

Gauss's Law 1st application

if E = 0 then V = const.



if E=0, V = const, ΔV = 0



potential difference b/w the oppositely charged parallel plates ∴ $\Delta V = -Ed$

↳ negative sign shows the work done against the electric field.

→ As P.D is a scalar quantity, so negative sign can be ignored.

potential ratio = 1:1

but Q ratio = their sizes i.e $\frac{Q}{q} = \frac{R}{r}$

points in ... field, ... same potent...

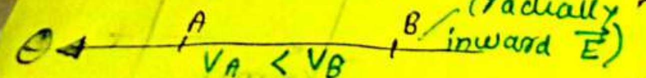
Area of ...

INCREASE / DECREASE IN ELECTROSTATIC POTENTIAL ENERGY WITH WORK DONE:-

→ when work is done against the electric (e.g moving a positive charge closer to another positive charge) the electrostatic potential energy of the system inct.

(work done against → electrostatic the electric field) ∴ P.E inct.

→ electric potential ... direction of electric field.



electric potential decl along the direction of electric field.

... case $V_A < V_B$.

if $E=0$

potential difference b/w the oppositely charged parallel plates.

$\because \Delta V$

↳ n

the

INCREASE / DECREASE IN ELECTROSTATIC POTENTIAL ENERGY WITH WORK DONE:-

→ when work is done against the electric (e.g moving a positive charge closer to another positive charge) the electrostatic potential energy of the system inc↑.

(work done against the electric field) → electrostatic P.E inc↑.

→ ...tion of electric field.

A

B (radially inward $\vec{E}$)

$V = \text{const.}$ $V=0$ ∞

hen work is done by the electric field (e.g moving the charge away from another +ive charge) the electrostatic P.E of the sys. dec↓. (work done by the electric field the E.P.E dec↓).

→ the electric field does work on the Q, causing it to move in the direction of field →

→ (if it is an attractive force) or away from a charge (if it is a repulsive force).

x ———— x

$V_A > V_B$

⊕ —— A —— B ——▷ (radially outward $\vec{E}$)

→ electric potential dec↓ along the direction of electric field.

(radially inward $\vec{E}$)

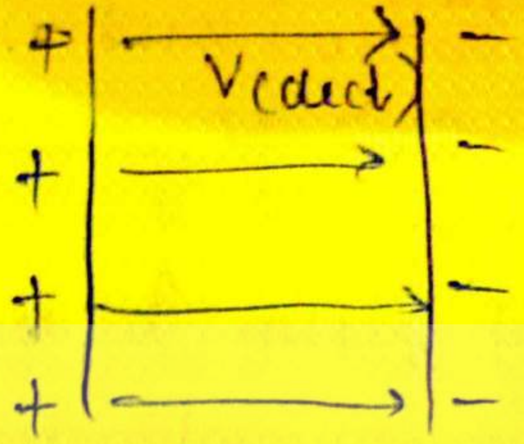
⊖ ◁—— A —— B ——

$V_A < V_B$

lectric potential dec↓ along the direction of electric field.

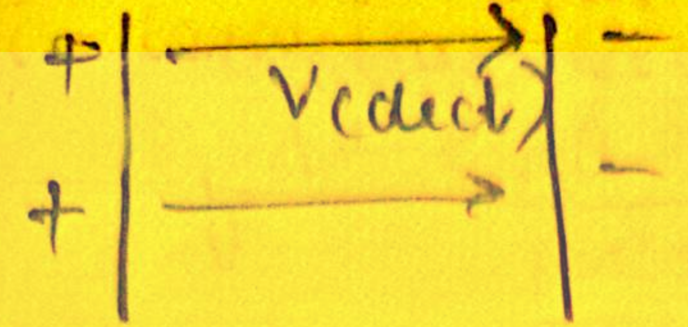
is bigger, that's why in secon

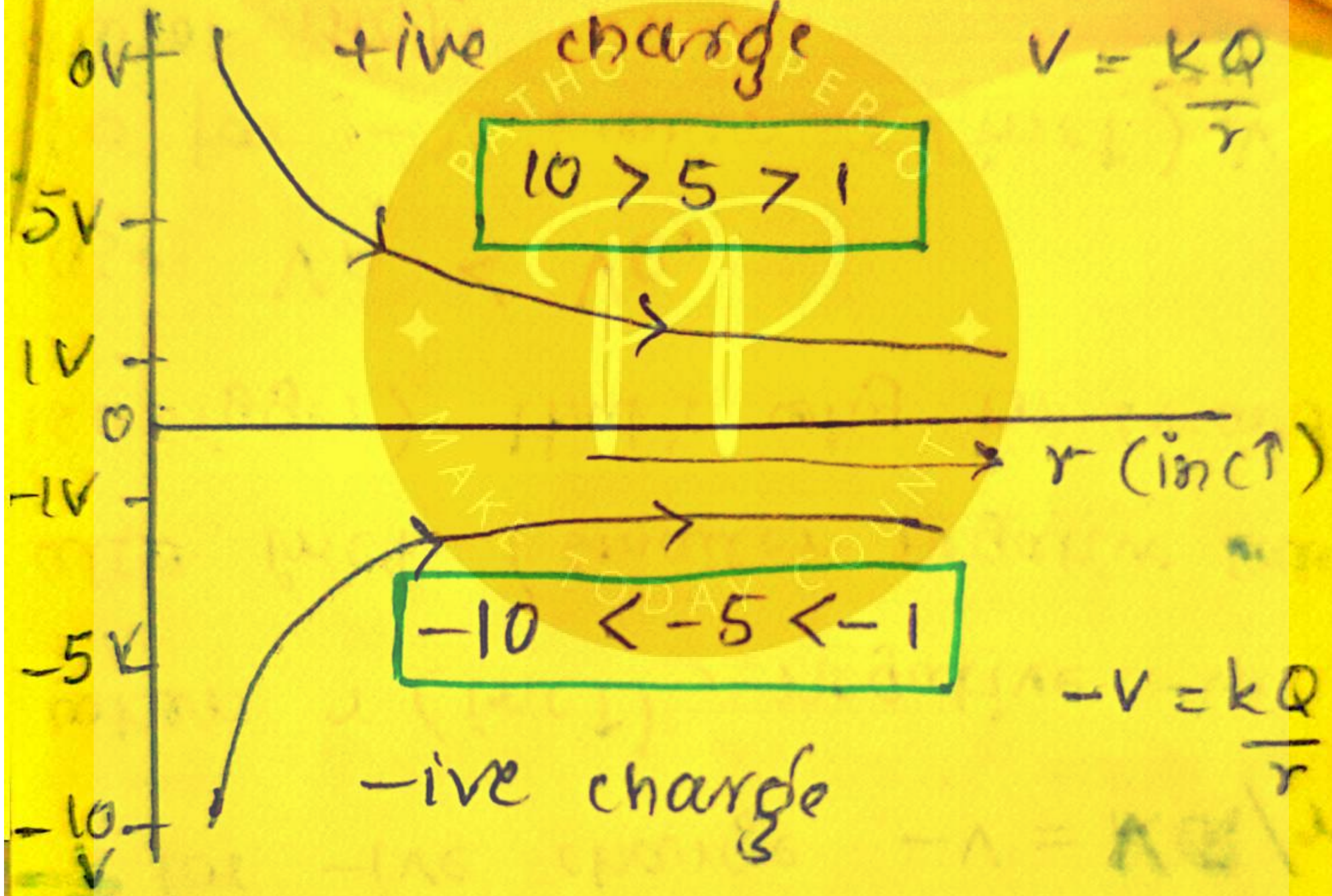
dec↓ (work done by the ... the C.D.S. decL)



→ for +ive charge $+V = kq/r$
when r (inc↑), V (dec↓) and vice versa.

→ for −ive charge $-V = KQ/r$
when r (inc↑), negative $-V$ also inc↑ (smaller negative value is bigger) that's why in second case $V_A < V_B$.
so for $-V$, when r (inc↑) V also inc↑.


+
+
V(elect)
−
−


+ive charge
V = kQ/r
10 > 5 > 1
0V
5V
1V
0
−1V
−5V
−10V
r (inc↑)
−10 < −5 < −1
−V = kQ/r
−ive charge

[illegible] (bodies)

Two charged spheres/ connected by a conductor → their potentials becomes same → and $\boxed{Q \propto size}$

$V_1 = V_2$

$\frac{Kq}{r} = \frac{KQ}{R}$

$$\boxed{\frac{Q}{q} = \frac{R}{r}}$$

$\boxed{Q \propto size}$

potential ratio = 1 : 1

but Q ratio = their sizes i.e $\frac{Q}{q} = \frac{R}{r}$