Chapter 1 :-

Q. Write any two basic properties of charges?

Ans. (i) Conservation of charges

(ii) Quantization of charges

(iii) Charge is Additive in nature.

∴ Charges possessed by a body is always equal to the internal multiple of charge over one electron i.e.

$$\boxed{Q = ne}$$

∴ Where $n = 1, 2, 3$ -------- or any other integer.

$e = 1.6 \times 10^{-19} C.$

Suppose, $1\,C = Ne$

$$N = \frac{1}{e} = \frac{1}{1.6 \times 10^{-19}}$$

$$= 6.25 \times 10^{18}$$

Coulomb's Law of Electrostatics :-

$$F \propto q_1 q_2$$

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

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

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

$$F = \left(\frac{1}{4\pi\epsilon_0}\right) \frac{q_1 q_2}{r^2} \rightarrow (1)$$

∴ Where ϵ = Permittivity of a medium.

$$\frac{1}{4\pi\epsilon_0} = 9 \times 10^9 \, Nm^2c^2$$

$\epsilon_0 = 8.85 \times 10^{-12} \, c^2 N^{-1} m^2$ = Permittivity of free space.

Force experienced in a medium.

$$F' = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r^2} \longrightarrow (2)$$

Dividing (1) by (2)

$$\frac{F}{F'} = \frac{C}{\epsilon_0} = K = \text{Di-electric constant of the medium}$$

Q. Find out the distance b/w 2 protons between which the electrostatic force is equal to the weight of either of them.

Ans.

$$F = mg = \frac{1}{4\pi\epsilon_0} \cdot \frac{q_1 q_2}{r^2}$$

$$F = \frac{q_1 q_2}{4\pi\epsilon_0} \frac{1}{mg}$$

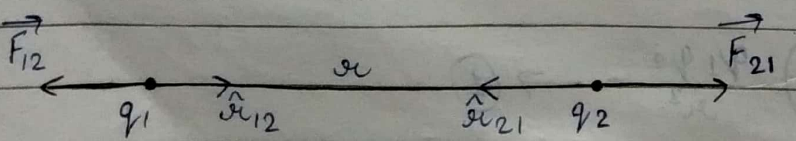
$$= \sqrt{\frac{9\times10^{9} \times 1.6\times10^{-19} \times 1.6\times10^{-19}}{1.6\times10^{-27}\times10}}$$

$$= \sqrt{\frac{9\times10^{9} \times 1.6\times1.6\times10^{-27}}{1.6\times10^{18}\times10^{18}\times10}} = \frac{3\times\cancel{1.6}^{\,0.4}\times\sqrt{10^{-2}}}{\cancel{4}}$$

$$= 3\times0.04 = 0.12$$

$$= 120\text{ mm}.$$

Coulomb's Law in Vector form :-



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

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

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

Q. How will the force between 2 charges change if they are kept in water?

Ans. Force will become $\frac{1}{81}$ times

$$F_v = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r^2}$$

$$F_w = \frac{1}{4\pi\epsilon_0 K} \frac{q_1 q_2}{r^2}$$

∴ Where $K = 81$ for water

$$\therefore \frac{F_v}{F_w} = 81.$$

Q. Define 'di-electric' constant of a medium?

Ans. It is defined as the ratio of force b/w two point charges seperated by a distance kept in vaccum to the force b/w same two point charges kept in medium seperated by the same distance. For metals K= infinite & for water K = 81 & for vaccum, K = 1.

$$\frac{F_v}{F_m} = K \text{ or } \epsilon$$

Principle of Superposition:-

Acc. to this principle the net force acting over a point charge due to a cluster of charges is equal to the vector sum of the forces experienced by the first charge due to all other individual charges.

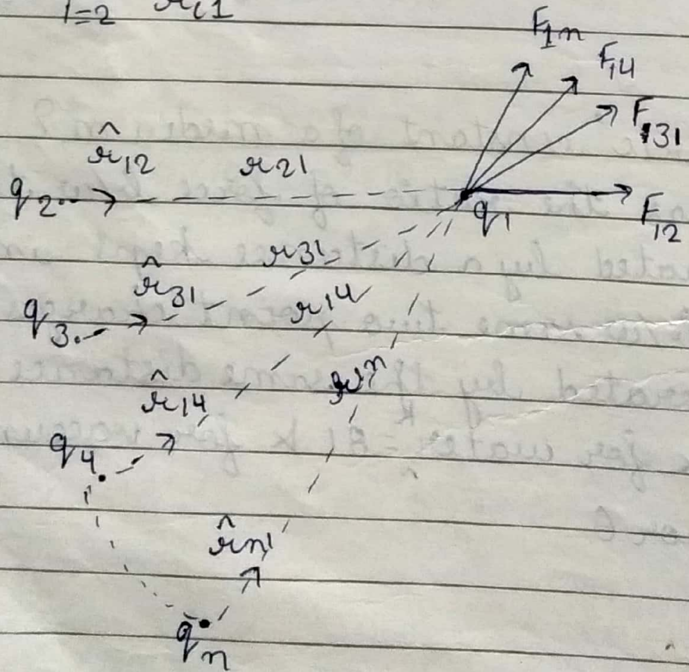
Mathematically, Force experienced by q_1 due to all other charges can be written as $\vec{F}_1 = \vec{F}_{12} + \vec{F}_{13} + \cdots \vec{F}_{1n}$

$$= \frac{1}{4\pi\epsilon_0} \cdot \frac{q_1 q_2}{r^2} \hat{r}_{21} + \frac{1}{4\pi\epsilon} \frac{q_1 q_3}{r_{31}^2} \hat{r}_{31} + \cdots$$

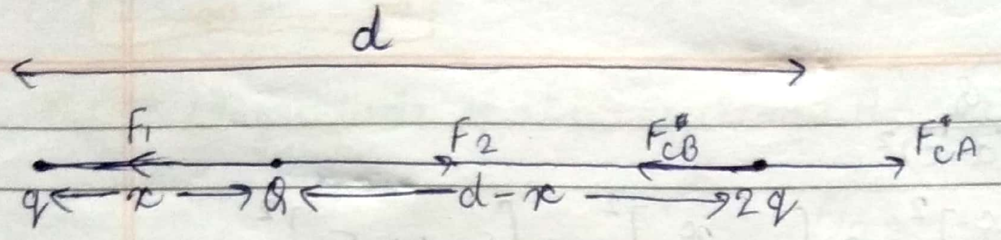
$$\frac{1}{4\pi\epsilon_0} \cdot \frac{q_1 q_n}{r_{n1}^2} \hat{r}_{n1}$$

$$= \frac{q_1}{4\pi\epsilon_0} \left[\frac{q_2}{r_{21}^2} \hat{r}_{21} + \frac{q_3}{r_{31}^2} \hat{r}_{31} + \cdots \frac{q_n}{r_{n1}^2} \hat{r}_{n1} \right]$$

$$= \frac{q_1}{4\pi\epsilon_0} \sum_{i=2}^{n} \frac{q_i}{r_{i1}^2} \hat{r}_{i1}$$



Q. State's principle of superposition? Explain it by taking an example of n charge system?



$$F_1 = \frac{1}{4\pi\epsilon_0} \frac{Q2q}{(d-x)^2}$$

$$F_2 = \frac{1}{4\pi\epsilon_0} \frac{q \cdot Q}{x^2}$$

For equilibrium we must have $F_1 = F_2$

$$\cancel{\frac{1}{4\pi\epsilon_0}} \frac{\cancel{Q}2\cancel{q}}{(d-x)^2} = \cancel{\frac{1}{4\pi\epsilon_0}} \frac{\cancel{qQ}}{x^2}$$

$$\frac{2}{(d-x)^2} = \frac{1}{x^2}$$

$$2x^2 = (d-x)^2$$

$$x\sqrt{2} = d - x$$

$$x + x\sqrt{2} = d$$

$$x(\sqrt{2}+1) = d$$

$$x = \frac{d}{\sqrt{2}+1}$$

$$= \frac{d}{\sqrt{2}+1} \times \frac{\sqrt{2}-1}{\sqrt{2}-1}$$

$$= d(\sqrt{2}-1) = 0.41d$$

On the basis of above fig.

$$F_{CA} = F_{CB}$$

$$\frac{1}{4\pi\epsilon_0} \frac{q2q}{d^2} = \frac{1}{4\pi\epsilon_0} \frac{Q2q}{(d-x)^2}$$

$$\frac{q}{d^2} = \frac{Q}{(d-x)^2}$$

$$Q = q\left[\frac{d-x}{d}\right]^2 = q\left[1-\frac{x}{d}\right]^2 = q\left[1-1+\sqrt{2}\right]^2$$

$$\boxed{Q = 2q}$$

$$Q = q\left[1-\frac{x}{d}\right]^2$$

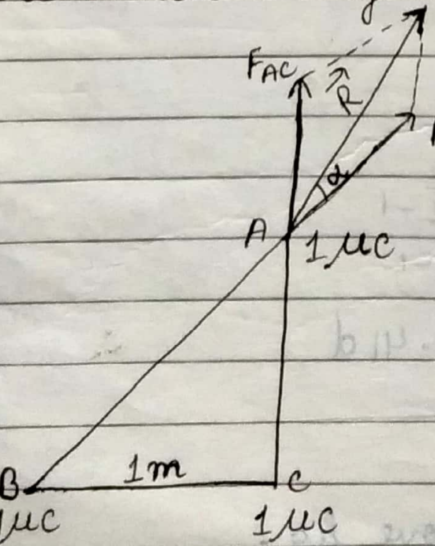
$$Q = q\left\{1-(1+\sqrt{2})\right]^2$$

$$Q = q\left[1+1-\sqrt{2}\right]^2$$

$$Q = q\left[2-\sqrt{2}\right]^2$$

$$Q = q\left[0.35\right] \Rightarrow Q = 0.36q.$$

Q. Find out the force on the charge kept at A in fig:-



Ans. $F_{AC} = 9\times10^9 \times \frac{1\times1\times10^{-6}\times10^{-6}}{(1)^2} = 9\times10^{-3}N$

$F_{AB} = 9\times10^9 \times \frac{10}{(\sqrt{2})} = 4.5\times10^{-3}N$

∴ Magnitude of the resultant $R = \sqrt{F_{AC}^2 + F_{AB}^2 + 2F_{AB} \cdot F_{AC} \cos 45°}$

$$= \left(\sqrt{9^2 + 4.5^2 + 2 \times 9 \times 4.5 \times \frac{1}{\sqrt{2}}}\right) \times 10^{-3}$$

$$= \sqrt{81 + 20.25 + \frac{81}{\sqrt{2}}} \times 10^{-3}$$

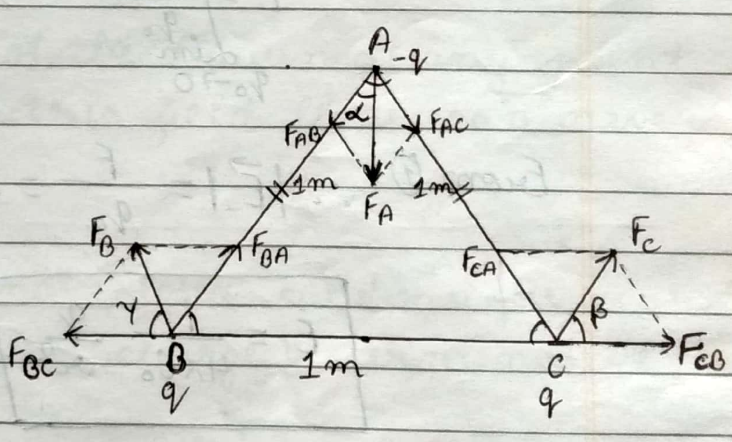
$$=$$

$$\tan\alpha = \frac{F_{AC} \sin 45°}{F_{AB} + F_{AC} \cdot \cos 45°}$$

$$= \frac{9 \times 10^{-3} \times 1/\sqrt{2}}{4.5 \times 10^{-3} + 9 \times 10^{-3} \times 1/\sqrt{2}}$$

Q. Example 1.7 (NCERT)

Ans.



Note:- Direction of electric field at any field of line can be determined by drawing the tangent on point.

Electric Fields :-

The space around a charge in which an infinitesimally small test charge (q_0) experiences an electro-static force is known as electric field

$$F = \frac{1}{4\pi\epsilon_0} \frac{q q_0}{r^2}$$

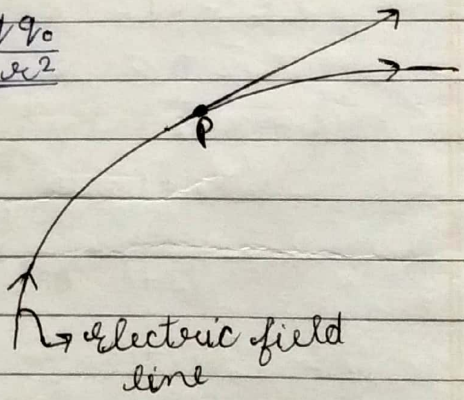
Electric Field Strength or Electric field intensity :

Electric Field intensity at a point is defined as the force per unit charge experienced by a very small test charge in the electric field of source charge. (It is a vector quantity)

$$\vec{E} = \lim_{q_0 \to 0} \frac{\vec{F}}{q_0} \longrightarrow ①$$

From ① $\therefore |\vec{E}| = \frac{F}{q_0} = \frac{\frac{1}{4\pi\epsilon_0}\frac{q q_0}{r^2}}{q_0}$

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



Electric Lines of Forces :-

It can be defined as the imaginary path along which a very small test charge tends to move or start moving.

Properties of electric field lines :-

(i) Electric field lines are always directed away from isolated (+)ve charge & isolated (-) ve charge.

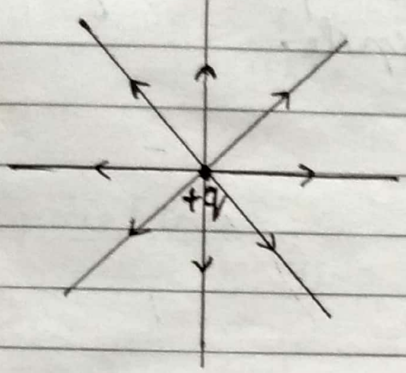


Fig. ⓐ

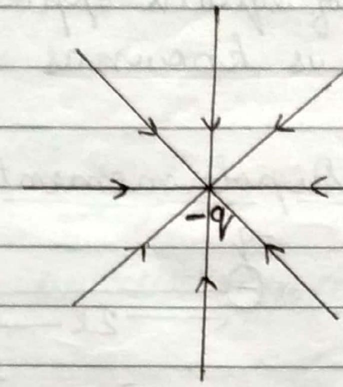


Fig. ⓑ

(ii) The tangent drawn at any point of an electric field lines gives the direction of electric field at that point

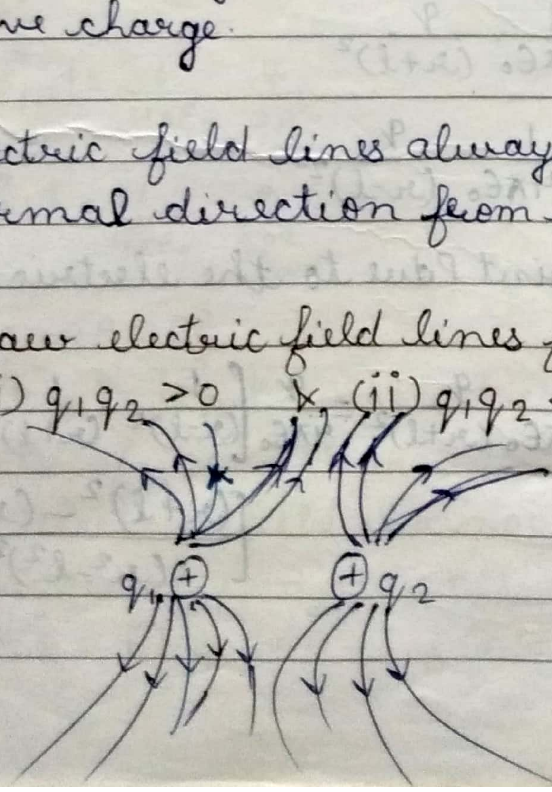
(iii) As two tangents cannot be drawn at any point of a curve therefore electric field lines can never intersect each other.

(iv) Electric field lines are not closed continuous curves because they originate (+)ve charge & terminative (-)ve charge.

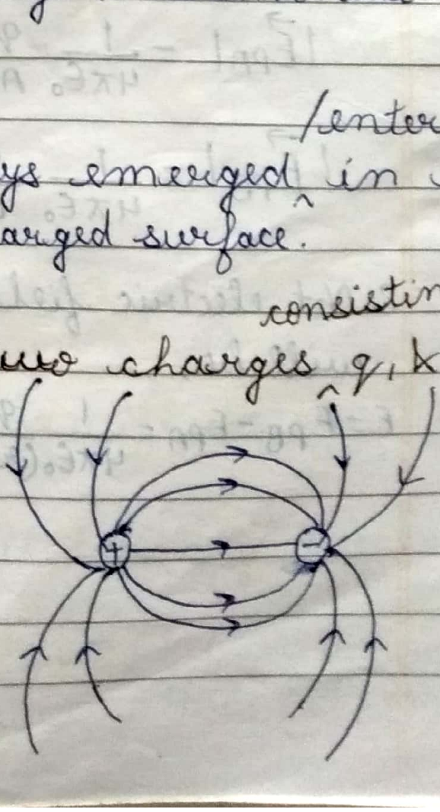
(v) Electric field lines always always emerged /enter in the normal direction from any charged surface.

Q. Draw electric field lines for a two charges consisting of q_1 & q_2 if (i) $q_1 q_2 > 0$ & (ii) $q_1 q_2 < 0$

Ans (i)



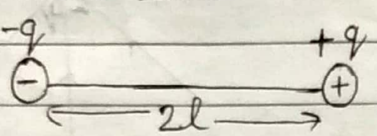
(ii)



Electric Dipole:-

A system of equal & opposite charges seperated by a small distances is known as electric dipole.

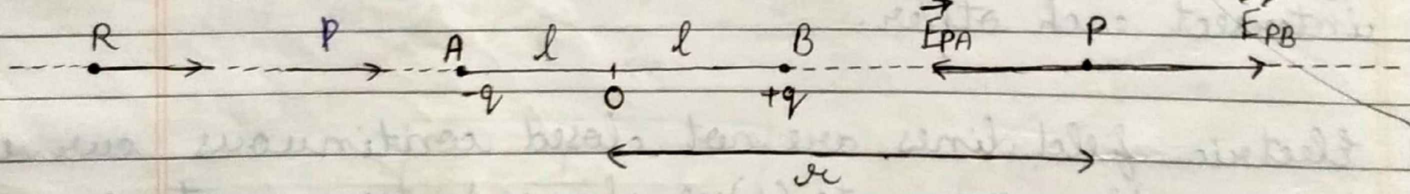
Electric Dipole moment :-



$$\vec{p} = q \cdot 2\vec{l}$$

It is a vector quantity.

Electric field strength due to an dipole on an axial point :-



$$|\vec{E}_{PA}| = \frac{1}{4\pi\epsilon_0}\frac{q}{AP^2} = \frac{1}{4\pi\epsilon_0}\frac{q}{(r+l)^2}$$

$$|\vec{E}_{PB}| = \frac{1}{4\pi\epsilon_0}\frac{q}{BP^2} = \frac{1}{4\pi\epsilon_0}\frac{q}{(r-l)^2}$$

∴ Net electric field at point P due to the electric dipole will be,

$$E = E_{PB} - E_{PA} = \frac{1}{4\pi\epsilon_0}\frac{q}{(r-l)^2} - \frac{1}{4\pi\epsilon_0}\frac{q}{(r+l)^2} = \frac{q}{4\pi\epsilon_0}\left[\frac{1}{(r-l)^2} - \frac{1}{(r+l)^2}\right] = \frac{q}{4\pi\epsilon_0}\left[\frac{(r+l)^2 - (r-l)^2}{(r^2-l^2)^2}\right]$$

$$= \frac{q}{4\pi\epsilon_0}\left[\frac{4rl}{(r^2-l^2)^2}\right] = \frac{1}{4\pi\epsilon_0}\frac{2(q2l).r}{(r^2-l^2)^2} = \frac{1}{4\pi\epsilon_0}\frac{2pr}{(r^2l^2)^2}$$

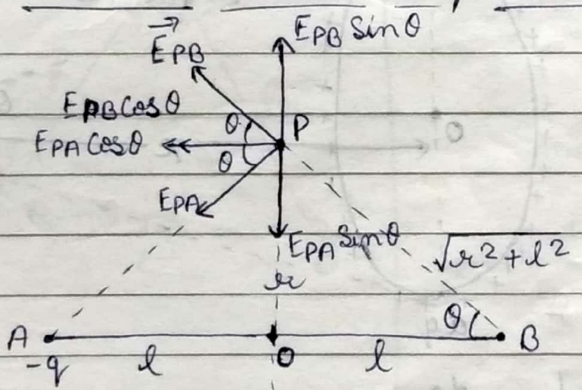
$$E = \frac{1}{4\pi\epsilon_0}\frac{2pr}{(r^2-l^2)^2}$$

Special Case :-

(i) If, $r \gg l$, ~~[illegible]~~

$$\boxed{E = \frac{1}{4\pi\epsilon_0}\frac{2P}{r^3}}$$

(ii) Electric field due to an electric dipole at an equatorial point :-



$$|\vec{E}_{PA}| = \frac{1}{4\pi\epsilon_0}\frac{q}{AP^2}$$

$$|\vec{E}_{PA}| = \frac{1}{4\pi\epsilon_0}\cdot\frac{q}{BP^2}$$

As, $AP = BP$

$\therefore |\vec{E}_{PA}| = |\vec{E}_{PB}|$ $\therefore$ Vertical components will cancel out the effects of each other.

Net electric field at a point P will be only due to the horizontal components.

$$\therefore E = E_{PA}\cos\theta + E_{PB}\cos\theta = 2E_{PA}\cos\theta = 2\times\frac{1}{4\pi\epsilon_0}\frac{q}{(r^2+l^2)}\times\frac{l}{(r^2+l^2)}$$

Note:- $2\pi a \longrightarrow q$

$1 \longrightarrow \frac{q}{2\pi a}$

$dl \longrightarrow \frac{q}{2\pi a} dl = dq$

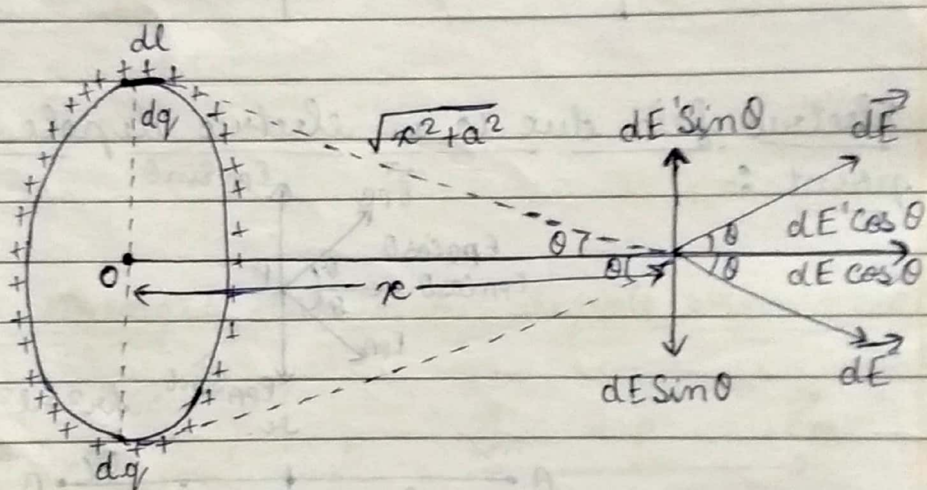
$$\boxed{E = \frac{1}{4\pi\epsilon_0} \frac{p}{(r^2+l^2)^{3/2}}}$$

Antiparallel to the dipole moment

Special Case:- If $r \gg l$

$$\boxed{E = \frac{1}{4\pi\epsilon_0} \frac{p}{r^3}}$$

* Electric Field at a point on the axis of a uniformly charged ring :-



$$dE = \frac{1}{4\pi\epsilon_0} \frac{dq}{(x^2+a^2)}$$

Net electric field will be due to the horizontal compo-nents only.

$$\therefore \oint dE \cos\theta = \oint \frac{1}{4\pi\epsilon_0} \frac{dq}{(x^2+a^2)} \times \frac{x}{\sqrt{x^2+a^2}}$$

$$= \oint \frac{1}{4\pi\epsilon_0} \frac{x}{(x^2+a^2)^{3/2}} \frac{q}{2\pi a} \cdot dl$$

$$= \frac{qx}{4\pi\epsilon_0 (x^2+a^2)^{3/2}\, 2\pi a} \oint dl$$

$$\boxed{E = \frac{qx}{4\pi\epsilon_0 (x^2+a^2)^{3/2} \cancel{2\pi a}} \times \cancel{2\pi a}}$$

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$$\boxed{E = \frac{qx}{4\pi\epsilon_0 (x^2-a^2)^{3/2}}}$$

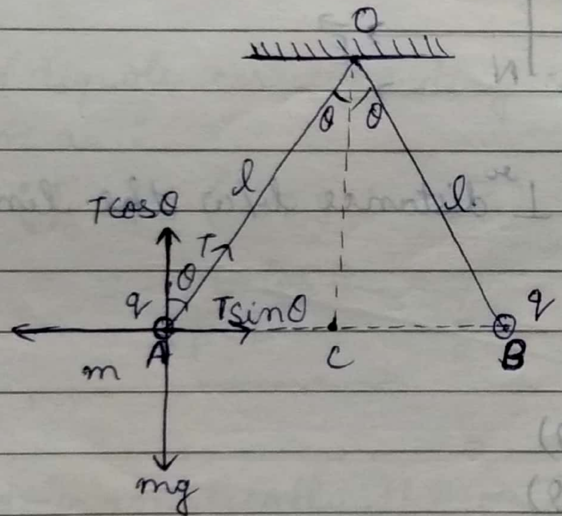
Special Case :- For $x >> a$

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

∴ The uniformly charge ring is behaving like a point charge for the point for which $x >> a$

Q. To find out q if the system in the following is in equilibrium?

Ans.



$$\oint dE\cos\theta = \oint \frac{1}{4\pi\epsilon_0}\frac{dq}{(x^2+a^2)} \times \frac{x^2}{\sqrt{x^2+a^2}}$$

$$F = \frac{1}{4\pi\epsilon_0}\frac{q^2}{(2l\sin\theta)^2}$$

$$\left(\frac{F}{AC} = \frac{mg}{l\cos\theta}\right) = \frac{T}{OA}$$

$$\frac{F}{l\sin\theta} = \frac{mg}{l\cos\theta}$$

$$F = mg\tan\theta$$

$$\frac{1}{4\pi\epsilon}\frac{q^2}{4l^2\sin^2\theta} = mg\tan\theta$$

$$q^2 = 4\pi\epsilon_0 \cdot 4l^2\sin^2\theta \cdot mg\tan\theta$$

$$q = 4l\sin\theta(\pi\epsilon_0 mg\tan\theta)^{1/2}$$

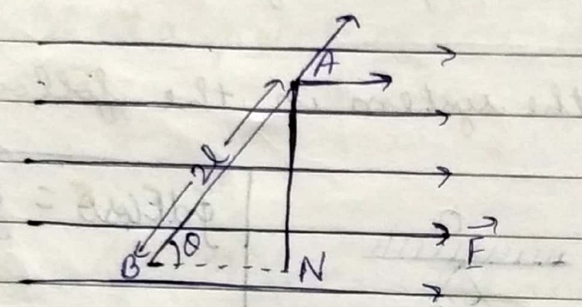
$q = ?$ l, θ, m

$T \sin\theta = F$

$T \cos\theta = mg$

$\cancel{mg\, T\theta} = mg \tan\theta = F$

Torque ~~acting on uniform~~ acting on an electric dipole placed in an uniform electric field :-



τ = Either force × $\perp^r$ distance b/w the lines of action of forces.

$= qE\,(BN)$

$= qE\,(AB \sin\theta)$

$= qE\,(2l \sin\theta)$

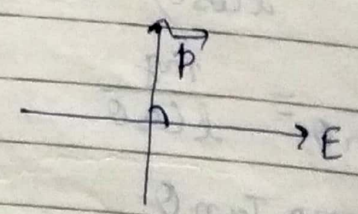
$= \cancel{q(2l)}\,(q \cdot 2l)\, E \sin\theta$

$= q = pE \sin\theta \quad \Rightarrow \boxed{q = pE \sin\theta}$

In vector for $\vec{\tau} = \vec{p} \times E$

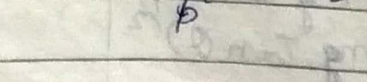
τ_{max} when $\sin\theta$ max.

$\theta = 90$



$\tau_{max} \quad \sin\theta = 0 \quad \boxed{\theta = 0}$

$\theta = 0$

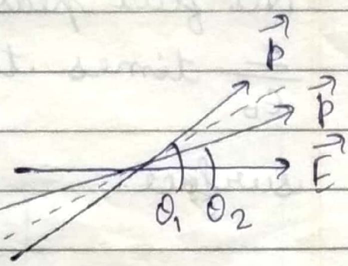


Electstatic Potential of an Electric Dipole placed in a uniform Electric field:-

$dW = \tau d\theta$

$dW = pE \sin d\theta$

$\therefore W = \int dW = \int_{\theta_1}^{\theta_2} pE \sin\theta \, d\theta$



$W = pE \left[-\cos\theta \right]_{\theta_1}^{\theta_2}$

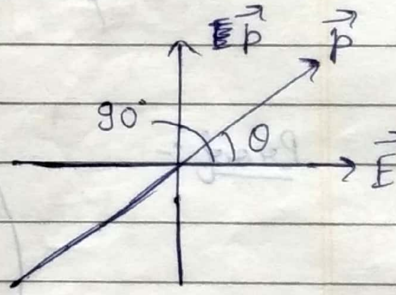
$EPE = \boxed{U = pE \left[\cos\theta_1 - \cos\theta_2 \right]}$

EPE of dipole corresponding to the orientation θ can be given as :

$U_0 = pE (\cos 90^\circ - \cos\theta)$

$= -pE \cos\theta$

$= -\vec{p} \cdot \vec{E}$



Q. Show diagramatically the orientation of an electric dipole placed in an electric field corresponding to

(i) Stable equilibrium.

(ii) unstable equilibrium.

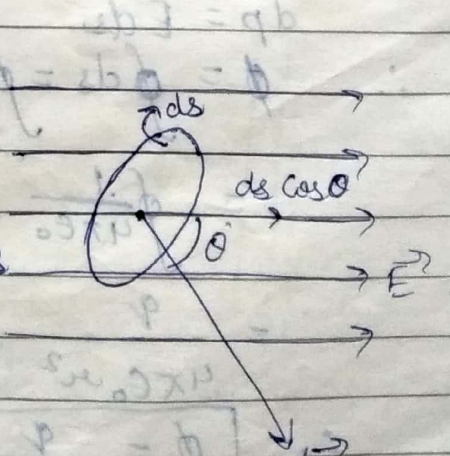
Electric flux:-

$d\phi = \vec{E} \cdot \vec{ds}$

$d\phi = E(ds \cos\theta)$ or $(E\cos\theta) ds$

$\phi = \int ds$

$\phi = \int \vec{E} \cdot \vec{ds}$



Electric flux is a scalar quantity.

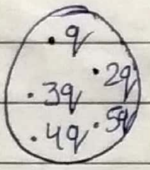
SI unit $\rightarrow$ Nm^2C^{-1}

* Gauss' Theorm

Net flux passing through a closed surface is equal to $\frac{1}{\epsilon_0}$ times the total charge enclosed within the surface.

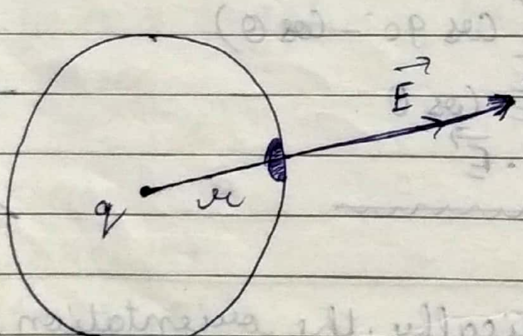
Mathematically, $\phi = \frac{q}{\epsilon_0}$ → Charge enclosed

ex.



$$\phi = \frac{q + 2q + 3q + 4q + 5q}{\epsilon_0}$$

Proof :-

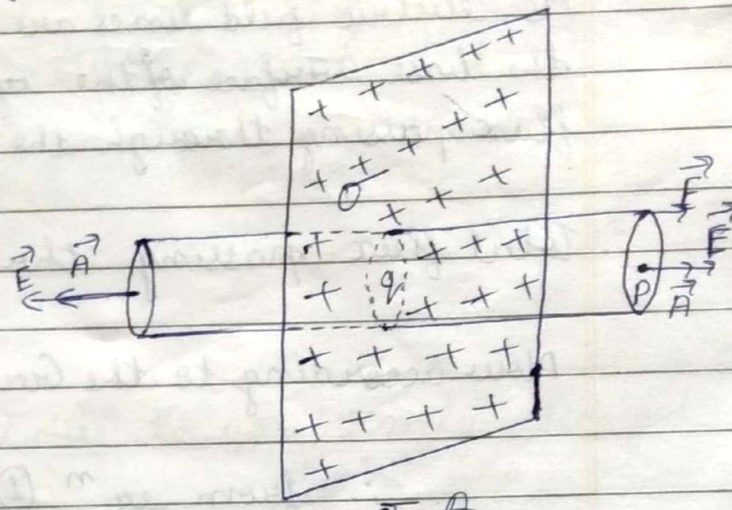


$$dp = \vec{E} \cdot \vec{ds}$$
$$= E\, ds \cos\theta$$
$$dp = E\, ds$$
$$\therefore \phi = \oint ds = \oint E\, ds$$
$$= \oint \frac{1}{4\pi\epsilon_0} \frac{q}{r^2} \cdot ds.$$
$$= \frac{q}{4\pi\epsilon_0 r^2} \oint ds = \frac{q}{4\pi\epsilon_0 r^2} (4\pi r^2) = \frac{q}{\epsilon_0}$$

$$\therefore \boxed{\phi = \frac{q}{\epsilon}}$$

Applications of Gauss's Theorm:

Electric field at a point ~~due~~ ~~to~~ near an infinitely large plane sheet of charge:



$d\vec{s}$ $\phi = \vec{E} \cdot \vec{A}$

$= EA \cos\theta$

$\theta = 90^\circ$

$\phi = 0$

$\theta = 0$

$\phi = EA$

$\phi = \frac{q}{\epsilon_0} \Rightarrow 2EA = \frac{q}{\epsilon_0} \Rightarrow 2EA = \frac{\sigma A}{\epsilon_0}$

$E = \frac{q}{2A\epsilon_0} = \frac{q/A}{2\epsilon_0} = \frac{\sigma}{2\epsilon_0}$ $\qquad E = \frac{\sigma}{2\epsilon_0}$

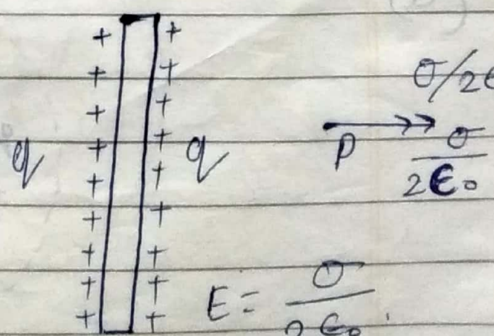
where σ = Surface charge density.

$$\boxed{E = \frac{\sigma}{2\epsilon_0}}$$

Special Case: If the plane sheet is of finite thickness then:

$E = \frac{\sigma}{2\epsilon_0} + \frac{\sigma}{2\epsilon_0} = \frac{\sigma}{\epsilon_0}$

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



$E = \frac{\sigma}{2\epsilon_0}$

(ii) Electric field at a point due to a line charge:

inside which

Gaussian Surface:- An imaginary surface in ~~which~~ charge is enclosed is called Gaussian Surface.

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

As electric field lines are just a ~~ch~~ touching tangentially the base surface of the cylinder, therefore, the electric flux passing through the base surface is zero.

$\therefore$ Total flux passing through curved surface $= E \times (2\pi r l)$ $\rightarrow$ (1)

Now according to the Gauss Theorem $\phi = \frac{q}{\epsilon_0}$

$\therefore$ from eq^n (1) we have

$$E (2\pi r l) = \frac{q}{\epsilon_0}$$

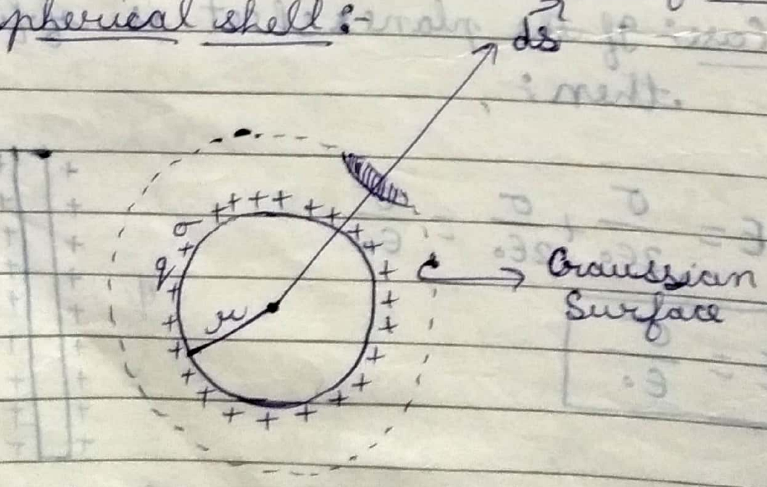
$$E = \frac{1}{2\pi\epsilon_0} \frac{q}{rl} = \frac{1}{2\pi\epsilon_0} \frac{q}{r}$$ → linear charge density.

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

Imp.

(iii) Electric field at a point due to uniformly charged hollow spherical shell:-

(a)



At a point outside the sphere:-

$$d\phi = \vec{E}\cdot\vec{ds} = E\,ds\cos\theta = E\,ds$$

some

$$\therefore \phi = \oint d\phi = \oint E\,ds = E\oint ds = E(4\pi r^2) \rightarrow ①$$

Acc. to the Gauss Th. $\phi = \frac{q}{\epsilon_0}$

$\therefore$ From ① $E(4\pi r^2) = \frac{q}{\epsilon_0}$

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

$\therefore q = \sigma \cdot 4\pi R^2$

$$\boxed{E = \frac{\sigma R^2}{\epsilon_0 r^2}}$$

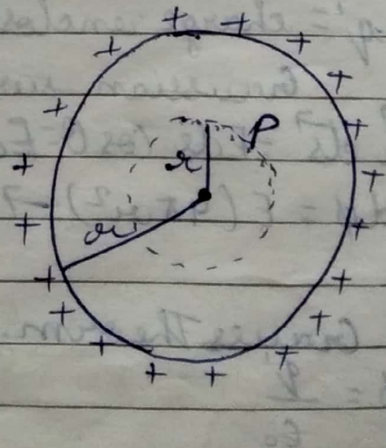
(iii) Electric field at a point due to uniformly charged hollow spherical shell:-

(b) At a point on the surface

$r = R \therefore \boxed{E = \frac{\sigma}{\epsilon_0}}$

(c) At a point inside the shell:-

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



OR, $\oint \vec{E}\,d\vec{s} = \frac{q}{\epsilon_0}$

$= \frac{0}{\epsilon_0}$

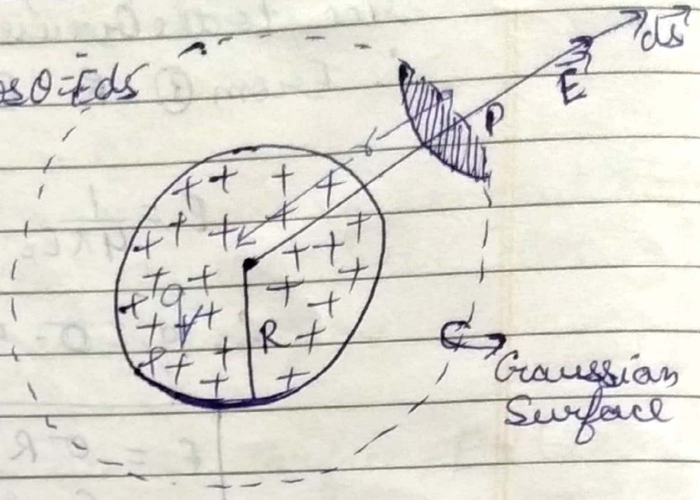
$\oint \vec{E}\,d\vec{s} = 0$

$E = 0$

(iv) Electric field at a point due to a uniform spherical charge distribution:-

(a) <u>At a point outside the sphere</u>:-

Small flux $d\phi = \vec{E}\,\vec{ds} = \vec{E}\,\vec{ds}\cos\theta = E\,ds$



$\phi = \oint d\phi = \oint E\,ds =$

$\phi = E(4\pi r^2) \rightarrow (1)$

Acc. to the Gauss Theorm

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

$\therefore$ from eq^n (1)

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

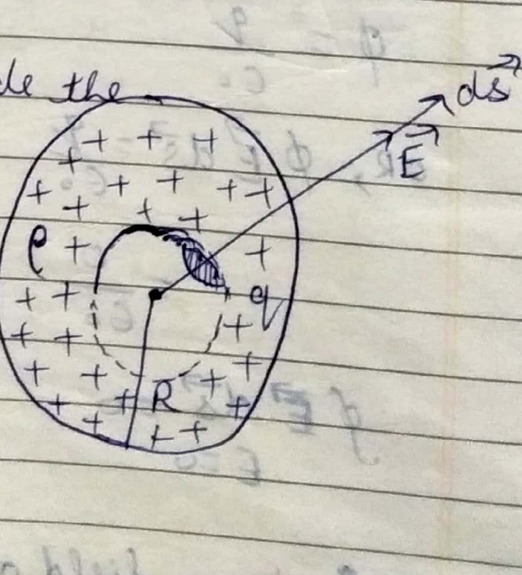
$E = \frac{q}{\epsilon_0(4\pi r^2)} = \frac{1}{4\pi\epsilon_0} \cdot \sigma \frac{R^2}{r^2}$

$\therefore \; q = \sigma 4\pi R^2$

$$\boxed{E = \frac{\sigma}{\epsilon_0} \frac{R^2}{r^2}}$$

(c) <u>At a point inside the sphere</u>:-

Let q' = charge enclosed inside the Gaussian surface.



$\therefore d\phi = \vec{E}\,\vec{ds} = E\,ds\cos\theta = E\,ds$

$\therefore \phi = \oint d\phi = E(4\pi r^2) \rightarrow (1)$

Acc. to Gauss Theorm.

$\phi = \frac{q'}{\epsilon_0}$

$\therefore E(4\pi r^2) = \frac{q'}{\epsilon_0}$

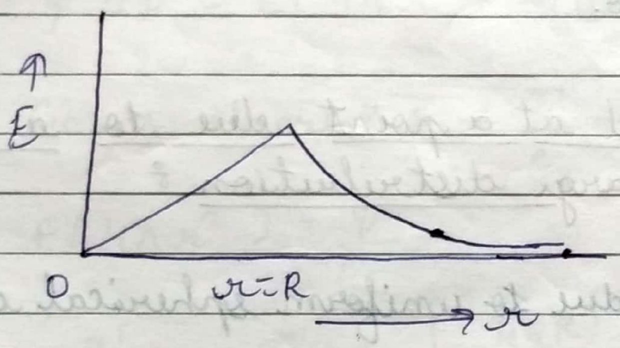
$$E = \frac{4}{4\pi\epsilon_0} \frac{q'}{r_0} \rightarrow \text{(2)}$$ $$\frac{4}{3}\pi R^3 \rightarrow q$$

$$\therefore E = \frac{1}{4\pi\epsilon_0} \times \frac{qr^3/R^3}{r^2}$$ $$1 \rightarrow \frac{q}{4/3\,\pi R^3}$$

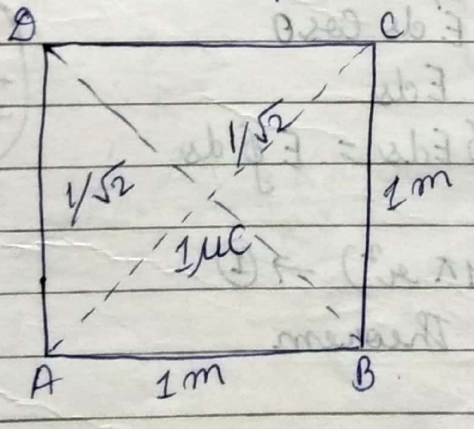
$$= \frac{1}{4\pi\epsilon_0} \frac{qr}{R^3}$$ $$\frac{4}{3}\pi r^3 \rightarrow \frac{q}{4/3\,\pi R^3} \times \frac{4}{3}\pi r^3$$

$\cancel{4\pi R^2}$ $$= \frac{qr^3}{R^3} = \rho q$$

$$\therefore E = \frac{1}{4\pi\epsilon_0} \frac{\rho \frac{4}{3}\pi R^3 r}{R^3} = \cancel{\frac{\rho r}{3\epsilon_0}} \; \frac{\rho r}{3\epsilon_0}$$

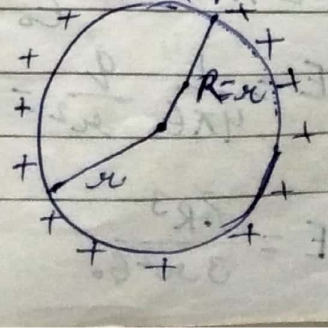


$$W_{CD} = q_0(V_D - V_C) = 0$$
$$q_0 = mC$$



At a point on the surface:-

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



At a point outside the shell :-

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

$$\oint \vec{E} d\vec{s} = \frac{q}{\epsilon_0}$$

$$= \frac{0}{\epsilon_0} = 0$$

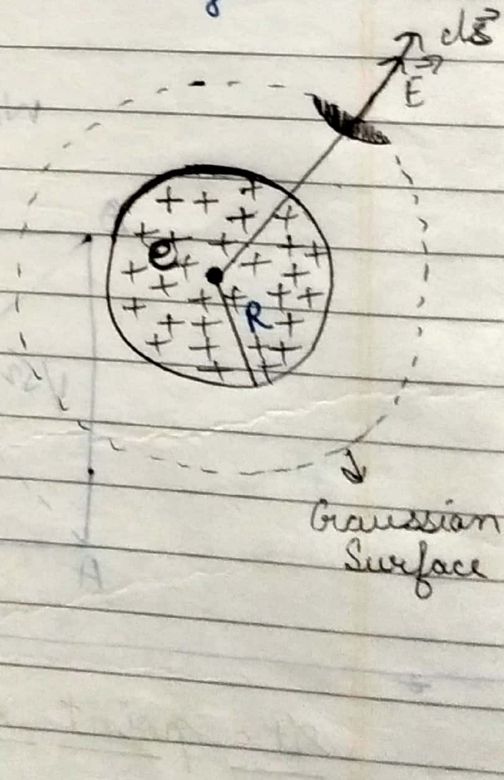
$$\oint \vec{E} d\vec{s} = 0$$

$$\therefore \vec{E} = 0 \quad d\vec{s} \neq 0$$

Electric field inside an uniformly charged spherical shell is zero.

Electric field at a point due to a uniformly spherical charge distribution :

(a) At a point due to uniform spherical charge distribution.



$$\text{Small flux } \phi = \vec{E} \cdot \vec{ds}$$

$$= \vec{E} ds \cos\theta$$

$$= E ds$$

$$\therefore \phi = \oint d\phi = \oint E ds = E \oint ds$$

$$\phi = E(4\pi r^2) \rightarrow (1)$$

Acc. to Gauss Theorem

$$\oint \phi = \frac{q}{\epsilon_0}$$

$\therefore$ From eq^n (1)

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

$$E = \frac{1}{4\pi\epsilon_0} \frac{q}{r^2} = \frac{1}{4\pi\epsilon_0} \frac{\rho \cdot \frac{4}{3} \pi R^3}{r^2}$$

$$\therefore \rho = \frac{q}{V}, \quad q = \rho V = \rho \cdot \frac{4}{3} \pi R^3$$

$$E = \frac{\rho R^3}{3 r^2 \epsilon_0}$$

(b) $r = R$

$\therefore E = \frac{\rho R^3}{3\epsilon_0 R^2}$

$E = \frac{\rho R}{3\epsilon_0}$

(c) At a point inside the sphere :

Let q' = charge enclosed inside the Gaussian surface

$\therefore d\phi = \vec{E} \cdot d\vec{s} = E\, ds \cos 0 = E\, ds$

$\therefore \phi = \oint d\phi = E(4\pi r^2) \rightarrow (1)$

$\therefore$ From Gauss theorem $\phi = \frac{q'}{\epsilon_0}$

$\therefore E(4\pi r^2) = \frac{q'}{\epsilon_0}$

$E = \frac{1}{4\pi\epsilon_0} \cdot \frac{q'}{r^2} \rightarrow (2)$

$\frac{4\pi R^3}{3} \rightarrow q$

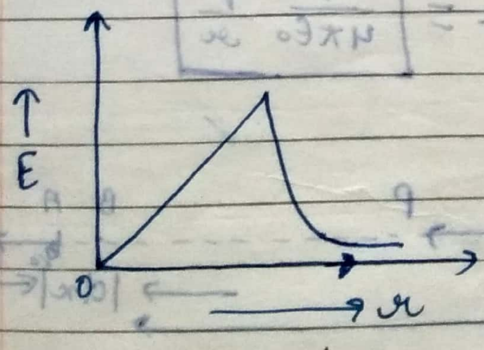
$1 \rightarrow \frac{3q}{4\pi R^3}$

$\frac{4\pi}{3} = \frac{\cancel{3}q}{\cancel{4\pi} R^3} \times \frac{\cancel{4\pi} r^3}{\cancel{3}} = \frac{qr^3}{R^3} = q'$

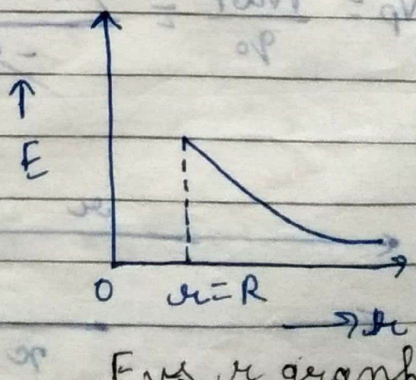
$\therefore E = \frac{1}{4\pi\epsilon_0} \times \frac{qr^3}{R^3 \cdot r^2}$

$= \frac{1}{4\pi\epsilon_0} \frac{qr}{R^3}$

$\therefore E = \frac{1}{4\pi\epsilon_0} \frac{\rho \frac{4}{3}\pi R^3 r}{R^3} = \frac{\rho r}{3\epsilon_0}$



E vs r graph for uniform spherical charge.



E vs r graph for uniformly charged hollow sphere.