Text Book of Physics

BY

Er. Lalit Sharma
B.Tech (Electrical)
Ex. Lecturer Govt. Engg. College Bathinda
Physics Faculty Ranker's Point, Bathinda

Arun Garg
M.Sc. Physics
Gold Medalist
Physics Faculty Ranker's Point, Bathinda

Class:10+2
Unit: I
Topic: Electrostatics

SYLLABUS: UNIT-I

Charges and their conservation. Coulomb's law-force between two charges, forces between multiple charges; superposition principle and continuous charge distribution.
Electric field, electric field due to a point charge, electric field lines; electric dipole, electric field to a dipole; torque on a dipole in a uniform electric field.
Electric flux, statement of Gauss's theorem and its applications to find field due to infinitely long straight wire, uniformly charged infinite plane sheet and uniformly charged thin spherical shell (field inside and outside).
Electric potential, potential difference, electric potential due to a point charged, a dipole and system of charges; equipotential surfaces, electrical potential energy of a system of two point charges and of electric dipoles in an electrostatic field.
Conductors and insulators, free charges and bound charges inside a conductor, Dielectrics and electric polarization, capacitors and capacitance, combination of capacitors in series and in parallel, capacitance of a parallel plate capacitor with and without dielectric medium between the plates, energy stored in a capacitor, Van de Graff generator.

Q.1. **a) Properties of charges?**
b) When glass rod is rubbed with silk, why glass rod gets +ve charge and silk gets –ve charge. (Charging by rubbing).

Ans. a) **<u>Properties of charges</u>**:-

1. **Charges are of two types** → +ve and –ve.
2. **Additively of charges**:
   Total charge on a body/system is simple algebraic sum of all charges. Charge is scalar.

   Example:- q $= q_1 + q_2 + q_3 + q_4 + q_5$

   = (+1) + (+2) + (-3) + (+4) + (-5) = -1

3. **Charge is conserved**:
   Total charge of an isolated system is always conserved.

   Example 1:- n → $p^+ + e^-$

   Total charge on left zero.
   Total charge on right zero.

   Example 2:- When glass rod is rubbed with silk, glass loses electrons and silk gains equal number of electrons.

4. **Quantisation of Charge**:-
   All charges are integral multiple of basic unit of charge i.e.

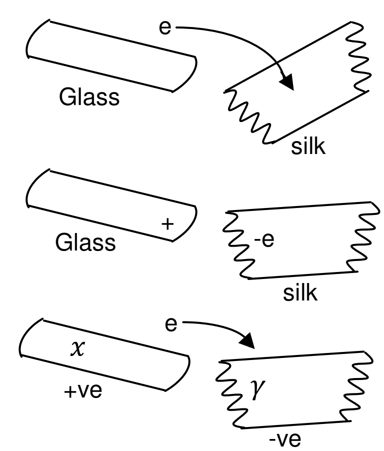
   $$\boxed{Q = n.e}$$

   It was suggested by Faraday and confirmed by Millikan in 1912.

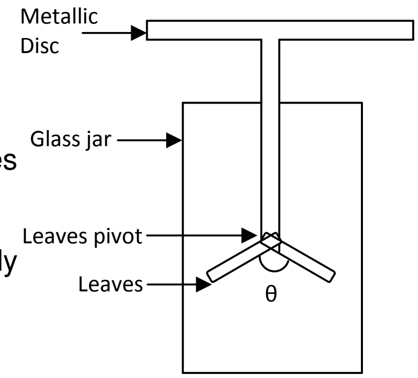
   Another similar concept is quantization of energy.

   $\boxed{E = n.(h.v)}$ and $\boxed{L = n.\frac{h}{2v}}$

b) When glass rod is rubbed with silk, electrons get detached from glass and stick to silk. It is because amount of work done to detach electron from glass is less in comparison to silk. It is called work function of material. When two materials are rubbed, material having low work function loses electrons and becomes +ve charge. Another material gains electrons and becomes –ve charge.



Q.2. a) Construction and use of gold-leaf electroscope.
b) Response of electroscope to differently charged bodies.



Ans.a) **Construction and use of Electroscope**:-

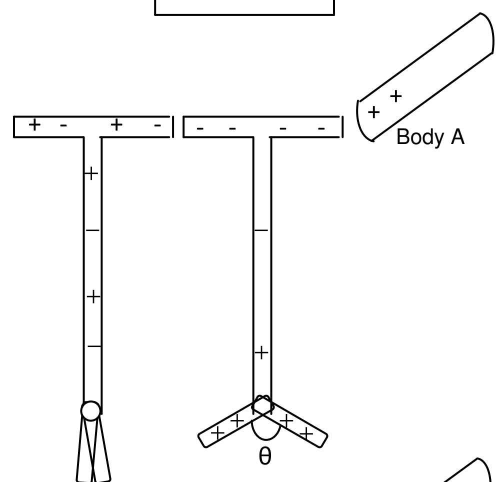
Leaves are pivoted such that angle between the leaves can change on charging.

Electroscope is used to detect nature of charge on a body or neutrality of body.

b) **Case I**:-

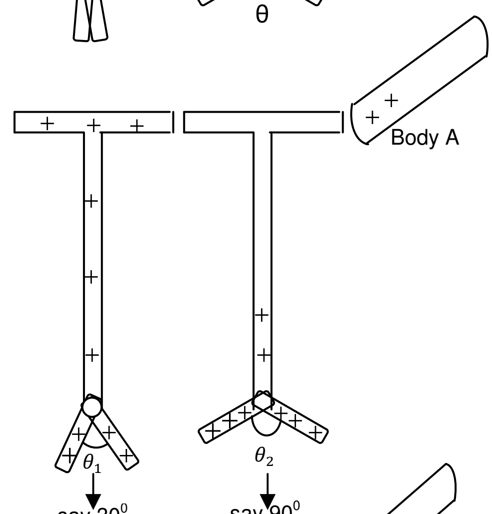
Electroscope is neutral and +ve charge body is brought near to it.

When a +vely charged body is brought near a neutral electroscope, body a repels +ve charge to leaves of electroscope. As charges on leaves are similar, they repel each other and diverge by angle θ.



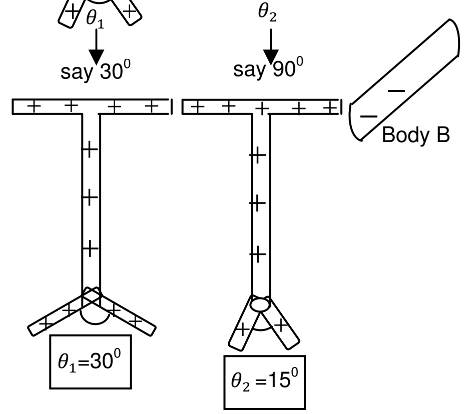
Case II:-

Electroscope is +vely charged and +vely charged body is brought near it. +vely charged body A pushes the charges towards leaves. Angle θ_2 is more than θ_1 due to high repulsion.



Case III:-

When a –vely charged body B is brought near electroscope shifts to disc charge on leaves decreases and they come close.

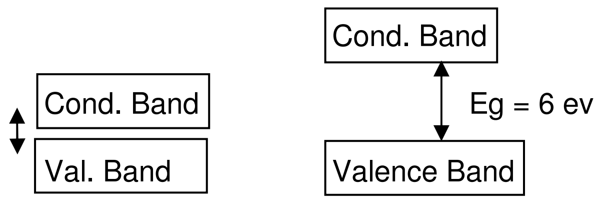


Q.3. **a) What are conductors and Insulators?**
b) How "Earthing" of devices reduces injury to humans?

Ans.a) **Conductors**:-
Materials in which electrons are comparatively free to move e.g. Cu, Ag etc. Conductors offer low resistance to flow of current.

Insulators:-
Materials in which electrons are not free to move e.g. paper, rubber. Insulator offer high resistance to flow of current.

In terms of forbidden gap:-

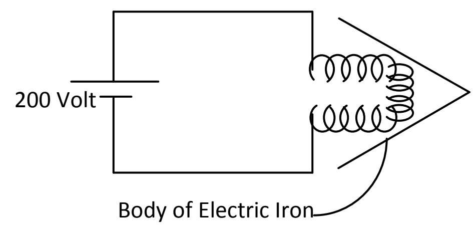


Eg ≈ 0 ev for conductors

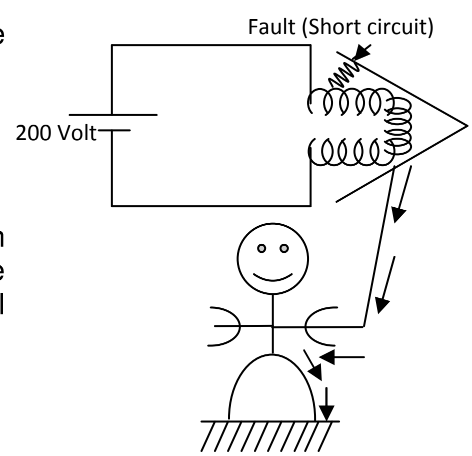
Eg = 6 ev for insulators

Eg → Energy gap.

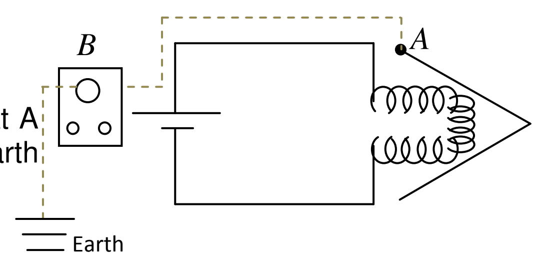
b) **Without earthing circuit**:-
In case of no fault, circuit is shown in fig. and there is no harm.



In case of a fault, body of electric iron also at high voltage (say 200 volt). In case anybody touches the electric iron, current will flow through the body and will cause injury or death.



With earthing wire circuit:-
Earthing wire touches the body of electric iron at A and at B in plug. In case of fault, current will flow to earth through dotted path and not through the human body.



Q.4. Can you charge a ball from a distance?

OR

Two methods of charging:-

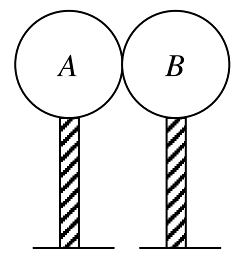
1. **Charging by conduction.**
2. **Charging by induction.**

Ans. **Induction**:-

Action from a distance is called induction. Here we will charge a body (say A) by a charged rod, without touching.

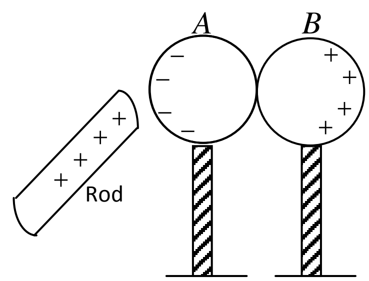
Step-1:-

Two balls touch each others. These balls are neutral and are mounted on insulating stand.



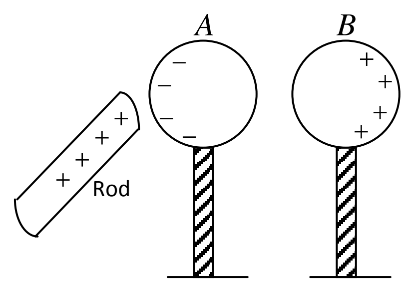
Step-2:-

Bring a +vely charged rod near A. –ve charge of (A and B) comes near rod and +ve charge moves away. This process of charge on surface is called induction.



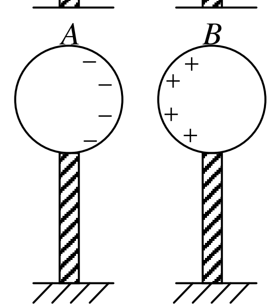
Step-3:-

Separate the sphere A and B, keeping the rod in the vicinity.



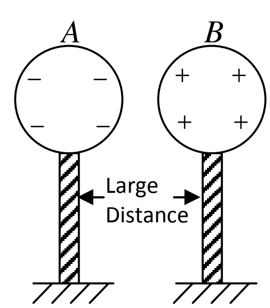
Step-4:-

Remove the rod, -ve and +ve charge on A and B come close to each other. Two spheres A and B attract each other at this stage.



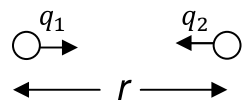
Step-5:-

Increase the distance between two spheres A and B.



In this process of charging by induction, Rod loses no charge. Two spheres A and B get equal and opposite charge.

Q.5. a) State and explain Coulomb's Law?
b) Compare Coulomb's Law with Newton's Law of Gravitation.



Ans.a) **Coulomb's Law**:-

If two charges q_1 and q_2 are placed r distance apart, force between two is directly proportional to product of charges and inversely proportional to square of distance r.

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

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

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

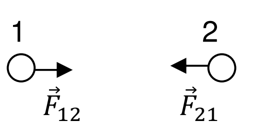
Where K = $\left(\frac{1}{4\pi\epsilon_0}\right)$ = 9 x 10^9 for free space.

$\epsilon_0 \rightarrow$ permittivity of free space.

b)

Coulomb's Law

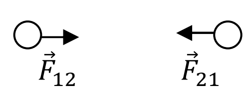
1. $F \propto \frac{q_1 q_2}{r^2}$
2. F can be attractive or repulsive.
3. F acts along the line joining the centres of two charges.
4. $F = \left(\frac{1}{4\pi\epsilon_0}\right) \cdot \frac{q_1 q_2}{r^2}$

   $\left(\frac{1}{4\pi\epsilon_0}\right)$ depends on material medium in between two charges.
5. 

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

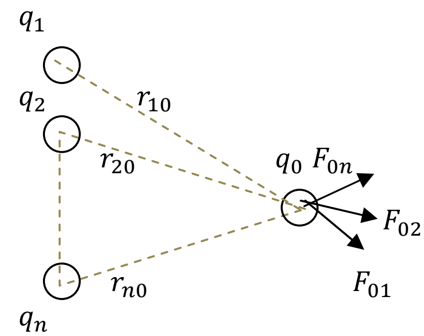
Newton's Law

1. $F \propto \frac{m_1 m_2}{r^2}$
2. F is attractive only
3. F acts along the ling joining the centres of two masses.
4. $F = \frac{G.m_1.m_2}{r^2}$

   G does not depend on material medium in between two masses. G is universal gravitational constant.
5. 

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

Q.6. **a) Find force F on a charge q_0 due to *n* charges?**
b) Three charges, each of magnitude q, are placed on corners of equilateral triangle of side L. Find force on any one due to other two.



Ans.a) $F_{01} \rightarrow$ Force on q_0 due to q_1

$F_{02} \rightarrow$ Force on q_0 due to q_2

$F_{0n} \rightarrow$ Force on q_0 due to q_n

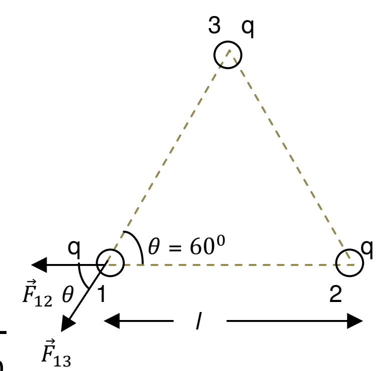
$\vec{F}_{total}$ = Vector sum of all forces on q_0

$$= \vec{F}_{01} + \vec{F}_{02} + \vec{F}_{03} \text{ ---------------- } \vec{F}_{0n}$$

$$= \frac{q_1.q_0}{4\pi\epsilon_0.r_{10}^2} . \hat{r}_{10} + \frac{q_2.q_0}{4\pi\epsilon_0.r_{20}^2} . \hat{r}_{20} \text{ --- } \frac{q_n.q_0}{4\pi\epsilon_0.r_{n0}^2} . \hat{r}_{n0}$$

$$\boxed{\vec{F}_{total} = \frac{q_0}{4\pi\epsilon_0} . \left[\frac{q_1}{r_{10}^2} . \hat{r}_{10} + \frac{q_2}{r_{20}^2} . \hat{r}_{20} - - - \frac{q_n}{r_{n0}^2} . \hat{r}_{n0}\right]}$$

b) Net force on charge at (1)



$$\vec{F}_1 = \vec{F}_{12} + \vec{F}_{13}$$

$$|\vec{F}_1| = \sqrt{F_{12}^2 + F_{13}^2 + 2.F_{12}.F_{13}.cos\theta}$$

$$= \sqrt{\left(\frac{q.q}{4\pi\epsilon_0 .l^2}\right)^2 + \left(\frac{q.q}{4\pi\epsilon_0 .l^2}\right)^2 + 2\left(\frac{q.q}{4\pi\epsilon_0 .l^2}\right)\left(\frac{q.q}{4\pi\epsilon_0 .l^2}\right). cos60^0}$$

$$|\vec{F}_{12}| = \frac{q.q}{4\pi\epsilon_0 .l^2} = |\vec{F}_{13}|$$

$$= \frac{q.q}{4\pi\epsilon_0 .l^2} \sqrt{1^2 + 1^2 + 2.1.1.\left(\frac{1}{2}\right)}$$

$$\boxed{|\vec{F}_1| = \frac{q.q}{4\pi\epsilon_0 .l^2} \sqrt{3}}$$

Q.7. a) What is a field?
b) Compare “Gravitational Field” and “Electric Field”.

Ans.a) **Field**:-

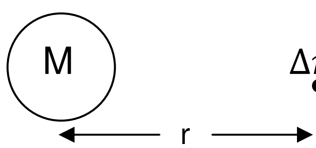
Field is space surrounding a mass/charge/magnet where effect of the mass/charge/magnet can be experienced.

Field due to mass is called “Gravitational Field”.
Field due to charge is called “Electric Field”
Field due to magnet is called “Magnetic Field”.

b)

Gravitational Field

1. Gravitational Field is due to mass.

2. 

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

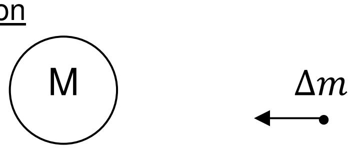
$$\frac{F_g}{\Delta m} = \frac{G.M}{r^2}$$

$$\boxed{g = \frac{G.M}{r^2}}$$

g → Gravitational Field intensity

3. Gravitational Field intensity at a point is defined as the force experienced by unit test mass.

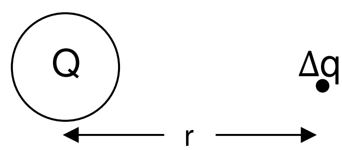
4. Direction



Towards centre of M as Gravitational Field is always attractive.

Electric Field

1. Electric Field is due to charge.

2. 

$$F_e = \frac{1}{4\pi\epsilon_0} \cdot \frac{Q.\Delta q}{r^2}$$

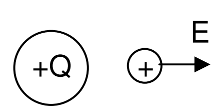
$$\frac{F_e}{\Delta q} = \frac{1}{4\pi\epsilon_0} \cdot \frac{Q}{r^2}$$

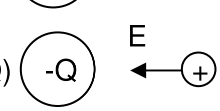
$$\boxed{E = \frac{1}{4\pi\epsilon_0} \cdot \frac{Q}{r^2}}$$

E → Electric Field intensity

3. Electric Field is defined as the force that a unit +ve charge would experience, if place at that point.

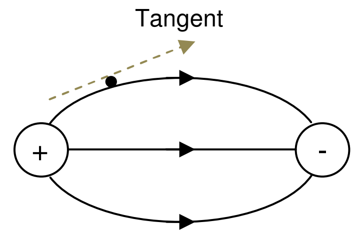
4. Direction

E is away due to (+Q) 

E is towards due to (-Q) 

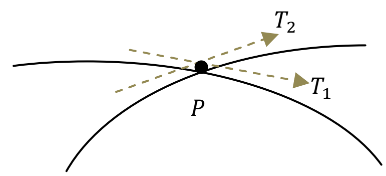
Q.8. Properties of Electric lines of force?

Ans. Electric Field line is a curve drawn in such a way that the tangent to it at each point is in direction of the net field at that point.



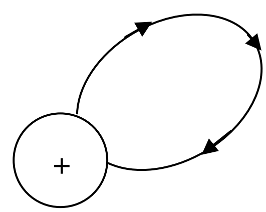
1. Electric Field lines start from +ve charge.
2. Electric Field lines end at –ve charge.
3. No two Electric lines of force can cross each other

Proof:-Let two electric lines cross each other at *P* as shown. Electric Field at any point is tangent to line at that point. At point *P*, there are two tangents T_1 and T_2. It means charge will have two accelerations when placed at *P*, which is not possible.



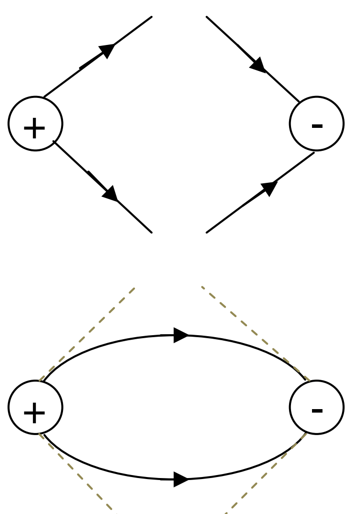
So, no two lines can cross each other.

4. Field lines do not form closed loop. (Electrostatic)

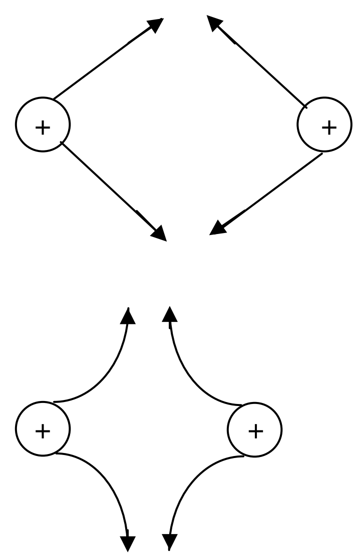


5.

Contract Longitudinally

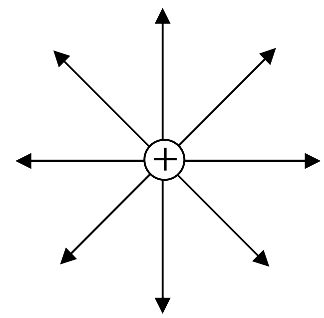


Repel Laterally



Q.9. a) What is electric flux? Number of lines of Electric flux from one, q coulomb charge?
b) Define electric field on the basis of "Electric Flux Lines". Relation between "Electric Flux ϕ" and "Electric Field E"?

Ans.a) **Electric Flux, ϕ_E**:-



Total number of Electric lines coming out of charge q is called "Electric Flux"

No. of lines coming out of 1C charge $= \frac{1}{\epsilon_0}$

$= 1.13 \times 10^{11}$

$$\left(\frac{1}{4\pi\epsilon_0} = 9 \times 10^9\right)$$

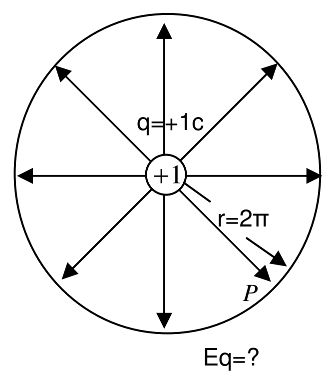
No. of lines coming out of q Coulomb charge $= \frac{q}{\epsilon_0}$

b) **Electric Field**:-

Electric Field is defined as
"No. of Electric lines per unit area".

Example:-

$$E_P = \frac{No.of\ lines}{Area}$$



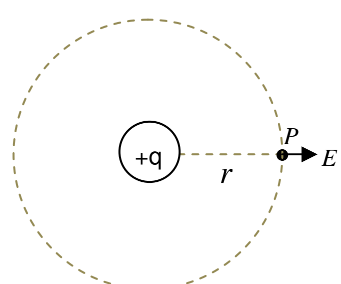
$$E_P = \frac{1/\epsilon_0}{4\pi.r^2}$$

$$E_P = \frac{1}{4\pi\epsilon_0.r^2}$$

$$= \frac{1}{4\pi\epsilon_0.2^2}$$

$= 2.25 \times 10^9$ lines/Area

General $$E_P = \frac{q/\epsilon_0}{4\pi.r^2}$$



$$E_P = \frac{q}{4\pi\epsilon_0.r^2}$$

E_P is electric field at any point *P*.

Q.10. State, Explain and prove "Gauss's Law"?

Ans. **Gauss's Law**:-

Total number of lines coming out of a closed surface is equal to $\frac{1}{\epsilon_0}$ times the charge enclosed by surface.

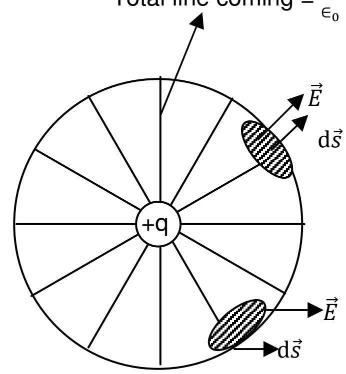
Small number of lines from

Area $d\vec{s}$ $= \vec{E} \, . \, \overrightarrow{ds}$

Total number of lines from

Surface $= \oint \vec{E} \, . \overrightarrow{ds}$

Law $\boxed{\oint \vec{E} \, . \overrightarrow{ds} = \frac{q}{\epsilon_0}}$



$\vec{E}$ (no. of lines/Area)

$d\vec{s}$ (Area)

(Spherical Shape)

Proof:-

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

LHS $= \oint \vec{E} \, . d\vec{s}$

$= \oint E \, . \text{ ds . cos}\theta$

$= \oint E \, . \text{ ds . 1.}$ (As $\theta = 0^0$)

$= \oint . \frac{q}{4\pi\epsilon_0 . r^2} \, . \text{ ds}$

$= \frac{q}{4\pi\epsilon_0 . r^2} \oint ds$

$= \frac{q}{4\pi\epsilon_0 . r^2} \, . \, 4\pi . r^2$ [Total Surface area of Sphere i.e. $\oint ds = 4\pi . r^2$]

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

= R.H.S

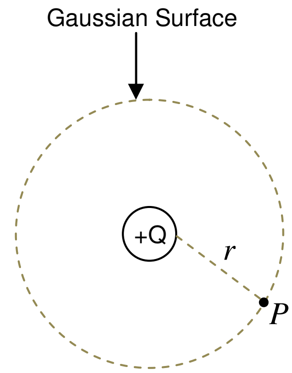
Q.11. Use Gauss's Law

a) To find E field at distance *r* from a charge Q.

b) To find E at distance *r* from a spherical shell of radius R and having charge Q.

Ans.a) **<u>E due to point charge</u>**:-

Assume a Gaussian Surface at distance *r*



As per Gauss's Law $\oint E.ds = \frac{Q}{\epsilon_0}$

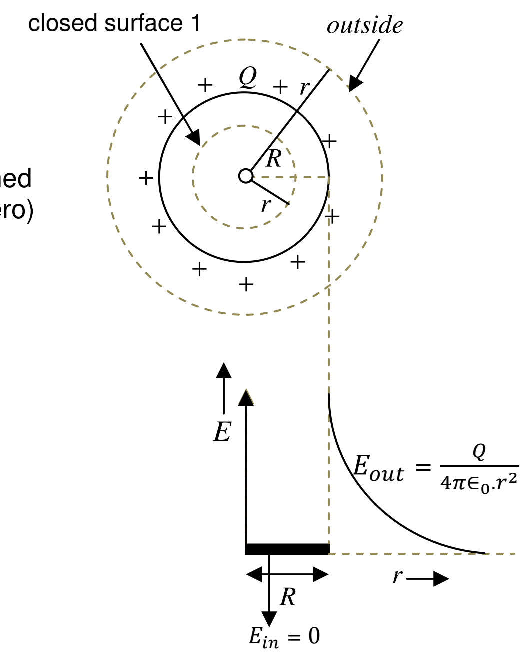
$$E.\oint ds = \frac{Q}{\epsilon_0} \quad \text{(E→constant in magnitude)}$$

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

$$E = \frac{Q}{4\pi\epsilon_0 r^2}$$

b) **<u>E due to charge on spherical shell</u>**:-

<u>Case I</u>:- Inside spherical shell



$$\oint E.ds = \frac{Q}{\epsilon_0}$$

$$E\,(4\pi r^2) = 0 \quad \text{(As charge contained in surface 1 is zero)}$$

$$E_{in} = 0$$

<u>Case II</u>:- Outside spherical shell

$$\oint E.ds = \frac{Q}{\epsilon_0}$$

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

$$E_{out} = \frac{Q}{4\pi\epsilon_0.r^2}$$

Q.12 Use Gauss's Law

a) To find Electric field, *E* due to infinitely long straight uniformly charged wire..

b) **To find Electric field, *E* due to uniformly charged infinite plane sheet.**

Ans.a) Let the length of conductor (under Consideration),

= L

Charge = Q

Charge per unit length, $\lambda = \frac{Q}{L}$

As per Gauss's Law

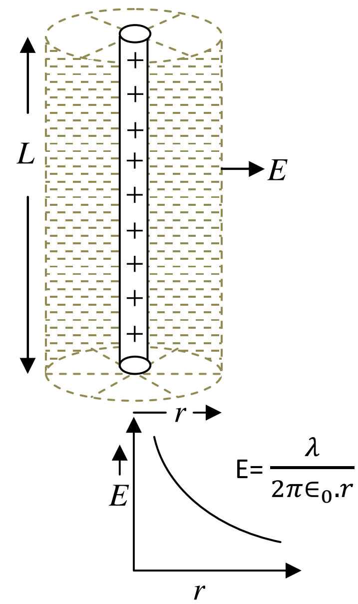
$$\oint E.ds = \frac{Q}{\epsilon_0}$$

$$E.\oint ds = \frac{Q}{\epsilon_0}$$

$$E.\ (2\pi r.L) = \frac{Q}{\epsilon_0}$$

$$E = \frac{Q/L}{2\pi\epsilon_0.r}$$

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



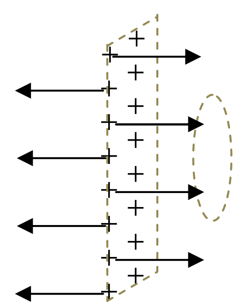
b) As charge is present in form of a sheet, 50% lines move to left and 50% lines move to right.

No. of lines moving to left = $\frac{Q}{2.\epsilon_0}$

No. of lines moving right = $\frac{Q}{2.\epsilon_0}$

No. of lines moving per unit area

$$= \frac{Q}{2.\epsilon_0} \cdot \frac{1}{\Delta} = \frac{Q/A}{2.\epsilon_0} = \frac{Q}{2.\epsilon_0} = \frac{\sigma}{2.\epsilon_0} \quad \boxed{E = \frac{\sigma}{2.\epsilon_0}}$$



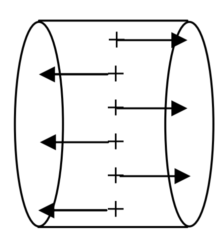
$\sigma \rightarrow$ charge per unit area

<u>**Alternate**</u>:- $\oint E.ds = \frac{Q/2}{\epsilon_0}$

$$E.S = \frac{Q}{2.\epsilon_0}$$

$$E.S = \frac{Q/S}{2.\epsilon_0}$$

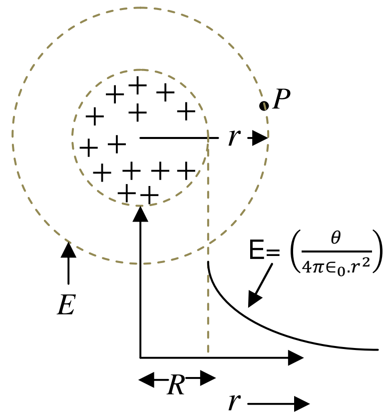
$$\boxed{E = \frac{\sigma}{2.\epsilon_0}}$$



Q.13. Given a spherical cloud of charge *Q* and radius *R*

a) Find E outside the cloud.

b) Find E inside the cloud.



Ans.a) **E outside**:- **R ≤ r < ∞**

Take a point *P* outside the sphere, Assume a Gaussian Surface of radius *r*.

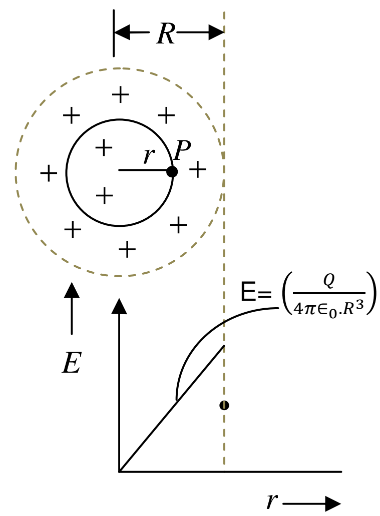
As per Gauss's Law

$$\oint E.ds = \frac{Q}{\epsilon_0}$$

$$E.\oint ds = \frac{Q}{\epsilon_0}$$

$$E.\ 4\pi r^2 = Q/\epsilon_0$$

$$\boxed{E_{out} = \frac{Q}{4\pi\epsilon_0.r^2}}$$



b) **E inside**:- **0 ≤ r ≤ R**

Take a point *P* inside the cloud. Assume a Gaussian Surface of radius *r*.

As per Gauss's Law

$$\oint E.ds = \frac{charge}{\epsilon_0}$$

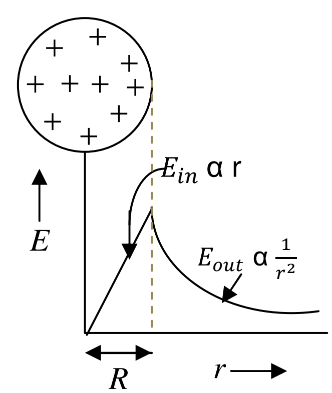
$$= \frac{\left(\frac{Q}{\frac{4}{3}\pi R^3} \cdot \frac{4}{3}\pi r^3\right)}{\epsilon_0}$$

$$E.\oint ds = \frac{Q}{\epsilon_0} \cdot \frac{r^3}{R^3}$$

$$E.\ 4\pi r^2 = \frac{Q}{\epsilon_0} \cdot \frac{r^3}{R^3}$$

$$\boxed{E_{in} = \left(\frac{Q}{4\pi\epsilon_0.R^3}\right).r}$$

E α r means a straight line



Conclusion:-

E_{in} α r

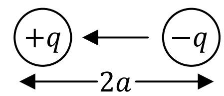
E_{out} α $\frac{1}{r^2}$

Q.14. a) What is an electric dipole? Units?
b) Find electric field on axial points and equatorial line.

Ans.a) **Electric Dipole**:-
An electric dipole is a pair of equal and opposite point charges +q and –q separated by distance 2a.

| Dipole moment, þ = q.2a |

Units → C-m.



Direction of dipole moment, $\hat{þ}$ is from –q to +q.

b) **Electric Field**:-

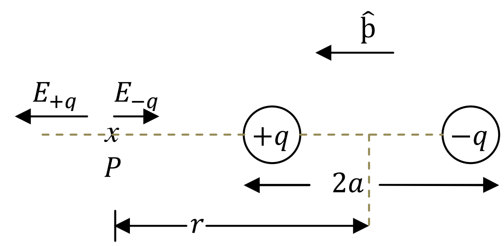
Case I:- For point on the axis

Total field at E = $E_{(+q)} + E_{(-q)}$

$= \frac{+q}{4\pi\epsilon_0(r-a)^2} + \frac{-q}{4\pi\epsilon_0(r+a)^2}$

$= \frac{q}{4\pi\epsilon_0} \cdot \frac{4.a.r}{(r^2-a^2)^2}\hat{þ}$

$\vec{E} \simeq \frac{4.q.r}{4\pi\epsilon_0.r^3} . \hat{þ}$ for r ≫ a



Case II:- For point on equatorial line

Electric filed at P due to +q

$E_{+q} = \frac{q}{4\pi\epsilon_0}(r^2 + a^2)$

$E_{-q} = \frac{q}{4\pi\epsilon_0}(r^2 + a^2)$

$|\vec{E}_{res}| = |E_{+q}|.\cos\theta + |E_{-q}|.\cos\theta$

$= \frac{2.q}{4\pi\epsilon_0(r^2+a^2)}. \cos\theta$

$= \frac{2.q}{4\pi\epsilon_0(r^2+a^2)}. \frac{a}{\sqrt{a^2+r^2}}$

$\vec{E}_{res} = \frac{2.q.a}{4.\pi.\epsilon_0.r^3}(-\hat{þ})$ for r >> a