Electric Charges & Field
SYNOPSIS

- Electrical charge is the property associated with mass. Net charge is because of excess or deficiency of electron.
- Charge is a scalar quantity having unit ampere-second or coulomb.
- Charge is transferable, quantised (i.e. exist as integral multiple of quanta e).
  q=ne
  n=positive or negative integer
- Charge is conserved i.e. in an isolated system total charge doesn't change with time though individual charge may change.
- Charge is invariant i.e., independent of frame of reference.
- Positive charge is because of deficiency of electron and negative charge is because of excess of electron.
- Conductor are materials in which outer electrons are loosely bound i.e. free to move which causes flow of current.
- Insulator are materials in which electron are tightly bound.
- There can be three method of charging of conductors.
  a) Friction b) Conduction c) Electrostatic induction

- The electrostatic force acting between two point charge acts always along the line joining two charges is given by coulomb law.

  $F = \frac{k\,q_1 q_2}{r^2}$ where $k = \frac{1}{4\pi \in}$

  $r =$ separtion between the charge.

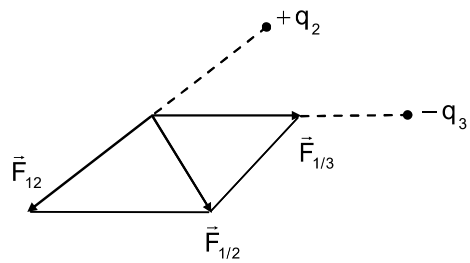
  q_1 and $q_2 =$ magnitude of charge

  $\in =$ permitivity of medium of placement of charge.

- Between same charges force will be repulsive and opposite charges force will be attractive
- Relative permittivity or the electric constant $(\in_r \text{ or } K)$

  $$= \frac{\text{permitivity of medium } (\in)}{\text{permitivity of air or vacuum } (\in_0)}$$

- For air or vacuum $(\in_r \text{ or } k) = 1$
- For all di-electric medium $\in_r$ or $k > 1$
- In case of multi charge interaction the effective force on any charge will be vector sum of force applied by all other charges.



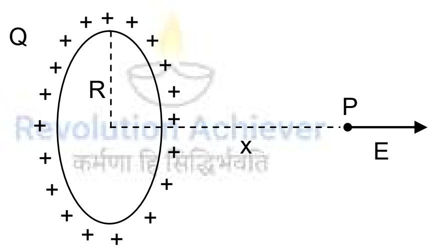
Electric field intensity is the electric force acting on unit test charge.

- Electric field is vector quantity having unit $\frac{\text{Newton}}{\text{Coulomb}}$ and dimension $\left[MLT^{-3}A^{-1}\right]$
- For positive charge electric field intensity is away from charge and for negative charge it is towards charge.

- Electric field intensity due to a point charge at a distance r from charge is

$$\left|\vec{E}\right| = \frac{1}{4\pi \in_0}\frac{q}{r^2}$$

- **Electric field intensity due to a uniformly charged ring at its axis.**

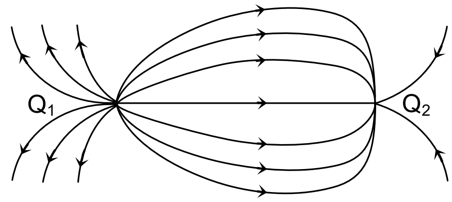


$$\left|\vec{E}_P\right| = \frac{1}{4\pi \in_0 K}\frac{Qx}{\left(x^2 + R^2\right)^{3/2}}$$

Where $\rightarrow$
Q = charge on ring
R=radius of ring
x=axial distance from centre of ring.

- For positive charge electric field is directed away and for negative charge electric field is directed towards centre of ring.
- Electric field lines are imaginary curves which represent the direction of electric field at any point and also compare intensity of field at any point.
- ***Electric field lines are smooth curve, never cut or touch each other and don't form close loop.***
- Electric field lines originate from positive charge and terminate at negative charge. No of field lines is proportional to magnitude of charge.

* ***At the surface of conductor field lines are always normal to the surface.*** If electric field will be zero there will be no field lines.
* Tangent to field lines denote direction of electric field and its number is proportional to magnitude of field intensity.



$|q_1| > |q_2|$

* Electric flux is field lines associated with a given area perpendicular to surface

$$\phi_E = \int \vec{E}.d\vec{s}$$

* Electric flux is a scalar quantity having unit $\left(\frac{N\text{-}m^2}{C}\right)$ or $(V - m)$ and dimension $\left[ML^3T^{-3}A^{-1}\right]$
* Gauss theorem relates electric flux linked with closed Gaussian surface to total charge inside Gaussian surface.

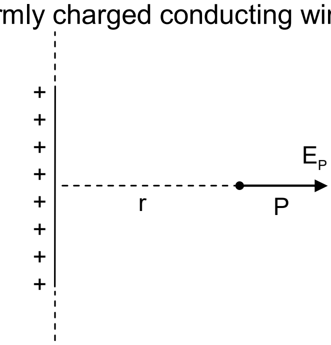
$$\phi_E = \oint \vec{E}.d\vec{s} = \frac{1}{\epsilon_0}(q_{in})$$

Where $\rightarrow$

q_{in} = charge inside closed Gaussian surface.

* Gaussian surface may be symmetrical or asymmetrical i.e. ***flux linked with closed surface is independent of its shape.***
* In a Gaussian surface $\phi_E = 0$ doesn't mean that E=0, it can be possible it surface is parallel to field. But E=0 show that $\phi_E = 0$.
* ***Electric flux through Gaussian surface (closed surface) is independent of position of charge.***

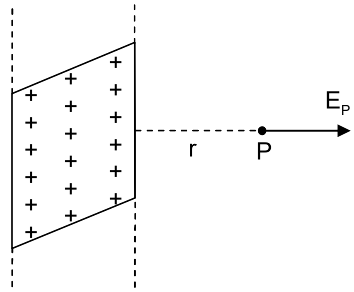
* Electric field due to a long uniformly charged conducting wire.



$$\left|\vec{E}_P\right| = \frac{\lambda}{2\pi \epsilon_0 r}$$

Where λ = linear charge density.

- Electric field due to uniformly charge long sheet.



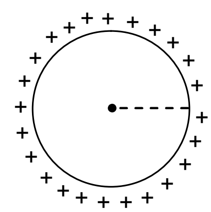
$$E_P = \frac{\sigma}{2\in_0}$$

Where σ = surface charge density

- ***Inside the conductors net charge will always be zero.***

Electric field due to a hollow (non-conducting), hollow or solid (conducting or non-conducting) sphere

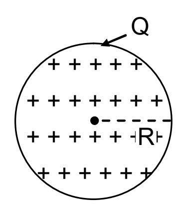
1) Inside point (r < R)
   E = 0
2) At surface (r=R)
   $$E = \frac{1}{4\pi\in_0}\frac{Q}{R^2}$$



3) Outside point (π > R) $E = \frac{1}{4r\in_0}\frac{Q}{R^2}$

   Where Q = Total surface charge
   R = radius of sphere

- **Electric field due to solid non-conducting sphere.**



1) Inside point (r < R)
   $$E = \frac{1}{4\pi\in_0}\frac{Qr}{R^3}$$
2) Inside point (r < R)
   $$E = \frac{1}{4\pi\in_0}\frac{Q}{R^2}$$
   Where Q=charge on the sphere
   R=radius of sphere
3) Outside point (r > R)
   $$E = \frac{1}{4\pi\in_0}\frac{Q}{r^2}$$

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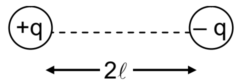
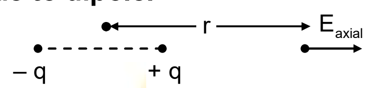
Electric dipole

Electric dipole → It is a system of two equal and opposite charge separated by small distance



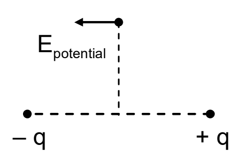
- Dipole moment = It is the product of charge to its separation $\vec{P} = q(2\ell)$
- Dipole moment in a vector quantity having direction from negative charge to positive charge.
- S.I. unit of dipole moment is coulomb metre and dimension [LTA]
- Net force acting on dipole in uniform electric field is zero.
- Torque acting on dipole kept in uniform electric field is $\vec{\tau} = \vec{P} \times \vec{E}$
- Electrostatic potential energy of a dipole kept in uniform electric field is
  $U = -\vec{P}.\vec{E} = -PE\cos\theta$
  Where θ =angle between electric field and dipole moment.
- Work done to rotate a dipole will be equal to change in electric potential energy of dipole.

- **Electric field and potential due to dipole.**



- Electric field at a distance r from the centre of dipole at axial position will be
  $$\left|\vec{E}_P\right| = \frac{1}{4\pi \in_0} \frac{2P}{r^3}$$
  Note → Direction of electric field will be in the direction of dipole moment.

1) Electric potential at a distance r from the centre of dipole at axial position will be
$$V = \frac{1}{4\pi \in_0} \frac{P}{r^2}$$
2) At equatorial position



Electric field at a distance r from centre of dipole at equatorial position will be
$$E = \frac{1}{4\pi \in_0} \frac{P}{r^3}$$
Note → Direction of electric field will be opposite to dipole moment.

- Electric potential at equatorial position will be V=0