- **Comparison between Coulomb force and gravitational force is as follows :**

  Coulomb force and gravitational force follow the same inverse square law.

  Coulomb force can be attractive or repulsive while gravitational force is always attractive.

  Coulomb force between the two charges depends on the medium between two charges while gravitational force is independent of the medium between the two bodies.

  The ratio of coulomb force to the gravitational force between two protons at a same distance apart is

  $$\frac{e^2}{4\pi\varepsilon_0 G m_p m_p} = 1.3 \times 10^{36}$$

Illustration 2

Electric force between two point charges q_1 and q_2 at rest is F. Now if a charge $-q$ is placed next to q_1 . What will be the (a) force on q_2 (b) total force on q_2?

Soln. : (a) As electric force between two body interaction *i.e.*, force between two particles is independent of presence or absence of other particles, the force between q_2 and q_1 will remain unchanged, *i.e.*, F.

(b) An electric force is proportional to the magnitude of charges, total force on q_2 will be given by

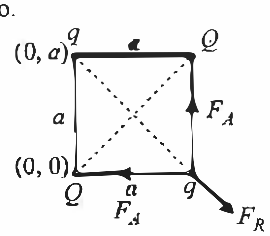
$$\frac{F'}{F} = \frac{q_2 q'}{q_2 q} = \frac{q'}{q} = \frac{0}{q} = 0$$

[as $q' = q + (-q) = 0$]

Hence, the resultant force on q_2 will be zero.

Illustration 3

For the system shown in figure. Find Q for which resultant force on q is zero.



Soln.: For force on q to be zero, charges q must be of opposite of nature.

Net attraction force on q due to Q = repulsion force due to q

$$\sqrt{2}F_A = F_R \Rightarrow \sqrt{2}\frac{KQq}{a^2} = \frac{Kq^2}{(\sqrt{2}a)^2}$$

$\Rightarrow \quad q = 2\sqrt{2}Q$

Hence, $q = -2\sqrt{2}Q$

PRINCIPLE OF SUPERPOSITION

- It states that, when a number of charges are interacting with each other, the total force on a given charge is vector sum of forces exerted on it by all other charges;

  i.e., $F = K\frac{q_0 q_1}{r_1^2} + K\frac{q_0 q_2}{r_2^2} + \ldots\ldots + K\frac{q_0 q_n}{r_n^2}$

  In vector form,

  $$\vec{F} = Kq_0 \sum_{i=1}^{n} \frac{q_i \vec{r}_i}{r_i^2}$$

CONTINUOUS CHARGE DISTRIBUTION

- **Linear charge density :** Charge per unit length is known as linear charge density. It is denoted by symbol λ.

  $\lambda = \frac{\text{Charge}}{\text{Length}}$

  Its SI unit is C m^{-1}.

- **Surface charge density :** Charge per unit area is known as surface charge density. It is denoted by symbol σ.

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

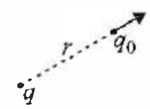
  Its SI unit is C m^{-2}.

ELECTRIC FIELD

- The region surrounding a charge (or charge distribution) in which its electric effects are perceptible is called the electric field of the given charge.

  Electric Field due to Point Charge

  $$\vec{E} = \lim_{q_0 \to 0} \frac{\vec{F}}{q_0} = \frac{kq}{r^3}\vec{r}$$

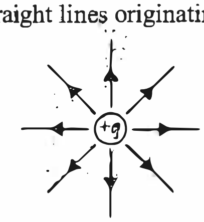
  

  Here, test charge q_0 is a fictitious charge that exerts no force on hearby changes but experiences force due to them.

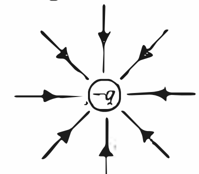
Electric Field Lines

- An electric field can be represented and so visualized by electric field lines. These are drawn so that, the field lines at a point, (or the tangent to it if it is curved) gives the direction of $\vec{E}$ at that point, *i.e.*, the direction in which of positive charge would move and the number of lines per unit cross-section area is proportional to E. The field lines are imaginary but the field it represents is real.

- The electric field due to a positive point charge is represented by straight lines originating from the charge.

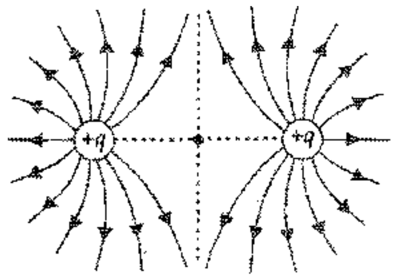


- The electric field due to a negative point charge is represented by straight lines terminating at the charge.

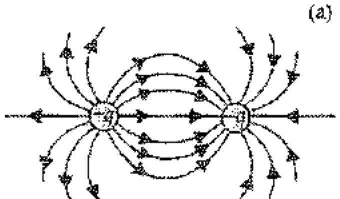


The lines of force for a charge distribution containing more than one charge. From each charge we can draw the lines isotropically. The lines may not be straight as one moves away from a charge.

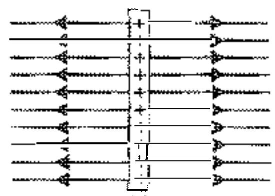
The shape of lines for same charge distribution shown above.



(a)



(b)



(c)

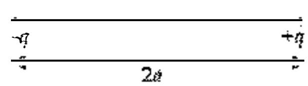
- The lines of force are purely a geometrical construction which help us to visualise the nature of electric field in the region. They have no physical existence.
- The number of lines originating or terminating on a charge is proportional to the magnitude of charge. In rationalised MKS system $(1/\varepsilon_0)$ electric lines are associated with unit charge. So if a body encloses a charge q, total lines of force associated with it (called flux) will be q/ε_0.
- Lines of force per unit area normal to the area of a point represents magnitude of intensity, crowded lines represent strong field while distant lines represent weak field.

ELECTRIC DIPOLE

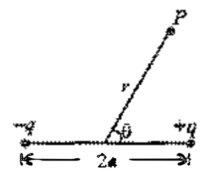
- It is a pair of two equal and opposite charges separated by a small distance.

Electric Dipole Moment

- It is a vector quantity whose magnitude is equal to product of the magnitude of either charge and distance between the charges. *i.e.* $|\vec{p}| = q2a$



- By convention the direction of dipole moment is from negative charge to positive charge.
- The SI unit of electric dipole moment is C m and its dimensional formula is $[M^0LAT]$. The practical unit of electrical dipole moment is debye.
- **Electric Field Intensity on Axial Line (End on Position) of the Electric Dipole**
  - At the distance r from the centre of the electric dipole, $E = \frac{1}{4\pi\varepsilon_0}\frac{2pr}{(r^2 - a^2)^2}$
  - At very large distance *i.e.*, $(r >> a)$, $E = \frac{2p}{4\pi\varepsilon_0 r^3}$
  - The direction of the electric field on axial line of the electric dipole is along the direction of the dipole moment (*i.e.* from $-q$ to q).
- **Electric Field Intensity on Equatorial Line (Board on Position) of Electric Dipole**
  - At the point at a distance r from the centre of electric dipole, $E = \frac{1}{4\pi\varepsilon_0}\frac{p}{(r^2 + a^2)^{3/2}}$.
  - At very large distance *i.e.*, $r >> a$, $E = \frac{1}{4\pi\varepsilon_0}\frac{p}{r^3}$.
  - The direction of the electric field on equatorial line of the electric dipole is opposite to the direction of the dipole moment.
    (*i.e.* from q to $-q$)
- **Electric Field Intensity at any Point due to an Electric Dipole**



The electrical field intensity at point P due to an electric dipole, $E = \frac{1}{4\pi\varepsilon_0}\frac{p}{r^3}\sqrt{1+3\cos^2\theta}$

- Electric Field Intensity due to a Charged Ring

  At a point on its axis at distance r from its centre,
  $$E = \frac{1}{4\pi\varepsilon_0}\frac{qr}{(r^2 + a^2)^{3/2}}$$
  where q is the charge on the ring and a is the radius of the ring.

  At very large distance *i.e.* $r >> a$, $E = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}$

  At the centre of the ring, *i.e.* $r = 0$, $E = 0$.

- **Torque on an Electric Dipole Placed in a Uniform Electric Field**

  When an electric dipole of dipole moment $\vec{p}$ is placed in a uniform electric field $\vec{E}$, it will experience a torque and is given by

  $\vec{\tau} = \vec{p} \times \vec{E}$

  $\tau = pE\sin\theta$

  where θ is the angle between p and E.
- Torque acting on a dipole is maximum ($\tau_{max} = pE$) when dipole is perpendicular to the field and minimum ($\tau = 0$) when dipole is parallel or antiparallel to the field.
- When a dipole is placed in a uniform electric field, it will experience only torque and the net force on the dipole is zero while when it is placed in a non uniform electric field, it will experience both torque and net force.

Illustration 4

Two positive point charges $q_1 = 16$ μC and $q_2 = 4$ μC are separated in vacuum by a distance of 3.0 m. Find the point on the line between the charges where the net electric field is zero.

Soln.: Between the charges the two field contributions have opposite directions, and the net electric field is zero at a point (say P) where the magnitude of $\vec{E}_1$ and $\vec{E}_2$ are equal. However, since $q_2 > q_1$ point P must be closer to q_2, in order that the field of the smaller charge can balance the field of the larger charge