Condition for coloumb's law

- The **coloumb's** law is valid under following **considerations** :
  - The **charges** are *stationary* .
  - The **charges** in consideration are point charges.
    - The **radius** is negligible compared to the distance of *separation*

Structures satisfying the condition of applicability of coloumb's law

- **Coloumb's law** is *satisfied* by conducting **spheres.**
  - **Charge** is distributed at the conducting sphere.
  - This **charge** appears to originate from the *center* of the **spheres.**
  - The **charge** at the center behaves as a **point** charge.

Couloumb's law

- The expression for **coloumb's** law is given by:

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

  - In CGS system:
    - k = 1
  - In MKS system:
    - k = 9×10^9

Value of k

- The term k is expressed as:

$$k = \frac{1}{4\pi\epsilon_0}$$

- ϵ_0 = $8.85 \times 10^{-12} C^2 N^{-1} m^{-2}$
- The term ϵ_0 is the **permitivitty** of **free space** .

- The **electrostatic force** in *air* and *vacuum* are equal.
- **Air** is not considered as a medium.
- **Electrostatic force** at medium of ϵ is given by:

$$F_{medium} = \frac{1}{4\pi\epsilon}\frac{q_1 q_2}{r^2}$$

Relative Permitivitty

- **Relative Permitivitty** expresses the *number* of times the **permitivitty** of a *medium* is greater than that of **air.**

$$\epsilon_r = \frac{\epsilon}{\epsilon_0}$$

- **Relative Permitivitty** is also termed as **dielectric constant** .

$$F_{medium} = \frac{q_1 q_2}{4\pi\epsilon r^2}$$
$$F_{medium} = \frac{q_1 q_2}{4\pi\epsilon_r \times \epsilon_0 r^2}$$

- The force in a medium of **relative** permitivitty ϵ_r is given by:

$$F_{medium} = \frac{F_{air}}{\epsilon_r}$$

Analysis of relative permitivitty

- The value of **relative permitivitty** only lies in between :

$$1 < \epsilon_r \leq \infty$$

- The value of **relative permitivitty** of metals is **infinity** .

Physical Meaning of Permitivitty

- **Current** is opposed by a conductor **maintained** at a **constant** *p.d.* .
- This **opposition** is called **resistance** .
- **Electric Force** set up by an **electric field** is opposed by **medium** .

- The **greater** the permittivity the **less** *lines of electric* force can pass through the **medium** .

Electrostatic Shielding

- **Metals** having **infinite** relative permittivity completely block **electrostatic** force.
- This **effect** is called **electrostatic shielding.**

Cases of sphere.

- If **two** spheres of same charges are *considered* :

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

- If **two** spheres of opposite charges are *considered* :

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

- These cases **charges** are not present exactly at the **center.**
- Change in **magnitude** of **radius** is seen.

Partial Medium

- The **electrostatic** *force* experienced at a *partial medium* of *thickness* t is:

$$F_{p.medium} = \frac{q_1 q_2}{4\pi\epsilon_0[(r-t) + \sqrt{\epsilon_r} \times t]^2}$$

Equilibrium

A body is said to be in equilibrium if net force is

-

$$0$$

Types of equilibrium on the basis of motion

The types of equilibrium on the basis of motion are

- Translational equilibrium
- Rotational equilibrium

Condition for Translation equilibrium

A body is said to be in translation equilibrium if net force in the body is zero.

Condition for Rotational equilibrium

A body is said to be in rotational equilibrium if net torque in the body is zero.

Types of equilibrium on the basis of number of particles

The types of equilibrium on the basis of number of particles are

- Particle equilibrium
- System equilibrium

Condition for particle equilibrium

A particle is said to be in particle equilibrium if net force in a particle is

- $$0$$

Condition for system equilibrium

A system is said to be in equilibrium if net force in every particle of the system is

- $$0$$

Rules for equilibrium

Location of equilibrium point in like charges

The location of equilibrium point in like charges is

- Between the charges

Location of equilibrium point in unlike charges

The location of equilibrium point in unlike charges is

- Outside the charges

Location of equilibrium point based on the magnitude

The location of equilibrium point lies

- Near the charge having smaller magnitude

Special cases for equilibrium of charges

Same magnitude of charge

Like charges

The equilibrium point of like charges of same magnitude is located at

- the mid point

Unlike charges

The equilibrium point of unlike charges of same magnitude

- does not exist

Problem Solving on two charges

Location of equilibrium point

- Equilibrium point is such a point where an external test charge cannot feel any force.

Like charges

- A external test charge is taken as
- $$q$$
- The charge of small magnitude is taken as
- $$q_{small}$$
- The distance of the test charge from the charge of small magnitude is taken as
- $$x$$
- The charge of greater magnitude is taken as
- $$q_{big}$$
- The distance of test charge from the charge of greater magnitude is taken as
- $$r - x$$

Derivation for magnitude of charges in equilibrium condition

$$
\begin{aligned}
F_{q_{big}\text{ on }q} &= F_{q_{small}\text{ on }q} \\
k \times q \times \frac{q_{small}}{(x)^2} &= k \times q \times \frac{q_{big}}{(r-x)^2} \\
(\frac{r-x}{x})^2 &= \frac{q_{big}}{q_{small}} \\
\frac{r}{x} &= \sqrt{\frac{q_{big}}{q_{small}}} + 1
\end{aligned}
$$

Expression for magnitude of bigger charge in equilibrium condition

$$q_{big} = q_{small}(\frac{r}{x} - 1)^2$$

Expression for magnitude of smaller charge in equilibrium condition

$$q_{small} = q_{big} \times \frac{1}{(\frac{r}{x} - 1)^2}$$

Expression for location of equilibrium point from smaller charge

$$x = \frac{r}{\sqrt{\frac{q_{big}}{q_{small}}} + 1}$$

Expression for distance of separation in equilibrium condition

$$r = x \times (\sqrt{\frac{q_{big}}{q_{small}}} + 1)$$

Unlike charges

- A external test charge is taken as
- $$q$$
- The charge of small magnitude is taken as
- $$q_{small}$$

- The distance of the test charge from the charge of small magnitude is taken as
- $$x$$
- The charge of greater magnitude is taken as
- $$q_{big}$$
- The distance of test charge from the charge of greater magnitude is taken as
- $$r + x$$

Derivation for magnitude of charges in equilibrium condition

$$\begin{aligned} F_{q_{big}\text{ on }q} &= F_{q_{small}\text{ on }q} \\ k \times q \times \frac{q_{small}}{(x)^2} &= k \times q \times \frac{q_{big}}{(r+x)^2} \\ (\frac{r+x}{x})^2 &= \frac{q_{big}}{q_{small}} \\ \frac{r}{x} &= \sqrt{\frac{q_{big}}{q_{small}}} - 1 \end{aligned}$$

Expression for magnitude of bigger charge in equilibrium condition

$$q_{big} = q_{small}(\frac{r}{x} + 1)^2$$

Expression for magnitude of smaller charge in equilibrium condition

$$q_{small} = q_{big}\frac{1}{(\frac{r}{x} + 1)^2}$$

Expression for location of equilibrium point from smaller charge

$$x = \frac{r}{\sqrt{\frac{q_{big}}{q_{small}}} - 1}$$

Expression for distance of separation in equilibrium condition

$$r = x \times (\sqrt{\frac{q_{big}}{q_{small}}} - 1)$$

System equilibrium

Special charge to maintain system equilibrium

- A charge q is considered to maintain the system at equilibrium.
- The equilibrium point is calculated as x .

Derivation for magnitude of charge at system equilibrium

- The sum of forces in system equilibrium amounts to zero.
- The magnitude of charge is such that the force with the smaller charge and special charge is equal with the force between smaller charge and greater charge.
- The direction of the forces are opposite.
- The forces cancel each other.

$$F_{q_{small} \text{ on } q} = -F_{q_{big} \text{ on } q_{small}}$$
$$k \times q_{small} \times \frac{q}{x^2} = -k \times \frac{q_{big} q_{small}}{r^2}$$

Expression for magnitude of special charge in equilibrium condition

$$q = -q_{big} \times (\frac{x}{r})^2$$

Electric field intensity

Electric field intensity at a point is defined as force experienced by unit positive test charge placed at that point.

Expression for electric field intensity

The expression for electric field intensity is given by

$$E = \frac{F}{q}$$

Derivation for dimension of electric field intensity

$$[E] = \frac{[F]}{[q]}$$
$$[E] = \frac{[MLT^{-2}]}{[AT]}$$

Expression for dimension of electric field intensity

The dimension of electric field intensity is

$$[E] = [MLA^{-1}T^{-3}]$$

Derivation for the expression of electric field intensity

$$E = \frac{F}{q}$$
$$E = \frac{kQq}{r^2} \times \frac{1}{q}$$

Expression for electric field intensity in terms of radius and charge

$$E = k\frac{Q}{r^2}$$

Direction of electric field intensity

Positive charges

The direction of electric field intensity of positive charge is

- Away from the charge
-

$$\leftarrow q^{+} \rightarrow$$

Negative charges

The direction of electric field intensity of negative charge is

- Towards the charge
-

$$\rightarrow q^{-} \leftarrow$$

Vector form of electric field intensity

The sign of charge is written in vector form of electric field intensity.

Expression of vector form of electric field intensity on positive charges

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

Direction of unit vector of radius

- The unit vector of radius ($\hat{r}$) is directed towards the observable point.
- The observable point is the point at which the electric field intensity is to be determined.

Expression of vector form of electric field intensity on negative charges

$$E = -(\frac{kQ}{r^2})\hat{r}$$