Electrostatics

Charge

Charge is that property of an object by virtue of which it apply electrostatic force of interaction on other objects.

Charges are of two types

(i) Positive charge

(ii) Negative charge

Like charges repel and unlike charges attract each other.

Conductors

Conductors are those substances which can be used to carry or conduct electric charge from one point to other, e.g. silver, copper, aluminium etc.

Insulators

Insulators are those substances which cannot conduct electric charge, e.g. glass, rubber, plastic etc.

Charging by Induction

The process of changing a neutral body nearby it without making contact between two bodies is known as charging by induction.

Additivity of Charge

If a system consists of n charges $q_1, q_2, q_3 \ldots\ldots\ldots q_n$, then the total charge of the system will be $q_1 + q_2 + q_3 + q_4 + \ldots\ldots q_n$.

Quantisation of Charge

Charge on any object can be an integer multiple of a smallest charge (e).

$$Q = \pm ne$$

where, $n = 1, 2, 3, \ldots$ and $e = 1.6 \times 10^{-19}$ C.

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Conservation of Charge

Charge can neither be created nor be destroyed, but can be transferred from one object to another object.

Recently a new particle has been discovered called 'Quark'. It contains charge $\pm\frac{e}{3}, \pm\frac{2e}{3}$.

The protons and neutrons are combination of other entities called quarks, which have charges $\frac{1}{3}$e. However, isolated quarks have not been observed, so, quantum of charge is still e.

Coulomb's Law of Electrostatics

Electrostatic force of interaction acting between two stationary point charges is given by

$$F = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}$$

where q_1, q_2 are magnitude of point charges, r is the distance between them and ε_0 is permittivity of free space.

Here, $$\frac{1}{4\pi\varepsilon_0} = \left(10^{-7}\frac{\text{N}-\text{s}^2}{\text{C}^2}\right)\text{C}^2$$

Substituting value of $c = 2.99792458 \times 10^8$ m/s,

we get $$\frac{1}{4\pi\varepsilon_0} = 8.99 \times 10^9 \text{ N-m}^2/\text{C}^2$$

In examples and problems we will often use the approximate value.

$$\frac{1}{4\pi\varepsilon_0} = 9 \times 10^9 \text{ N-m}^2/\text{C}^2$$

The value of ε_0 is 8.85×10^{-12} C^2/N-m^2.

If there is another medium between the point charges except air or vacuum, then ε_0 is replaced by $\varepsilon_0 K$ or $\varepsilon_0\varepsilon_r$ or ε.

where K or ε_r is called dielectric constant or relative permittivity of the medium.

$$K = \varepsilon_r = \frac{\varepsilon}{\varepsilon_0}$$

where, ε = permittivity of the medium.

For air or vacuum, $K = 1$

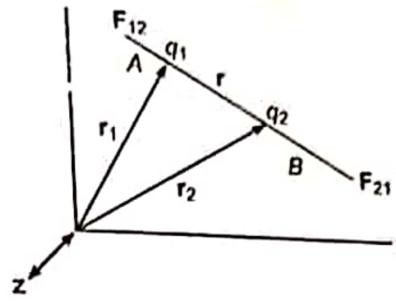
For water, $K = 81$

For metals, $K = \infty$

Coulomb's Law in Vector Form

Let q_1 and q_2 both are positive.

Force on q_2 due to q_1,



$$\mathbf{F}_{21} = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q_1 q_2}{r^2} \, \hat{\mathbf{r}}_{AB}$$

$$\mathbf{F}_{21} = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q_1 q_2}{r^3} \, \mathbf{r}_{AB}$$

$$\mathbf{F}_{21} = \frac{q_1 q_2}{4\pi\varepsilon_0} \cdot \frac{\mathbf{r}_2 - \mathbf{r}_1}{|\mathbf{r}_2 - \mathbf{r}_1|^3}$$

The above equations give the Coulomb's law in vector form.

Force on q_1 due to q_2 = − Force on q_2 due to q_1

$\because$ $$\mathbf{F}_{12} = -\mathbf{F}_{21}$$

$\therefore$ $$\mathbf{F}_{12} = \frac{q_1 q_2}{4\pi\varepsilon_0} \cdot \frac{\mathbf{r}_1 - \mathbf{r}_2}{|\mathbf{r}_1 - \mathbf{r}_2|^3}$$

The forces due to two point charges are parallel to the line joining the point charges; such forces are called **central forces** and so electrostatic forces are **conservative forces.**

Forces between Multiple Charges

Consider a system of n point charges $q_1, q_2, q_3 \ldots q_n$ are distributed in space. Let the charges be $q_2, q_3 \ldots q_n$, exert forces $F_{12}, F_{13}, \ldots F_{1n}$ on charge q_1. The total force on charge q_1 is given by

$$F_1 = \frac{1}{4\pi\varepsilon_0}\left(\frac{q_1 q_2}{r_{12}^2}\,\hat{\mathbf{r}}_{21} + \frac{q_1 q_2}{r_{13}^2}\,\hat{\mathbf{r}}_{31} + \ldots + \frac{q_1 q_2}{r_n^2}\,\hat{\mathbf{r}}_{n1}\right)$$

Contiuous Charge Distribution

The region in which charges are closely spaced is said to have continuous distribution of charge.

Linear Charge Density (λ)

It is defined as the charge per unit length of linear charge distribution. Its unit is coulomb/metre.

Surface Charge Density (σ)

It is defined as the charge per unit surface area of surface charge distribution. Its unit is coulomb/metre^2.

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Volume Charge Density (ρ)

It is defined as the charge per unit volume of volume charge distribution. Its unit is coulomb/metre^3.

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