| UNIT | ELECTROSTATICS ( STATIC ELECTRICITY ) |
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The branch of physics which deals with the study of electric charges at rest ( stationary ) is called electrostatics or static electricity.

## ELECTRIC CHARGE

**An electrical property of matter that exists because of excess or a deficiency of electrons is called an electric charge.**

There are two kinds of charges: positive and negative. All protons are alike and have the same charge $e^{+} = 1.6 \times 10^{-19}$ coulomb. Similarly all electrons are alike and have the same charge $e^{-} = 1.6 \times 10^{-19}$ coulomb. Like charges repel and unlike charges attract each other.

## ELECTRIC FORCE ( $\vec{F}_c$ )

**The force, which a charge exerts on another charge, is called electric force ( $\vec{F}_c$ ).**

## ELECTROSTATIC FORCE ( $\vec{F}_c$ )

**The force exerted by a static charge on another static charge is called electrostatic force ( $\vec{F}_c$ ).**

**Q.1 – 1. State and explain Coulomb's law. Discuss the role of the material medium in between the charges.**

## STATEMENT

This law states that two stationary point charges $q_1$ and $q_2$ repel or attract each other with a force which

(a) is directly proportional to the product $q_1 q_2$ of the magnitude of the charges,

(b) is inversely proportional to the square of the distance r between them,

(c) Acts along the line joining the charge.

### MATHEMATICAL FORM

Let $q_1$ and $q_2$ be two stationary point charges separated by a distance ( r ). According to the coulomb s law the force ( F ) between two stationary point charges is given by

$$F_c \propto q_1 q_2$$

And

$$F_c \propto \frac{1}{r^2}$$

Therefore

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

$$F_c = (\text{constant}) \frac{q_1 q_2}{r^2}$$

$$\boxed{\vec{F}_c = K \frac{q_1 q_2}{r^2} \hat{r}} \qquad \text{EQ. ( 1 )}$$

Where K is the constant of proportionality known as Coulomb constant. It value depends on the choice of units and the properties of the medium around the charges.

If $q_1$ is considered as the 'source' charge, which acts on the 'field' charge $q_2$ then the unit vector, $\hat{r}$ is directed from the $q_1$ to $q_2$ as shown in Fig. ( 1.1a ). However, If $q_2$ is taken as the 'source' charge then the force on $q_1$ is $(-\bar{F})$ which is directed from $q_2$ to $q_1$ as shown in Fig.( 1.1b ).

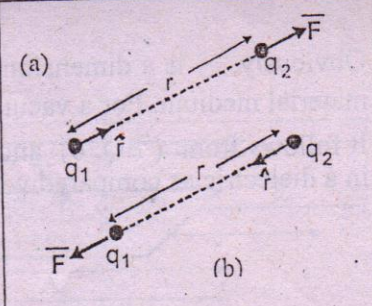


Fig. (1.1). Coulomb's law

For like charges, the product $q_1 q_2$ is positive;.the force is repulsive and $\hat{r}$ is directed away from the source charge $q_1$. For unlike charges, the product $q_1 q_2$ is negative; the force is attractive and $\hat{r}$ is directed towards the source charge $q_1$.

If ( $F_e$ ) is measured in newtons, ( $q_1$) and ( $q_2$ ) in coulombs ( r ) in meters and the medium between the two charges a free space then ( K ) is given by

$$K = \frac{1}{4\pi\varepsilon_o} \qquad \text{EQ. (2)}$$

In SI units Coulomb's law ( EQ.1) is written as:

$$\bar{F}_e = \frac{1}{4\pi\varepsilon_o}\frac{q_1 q_2}{r^2}\hat{r} \qquad \text{EQ.(3)}$$

The constant $\varepsilon_o$ is called the permittivity of free space. Its value is measured experimentally and is found to be

$$\varepsilon_0 = 8.85418 \times 10^{-12} \; C^2 N^{-1} \; m^{-2} \qquad \text{EQ. (4)}$$

Substituting the value of $\varepsilon_0$ in Eq.( 2 ), we have

$$K = 8.998 \times 10^9 N\,m^2 C^{-2} \qquad \text{E Q.(5)}$$

For sake of convenience and to the extent of good accuracy, we often take the values of $\varepsilon_0$ and $K$ as :

$$\varepsilon_0 = 8.9 \times 10^{-12} \; C^2 N^{-1} \; m^{-2} \text{ and}$$

$$K = 9 \times 10^9 N\,m^2 C^{-2} \text{ respectively.}$$

## COULOMB'S LAW IN MATERIAL MEDIA

**Dielectric**

**A material in which all the electrons are tightly bound to the nuclei of the atoms is called a dielectric ( or insulator ).**

Glass, plastic, mica, oil are examples of dielectrics.

When the medium surrounding the charges is not a vacuum but is a non-conducting or dielectric medium then the Coulomb force between the charges is reduced. The effective Coulomb force is now given by:

$$\vec{F}_c{}' = \frac{1}{4\pi\varepsilon}\frac{q_1 q_2}{r^2}\hat{r} \qquad \text{EQ. (6)}$$

The quantity ( ε ) is called the permittivity of the material. A material medium with high permittivity reduces appreciably the force between the charges as compared with the vacuum value. For air, $\varepsilon_{air} \approx \varepsilon_0$ :.


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**Q.1 – 3. Explain the concept of electric flux. Support your answer with diagrams and mathematical expressions.**

**Electric Flux ( Φ )**

The Electric flux ( Φ ) is defined as the scalar or dot product of electric field intensity $\vec{E}$ and the plane surface area $\vec{A}$.

Mathematically we can write , Electric flux , $\Phi = \vec{E}\cdot\vec{A}$

$$\Phi = E A \cos\theta$$

Where θ is the angle between the direction of electric field intensity $\vec{E}$ and the direction of vector area $\vec{A}$. Physically electric flux represents the number of lines of electric force passing normally ( perpendicularly ) through a surface.

**Condition for maximum flux :**

When the surface area is perpendicular to the electric field intensity. Then $\vec{E}$ will be parallel to $\vec{A}$, so that $\theta = 0^0$, under this condition flux passing through the surface is maximum. In other words under this condition maximum number of lines of force will normally pass through the surface.

Magnitude of electric flux is given by

$$\Phi = E A \cos\theta \qquad (\theta = 0^\circ)$$

$$\Phi = EA\cos 0^\circ \qquad (\cos 0^\circ = 1)$$

$$\boxed{\Phi = EA}$$

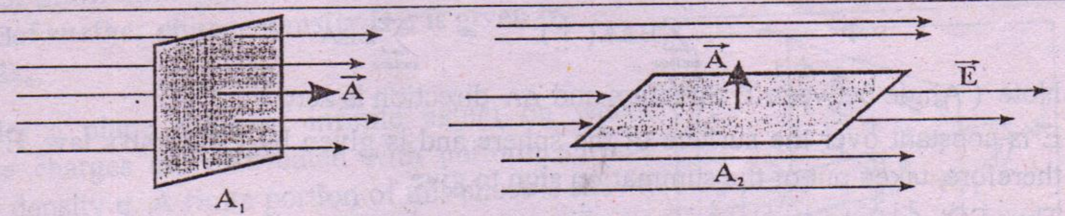


Fig 12.10 Electric flux through open plane surfaces

**:ondition for minimum flux :**

/hen the surface area is parallel to the electric field intensity. Then $\vec{E}$ will be erpendicular to $\vec{A}$, so that $\theta = 90^\circ$, under this condition flux passing through the ırface is minimum. In other words under this condition no lines of force will pass ırough the surface.

/lagnitude of electric flux is given by

$$\Phi = EA\cos\theta \qquad (\theta = 90^\circ)$$

$$\Phi = EA\cos 90^\circ \qquad (\cos 90^\circ = 0)$$

$$\boxed{\Phi = 0}$$

# NUMERICAL PROBLEMS

**1. Two charges of magnitudes 20 μC and 100μC are placed in air, 150 cm apart. Calculate the force of repulsion between them.**

**Solution** $q_1 = 20\ \mu C = 20 \times 10^{-6}\ C$ ( micro, $\mu = 10^{-6}$ )

$q_2 = 100\ \mu C = 100 \times 10^{-6}\ C$

$r = 150\ cm = 1.5\ m$

Value of Coulomb constant, $k = 9\times10^9\ Nm^2C^{-2}$

Using the equation

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

$$F = (9\times10^9\ Nm^2C^{-2})\frac{(20\times10^{-6}\ C)(100\times10^{-6}\ C)}{(1.5\ m)^2} = 8N$$

**2. The electric force between two point charges placed in air is 2.0N. Calculate the electric force between them when the medium between them is mica. Relative permittivity for mica is: $\varepsilon_r = 3.8$.**

**Solution**

Electric force between two point charges when the medium them is air, $F_e = 2.0\ N$

Relative permitivity for mica is: $\varepsilon_r = 3.8$

Electric force between two point charges when the medium them is mica, in air, $F' = ?$

Using the equation

$$F' = \frac{F}{\varepsilon_r} = \frac{2.0N}{3.8} = 0.53N$$

**3. What is the magnitude of the force of attraction between an iron nucleus bearing charge $q = +26\ e$ and its innermost electron. Distance between them is $1.0 \times 10^{-12}$ m.**

**Solution** Charge on the iron nucleus ( charge on the 26 protons ), $q_P = +26\ e$

$q_P = 26(1.6 \times 10^{-19}\ C) = 42 \times 10^{-19}\ C$

Charge on the single electron, $q_e = -1.6 \times 10^{-19}\ C$

Distance between the charges, $r = 1.0 \times 10^{-12}\ m.$

Value of coulomb constant, $K = 9 \times 10^9\ N\ m^2\ C^{-2}$

Magnitude of Coulomb force between iron nucleus ( $q_P$ ) and its outer most electron ( $q_e$ ), $F_e = ?$

The magnitude of Coulomb's force of attraction between the charges is

$$F_e = k\frac{q_e q_p}{r^2}$$

Substituting the values of these quantities: we get

$$F_e = 9 \times 10^9\ N\ m^2\ C^{-2} \times \left(\frac{(42 \times 10^{-19}\ C) \times (-1.6 \times 10^{-19}\ C)}{(1.0 \times 10^{-12}\ m)^2}\right)$$

$$\boxed{F_e = -6 \times 10^{-3}\ N}$$

The negative sign shows that the force is attractive.