Electrostatics

Electro → electric charge at Statics → rest

Chapter 1. (NCERT)

Electric Charges and Fields

Electric Charge : the physical property of matter that causes it to experience a force when placed in an electromagnetic field is called electric charge.

Charge is a **Scalar** quantity.

SI Unit of Charge is coulomb (C)

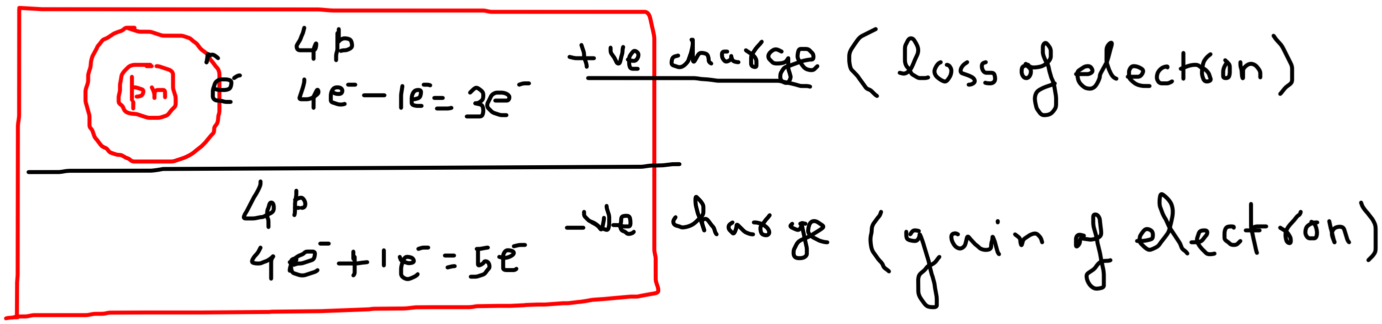
Types of charges:

i) Positive (+)

ii) Negative (−)

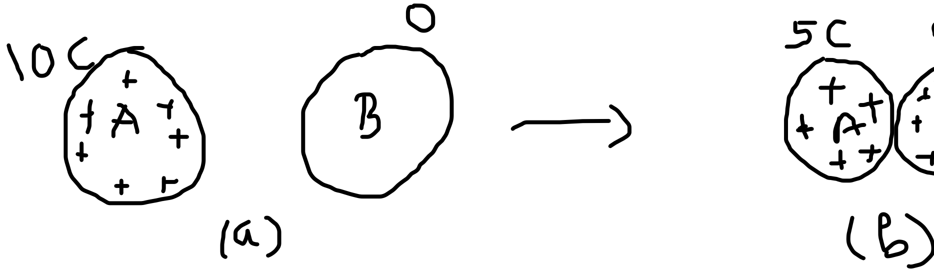
Electron theory of electrification

All the matter in universe are made up of atoms, and these atoms consists electrons, protons and neutrons, here neutron is neutral in charge, proton is positive and electron is negative. In an atom number of proton are equal to the number of electron which makes whole atom neutral in charge and hence matter is also neutral. If by any means an electron is removed from a matter it will acquire a positive charge because of imbalance created in charge of atom, similarly if a electron is added to matter it acquires negative charge to matter.



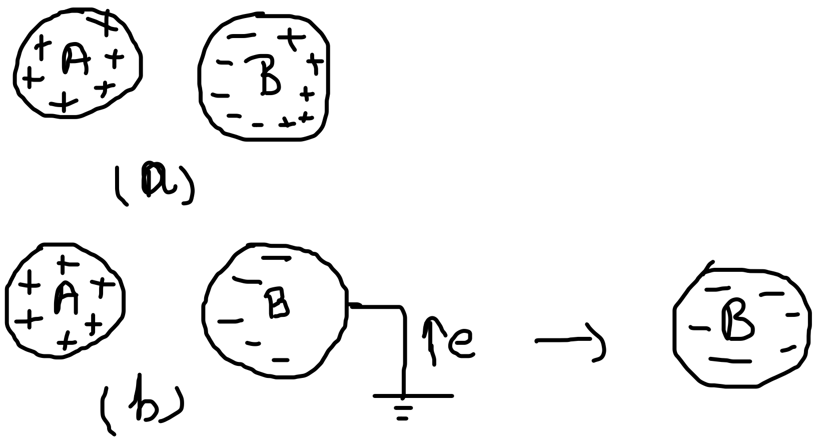
Methods of Charging

i) Conduction



> Physical contact is required
> Charge of charged body is shared with uncharged body
> uncharged body acquires same charge as that of charge body

ii) Induction



> Physical contact is NOT required
> Charge of charged body is NOT shared with uncharged body
> uncharged body acquires OPPOSITE charge as that of charge body

iii) Friction

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Basic Properties of Electric charge:

i) Additive In nature:

Total charge of a matter is algebraic sum of all the charges present in matter.

Example: +5C + -3C = +2C ; -7C + -9C = -16C

ii) Conservative property:

A charge can neither be created nor be destroyed it can only be transformed from one to another form.

Example:

(i) Total charge in radioactivity

$$U_{92}^{238} \rightarrow Th_{90}^{234} + He_2^4$$

(ii) Pair production

$$\gamma \rightarrow e^-(electron) + e^+(positron)$$

iii) Quantisation of charges:

The charge on any body can be expressed as an integral multiple of basic unit of charge. This is known as quantisation of charge.

$$Q = \pm ne$$

Where,

Q is total charge

e is charge of electron

and n= 1,2,3,…

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Que 1: Can 8.6×10^{-19} C of charge be given to a conductor? Explain.

Q

$$Q = ne$$

$$n = \frac{Q}{e} = \frac{8.6 \times 10^{-19} C}{1.6 \times 10^{-19} C} = 5.37$$

Que 2: How many electrons are there in one coulomb of negative charge?

$Q = -1C$, $e = -1.6 \times 10^{-19} C$

$$n = \frac{-1}{1.6 \times 10^{-19}} = 6.25 \times 10^{18} = 6250000000000000000$$

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Que 3: A body has a positive charge of 8×10^{-19} C. How much excess or deficiency of electrons does body has?

$$q = 8 \times 10^{-19} \, C$$

$$n = \frac{q}{e} = \frac{8 \times 10^{-19}}{1.6 \times 10^{-19}} = 5$$

Que 4: Explain the meaning of the statement "electric charge of a body is quantised ".

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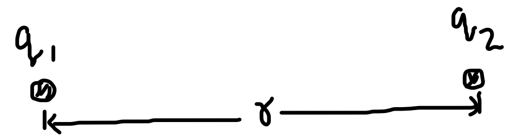
Coulomb's Law of Electrostatics:

The force of interaction between two stationary point charges in vacuum is directly proportional to the product of the charges and inversely proportional to the square of distance between them. Direction of force is along the line joining charges.



$$F \propto q_1 \times q_2$$

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

$$F \propto \frac{q_1 \times q_2}{r^2}$$

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

Where, k is proportionality constant

$k = \frac{1}{4\pi\epsilon_0} = 9 \times 10^9 \, Nm^2/C^2$

here $\epsilon_0 = 8.85 \times 10^{-12} \, C^2N^{-1}m^{-2}$, it is known as **permittivity** of free space.

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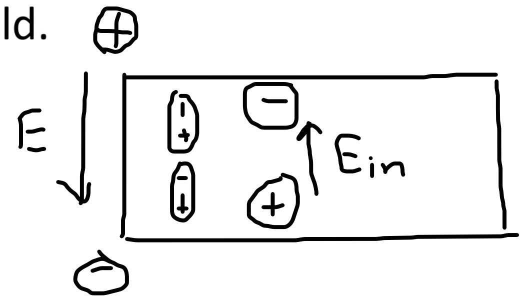
Note: Permittivity is a measure of how much the molecules opposes the external electric field.

Figure:



Permittivity of medium

The force between two charges q_1 and q_2 located at a distance of r apart in a medium may be expressed as,

$$F_m = \frac{1}{4\pi\epsilon}\frac{|q_1 \times q_2|}{r^2}$$

Where, ϵ is absolute permittivity of medium

Now,

$$\frac{F_v}{F_m} = \frac{\frac{1}{4\pi\epsilon_0}\frac{|q_1 \times q_2|}{r^2}}{\frac{1}{4\pi\epsilon}\frac{|q_1 \times q_2|}{r^2}} = \frac{\epsilon}{\epsilon_0}$$

The ratio of $\frac{\epsilon}{\epsilon_0} = \epsilon_r$ is known as **relative permittivity** and this is also known as dielectric Constant (K).

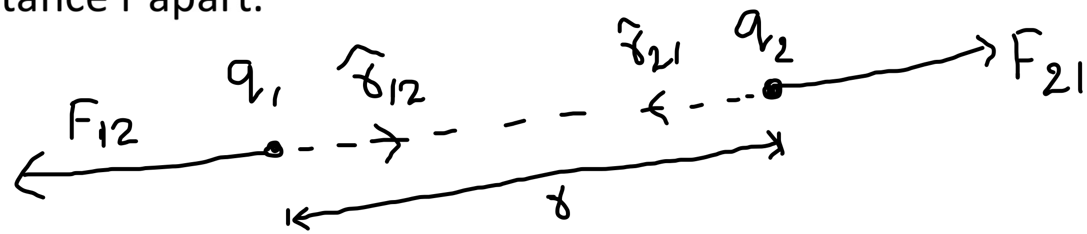
$$K = \epsilon_r = \frac{\epsilon}{\epsilon_0} = \frac{F_v}{F_m}$$

$$\epsilon = K\epsilon_0$$

Therefore, $$F_m = \frac{1}{4\pi\epsilon_0}\frac{|q_1 \times q_2|}{Kr^2}$$

Vector Form of Coulomb's Law

Let us consider two charges q_1 and q_2 kept at point A and B respectively in vacuum at a distance r apart.



Let the position vector of q_2 with respect to q_1 is $\overrightarrow{r_{12}}$

And the position vector of q_1 with respect to q_2 is $\overrightarrow{r_{21}}$

Magnitude of vector $\overrightarrow{r_{12}}$ *and* $\overrightarrow{r_{21}}$ is r_{12} and r_{21} respectively

But, $r_{12} = r_{21} = r$

So unit vector, $\widehat{r_{21}} = \frac{\overrightarrow{r_{21}}}{r}$

and , $\widehat{r_{12}} = \frac{\overrightarrow{r_{12}}}{r} = \frac{-\overrightarrow{r_{21}}}{r} = -\widehat{r_{21}}$ ----------------------(i)

thus, the force acting on charge q_1 due to q_2

$\overrightarrow{F_{12}} = \frac{1}{4\pi\epsilon_0}\frac{q_1 \times q_2}{r^2}\widehat{r_{12}}$ ------------------------------- (ii)

and , the force acting on charge q_2 due to q_1

$\overrightarrow{F_{21}} = \frac{1}{4\pi\epsilon_0}\frac{q_1 \times q_2}{r^2}\widehat{r_{21}}$ -------------------------------- (iii)

From (i), (ii) and (iii)

$$F_{21} = - F_{12}$$

i.e. Coulomb's law is in agreement with Newton's 3rd Law of motion.

It can also be written as,

$$\overrightarrow{F_{21}} = \frac{1}{4\pi\epsilon_0}\frac{q_1 \times q_2}{r^3}\overrightarrow{r_{21}}$$

Comparison of Coulomb's Law with Gravitational Law

i) Both Coulomb's Law and Gravitational law follow inverse square rule.

$$F_E = k\,\frac{q_1 \times q_2}{r^2} \quad ; \quad F_G = G\,\frac{m_1 \times m_2}{r^2}$$

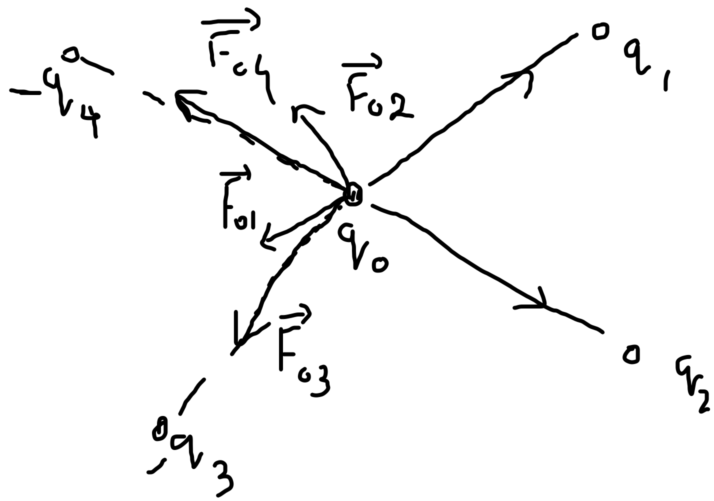
ii) Gravitational force is always attractive but Electrostatic force may be attractive or repulsive according to the nature of charges.

iii) For two proton Electrostatic force is 10^{36} times Gravitational force.

$$F_E = 10^{36} \times F_G$$

Superposition Principle (Force between multiple charges):

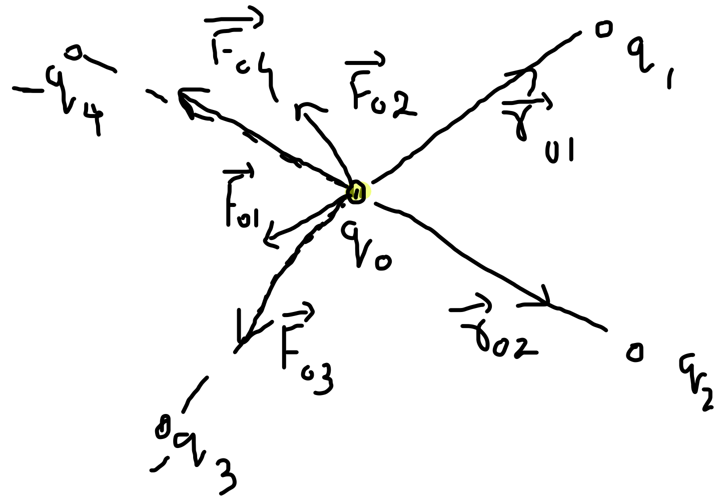
According to the superposition principle, force on any charge due to number of other charges is vector sum of all the forces on that charge due to other charges. The individual forces are unaffected due to the presence of other charges.



Let us consider a system of 'n' point charges $q_1, q_2, q_3 \ldots, q_n$ be distributed in space in a discrete manner around charge q_0. Let charges $q_1, q_2, q_3 \ldots, q_n$ exert forces $F_{01}, F_{02}, F_{03} \ldots F_{0n}$ on q_0 respectively.

Then according to the superposition principle, the total force on q_0 is given by,

$$\overrightarrow{F_{net}} = \overrightarrow{F_{01}} + \overrightarrow{F_{02}} + \cdots + \overrightarrow{F_{0n}}$$



Where,

$$\overrightarrow{F_{01}} = \frac{1}{4\pi\epsilon_0}\frac{q_0 \times q_1}{r_{01}^2}\widehat{r_{01}}$$

$$\overrightarrow{F_{02}} = \frac{1}{4\pi\epsilon_0}\frac{q_0 \times q_2}{r_{02}^2}\widehat{r_{02}}$$

$\vdots$

$$\overrightarrow{F_{0n}} = \frac{1}{4\pi\epsilon_0}\frac{q_0 \times q_n}{r_{0n}^2}\widehat{r_{0n}}$$

Then,

$$\vec{\mathrm{F}}_{net} = \frac{1}{4\pi\epsilon_0}\left(\frac{q_0 \times q_1}{r_{01}^2} + \frac{q_0 \times q_2}{r_{02}^2} + \cdots + \frac{q_0 \times q_n}{r_{0n}^2}\right)$$

$$\vec{\mathrm{F}}_{net} = \frac{\mathrm{q}_0}{4\pi\epsilon_0}\left(\frac{q_1}{r_{01}^2} + \frac{q_2}{r_{02}^2} + \cdots + \frac{q_0}{r_{0n}^2}\right)$$

Or, $\vec{\mathrm{F}}_{net} = \frac{\mathrm{q}_0}{4\pi\epsilon_0} \sum_{i=1}^{n} \frac{q_i}{r_{0i}^2}\widehat{r_{0\imath}}$

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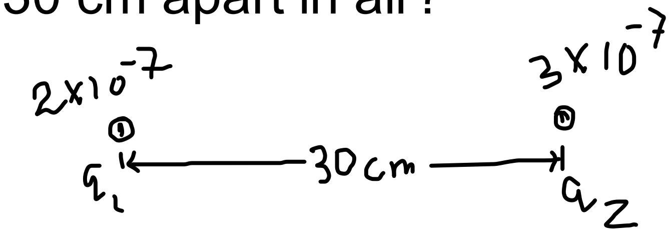
Numericals

Que 5: What is the force between two small charged spheres having charges of 2×10^{-7} C and 3×10^{-7} C placed 30 cm apart in air?

$$F = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r^2}$$

$$= 9 \times 10^9 \frac{2 \times 10^{-7} \times 3 \times 10^{-7}}{(30 \times 10^{-2})^2}$$

$$= \ ? \ N$$



Que 6: The dielectric constant of water is 80. What is its permittivity?

K

$$K = \frac{\epsilon_w}{\epsilon_0}$$

$$\epsilon_w = K \epsilon_0 = 80 \times 8.85 \times 10^{-12} = \underline{\qquad ? \qquad}$$

Numericals

Que 7: The sum of two-point charges is 7μC. They repel each other with a force of 1N when kept 30 cm apart in free space. Calculate the value of each charge.

$$F = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{r^2}$$

$$1 = 9\times10^{9}\,\frac{x\times10^{-6}\times(7-x)\times10^{-6}}{(30\times10^{-2})^2}$$

$x = ?$ $\qquad$ $7 - x = ?$