Chapter 19

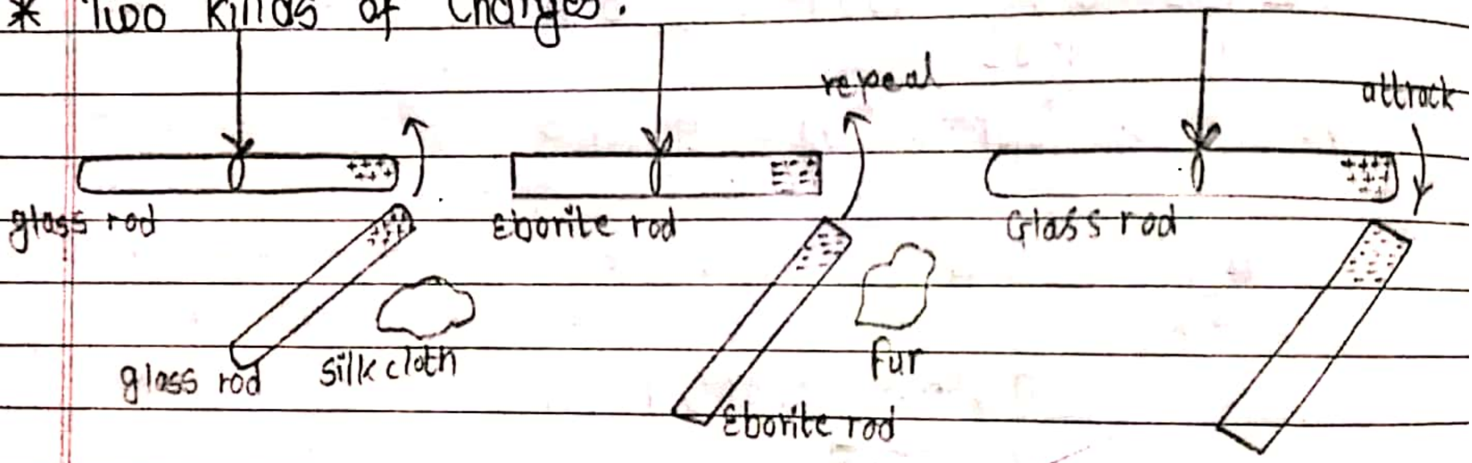
Electric Charges

→ Electro Statics is a branch of Physics which deals with the study of statics charge or the charges at rest.

Electric Charge

The flow of the charge from one point of conductor to another point is known as current.

* Two kinds of charges:



When a glass rod is robbed with a silkcloth which is suspended by a thread & another glass rod is robbed by a silk cloth, when taken close to it then they repeal each other.

Similarly, when eborite rode is robbed with a fur & another Eborite rod & taken close to it, it repeal due to similar charges develop in it.

But when glass rod is robbed with silk & Eborite rod is robbed with fur then they attrack each other.

Properties of Electric Charges.

i) Like charge repeal each other whereas, unlike charge attract eachother.

ii) Electric charges follow the law of conservation of charges.

iii) Electric charges are quantized that is $q = \pm ne$. The electric charges are integral multiple of charges of electron.

iv) Electric charges are scalar quantities that is they doesn't follow vetor law.

v) The magnitude of charges are not affected by the speed of the body.

Electrification (Charging a body)

→ The phenomenon of the production of electric charge in body is called electrification. In general, there are three methods of electrification.

(i) By fiction
(ii) By conductor
(iii) By Induction

1. Charging a body by friction: When two bodies are robbed with eachother & charges are produced then it is known as charging a body by friction. For eg: when silk is robbed with Glass rod glass rod is charged positively & silk negatively.

2. Charging a body by conductor: When a charged body is placed in contant with uncharged body then it

gets charge due to flow of charge is known as charging a body by conduction.

Imp 3. ~~electrostratic~~ Electrification by Induction : The temporary electrification of a charging a body by bring charged body close to uncharged body is known as electrostratic Induction.

(i) Inducing Charge
(ii) Induced Charge or bound charge
(iii) free charge

1. Inducing Charge

→ The charge present on a body which is used to charge another body when kept close to it.

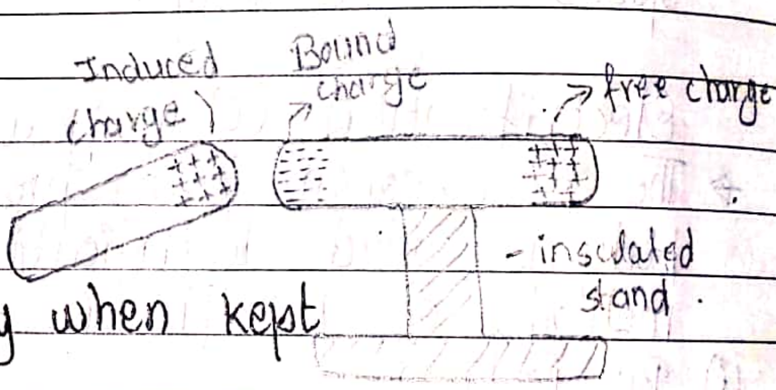
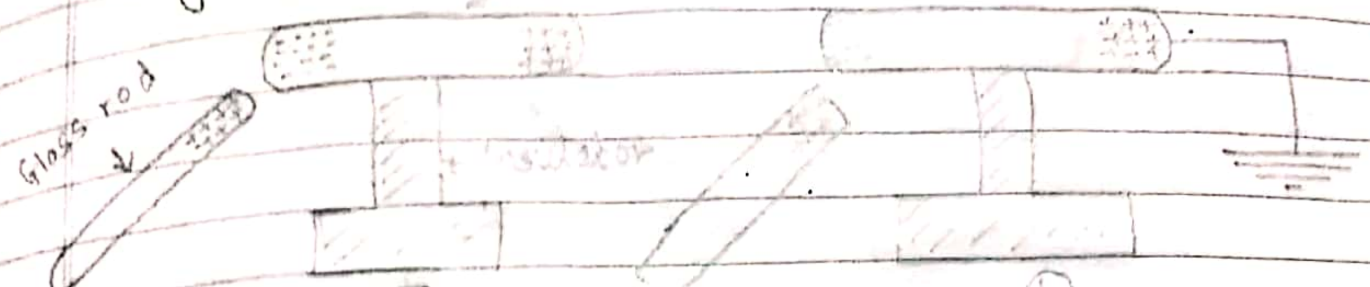


fig: Electrostatic induction of charge

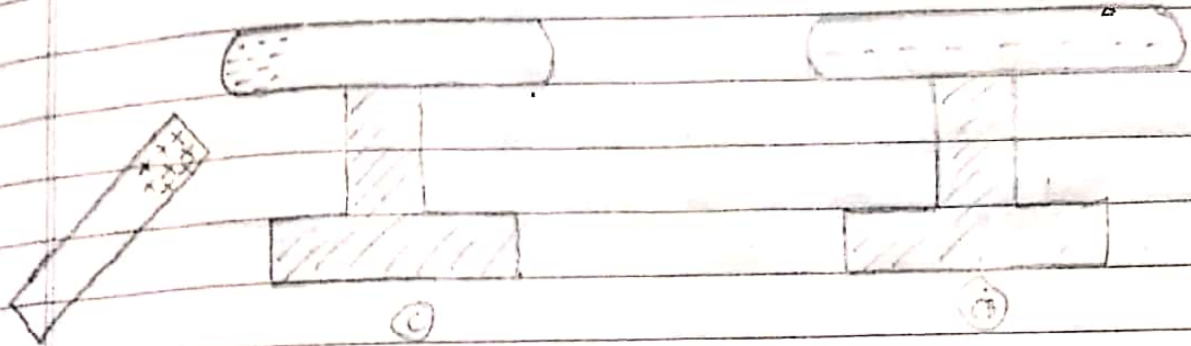
2. Bound charge
→ The charge produce on a body when inducing charge is brought close to it. is called Bound Charge

3. Free Charge
→ The charge produce on a body at the other end is known as free charge. They are free to flow.

charging on body negatively



(a) (b)



(c) (d)

(a) Consider a conductor which is charged to be charged negatively mounted on the insulator.

(2) ~~con~~ A glass rod is rubbed with a silk & placed close to a conductor.

(3) Since, the inducting charge on glass rod is positive, negative induced charge produces near to it.

(b) Without moving the position of glass rod earthing is done at the other end of the conductor & the charge flow towards the earth.

(c) Earthing is removed without removing the position of glass rod. (d) When the glass rod is removed the body is charged negatively.

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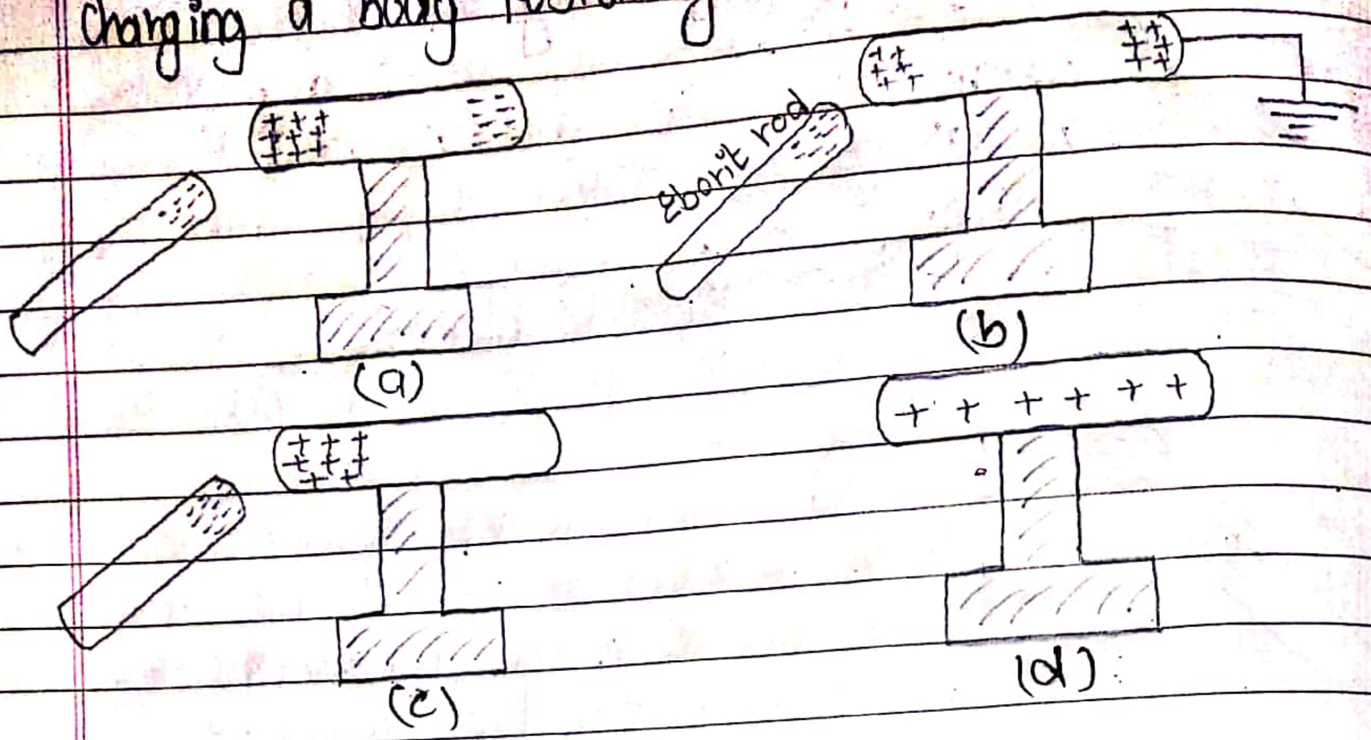
Charging a body Positively



(a) Consider a conductor which is charged to be charged negatively mounted on the insulator. A ~~glass~~ Eborite rod is rubbed with a fur & place closed to a conductor. Since, the inducing charge on eborite rod is negative, Positive induced charge produce near to it.

(b) Without moving the position of eborite rod earthing is done at the other end of the conductor & the charge flow towards the earth.

(c) Earthing is removed without removing the position of Eborit rod.

(d) When the eborite rod is removed the body is charged positively.

Surface charge Density

Surface charge Density is define as the ratio of charge per unit surface area. It is denoted as σ.

i.e. $\sigma = \frac{Q}{A}$

Its unit is $\frac{C}{m^2}$.

Linear Charge Density.

Linear Charge Density is define as the ratio of charge per unit length. It is denoted as λ.

i.e. $\lambda = \frac{Q}{l}$

Its unit is $\frac{C}{m}$.

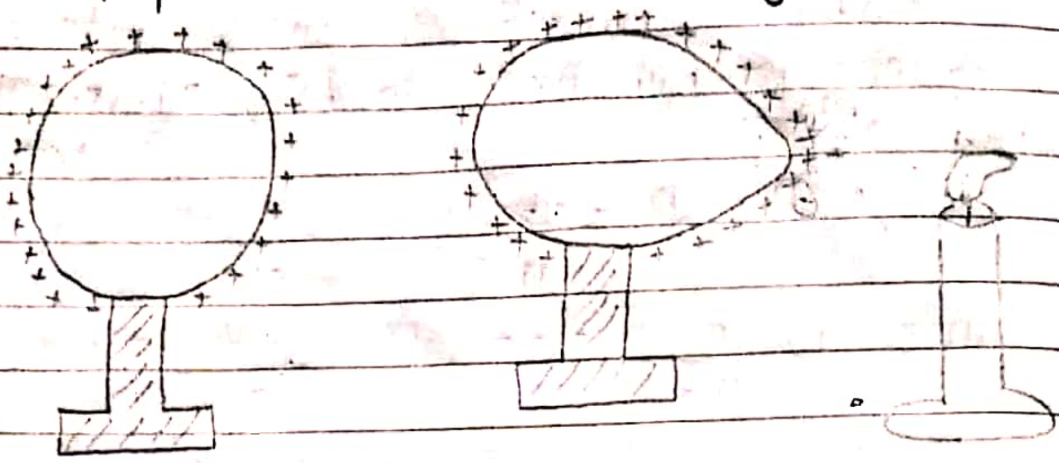
Volume Charge Density.

Volume charge density is define as the ratio of charge per unit volume. It is denoted as ρ.

i.e. $\rho = \frac{Q}{V}$

Its unit is $\frac{C}{m^3}$ ‖

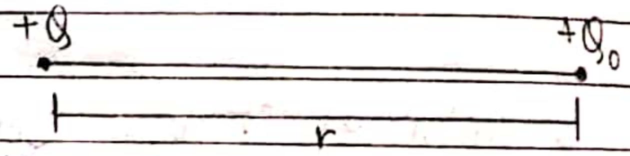
Action of point or corona discharge



This phenomenon of leakage of electric charge from the end or the corner of the charged body is called action of point.

The ~~fol~~ flow of charges (electric) due to action of point is known as electric wind.

Coulomb's law:



According to coulomb's law, the force of attraction or repulsion ~~are~~ between two electric charges is directly proportional to their magnitude & inversely proportional to the square of distance between them.

i.e. $F \propto QQ_0$ —— (i)

Also,

$$F \propto \frac{1}{r^2} \quad \text{—— (ii)}$$

Now, combining eq^n (i) & (ii), we get,

$$F \propto \frac{QQ_0}{r^2}$$

or, $F = \frac{KQq_0}{r^2}$

or, $F = \frac{1}{4\pi\epsilon_0} \times \frac{Qq_0}{r^2}$

where ϵ_0 is the permitivity of vacum or free space.
where k is a proportionality constant whose value depends upon volume or media.

$$\| K = 9 \times 10^9 \ Nm^2 c^{-2} \|$$

Also,

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

or, $\epsilon_0 = 8.85 \times 10^{-12} C^2 N^{-1} m^{-2}$

or, CGS System, $k = 1$

$\therefore F = \frac{Qq_0}{r^2}$.

1 Coulomb's : 1 coulomb is that electric charge which repeals on equal electric charge with a force of 9×10^9 N when placed at a distance of 1m in air or vacum.

Relative Permittivity or Dielectric Constant:
Relative Permittivity is defined as the ratio of Permittivity of medium to permittivity of vacium. It is denoted by K or ϵ_r.
Mathematically,

$$K = \epsilon_r = \frac{\text{Permittivity of medium}}{\text{Permittivity of vacum}}$$

$\epsilon_r \epsilon_0 = \epsilon$

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

We know, Force between two charges when placed at vaccum,

$$F_v = \frac{1}{4\pi\epsilon_0} \frac{QQ_0}{r^2} \quad \text{--- (i)}$$

$$F_m = \frac{1}{4\pi\epsilon} \frac{QQ_0}{r^2} \quad \text{--- (ii)}$$

Force between two charges when placed at medium

Now,

Dividing eq^n (i) by (ii) we get,

$$\frac{F_v}{F_m} = \frac{\frac{1}{4\pi\epsilon_0} \frac{QQ_0}{r^2}}{\frac{1}{4\pi\epsilon} \frac{QQ_0}{r^2}}$$

or, $\frac{F_v}{F_m} = \frac{\epsilon}{\epsilon_0} = \epsilon_r = \frac{\epsilon_r \cancel{\epsilon_0}}{\cancel{\epsilon_0}}$

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

or, $\epsilon = \epsilon_r \epsilon_0$

Very Short Questions Answers

4. How many electrons will have a total charge of 1 Coulomb?

→ From the quantization of electrons, the total charge contained on a body is $q=ne$, where n is an integer & e is a charge of an electron ($e=1.6\times10^{-19}$ C).

So, $n=\frac{q}{e}=\frac{1}{1.6\times10^{-19}}=6.25\times10^{18}$ electrons.

5. Why do we not experience the quantization of charge in daily life?

→ The value of the elementary charge is very small ($e=1.6\times10^{-19}$ C.) That's why, we do not experience the quantization of charge in daily life.

6. Can a charged body attract an uncharged body?

→ Yes, when a charged body is placed nearer to an uncharged body, the opposite induced charge is produced on the uncharged body. Consequently, the charge body can attract the uncharged body.

Short Q/A:

3. Why are sharp or pointed edges avoided strictly in electrical machines? Explain.

→ According to the action of the point, the surface charge density will be maximum at the point, if there is a sharp edge in the electrostatic machine. ($\because \sigma=\frac{q}{A}\Rightarrow\sigma\propto\frac{1}{A}$, for constant charge.) Due to this, when air molecules are exposed to such edges, the molecules get a similar charge from them & get repulsion. Other fresh air molecules come in contact, get some charge, & move away. The process is continuous so that the conductor leaks the charge continuously & an electric wind is formed if it has a sharp or pointed edge. Therefore, such sharp or pointed edges are avoided strictly in electrical machines.

4. An iron chain is suspended from a vehicle carrying inflammable material, why?

→ The vehicles get charged due to the friction during motion. The body of vehicles also gets charged due to the friction of air. If the accumulation of charge is enough it causes sparking, & inflammable material may catch fire, & an explosion may happen. When an iron or metallic chain is suspended from the vehicle, it drags charges from the body of the vehicle to the ground. Hence, the iron chain prevents explosion.

6. Why are gravitational forces neglected when computing the force between the charged object?

→ The gravitational force between two electrons with separation r is given by

$$F_g = G\frac{Mm}{r^2} = 6.67 \times 10^{-11}\frac{(9.1\times10^{-31})\times(9.1\times10^{-31})}{r^2}$$

$$= \frac{5.52\times10^{-71}}{r^2}\ N.$$

Similarly, the electrostatic force between two electronic

- charges separated by the distance r is.

$$F_e = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{r^2} = \frac{9\times10^9(1.6\times10^{-19})\times(1.6\times10^{-19})}{r^2}$$

$$= \frac{2.3\times10^{-28}}{r^2} N.$$

On dividing, we get,

$$\frac{F_g}{F_e} = 2.4\times10^{-43} = 10^{-43}$$

From the above discussion, it is clear that the gravitational force is very small than that of the electrostatic force. Therefore, gravitational forces are neglected while computing the force between charged objects.

7. How far apart should two electrons be placed if the force emerted on each is equal to the weight of the electron in free space?

→ Suppose d be the seperation between two electrons so that the force emerted on each is equal to the weight of the electron in free space, i.e.

weight of electron = force between two electrons in space

or, $mg = k\frac{q^2}{d^2}$ $\left(\because k = \frac{1}{4\pi\epsilon_0} = 9\times10^9\ Nm^2C^{-2}\right)$

where m & q are mass & charge on an electron respectively.

or, $d = \sqrt{\frac{kq^2}{mg}} = q\sqrt{\frac{k}{mg}}$

$\therefore d = 1.6\times10^{-19}\sqrt{\frac{9\times10^9}{9.1\times10^{-31}\times9.8}} = 5\ m$

Thus, the required value of seperation between two electrons is 5 m.

Examples:

2. What is the total charge of 1 kg of electrons?

Soln: Given,

Electronic charge $(e) = 1.6 \times 10^{-19}$ C

Mass of an electron $(m_e) = 9.1 \times 10^{-31}$ kg

Mass $(m) = 1$ kg

Charge of 1 kg electrons $(q) = ?$

Since the no. of electrons in 1 kg is

$$n = \frac{m}{m_e} = \frac{1}{9.1 \times 10^{-31}} = 1.1 \times 10^{30} \text{ electrons}$$

So the charge of 1 kg of electrons becomes

$$q = ne = 1.1 \times 10^{30} \times 1.6 \times 10^{-19} = 1.76 \times 10^{11} \text{ C}$$

Hence, the total charge of 1 kg of electrons is 1.76×10^{11} C.

3. Calculate the value of two equal charges if they repeal by a force equal to the weight of 45 kg person when situated 1m apart in a vacuum. $(\epsilon_0 = 8.85 \times 10^{-12}\ C^2 m^{-2} N^{-1})$

Soln: Given,

Force between two charge $(F) = 45$ kg $= 45 \times 9.8$ N $= 441$ N

First Charge $= q_1$ Second Charge $= q_2$

$\epsilon_0 = 8.85 \times 10^{-12}\ C^2 m^{-2} N^{1}$ Separation $(r) = 1$ m

$q_1 = q_2 = q = ?$

From Coulomb's law in electrostatics, we have

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

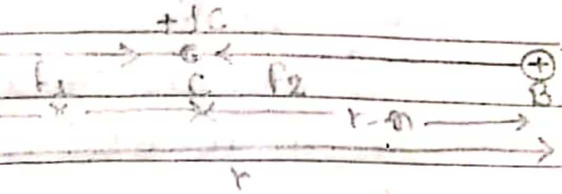
or, $441 = 9 \times 10^9 \dfrac{q_1 . q_2}{1^2}$ or, $q^2 = \dfrac{441}{9 \times 10^9} = 4.9 \times 10^{-4}$

$\therefore q = 2.2 \times 10^{-4}$ C.

Thus, the value of the given two equal charges is 2.2×10^{-4}

4. Two point charges $+1\,\mu C$ & $+4\,\mu C$ are placed at a distance of 0.12m apart. Determine the point on the line joining the line two charges where the net force acting on the unit positive charge is zero.

Soln: Given,



First point Charge $(q_1) = +1\,\mu C = 1\times10^{-6}\,C$

Second point charge $(q_1) = +4\,\mu C = 4\times10^{-6}\,C$

Distance between two charges $(r) = 0.12m$

Distance at which net force is zero $(x) = ?$

If x is the distance from the first charge at the point joining the line where the net force acting on the unit positive charge is zero, then,

$F_1 = F_2 \qquad [\because F_1 + (-F_2) = 0]$

or, $\frac{1}{4\pi\epsilon_0}\frac{q_1\times1}{x^2} = \frac{1}{4\pi\epsilon_0}\frac{q_2\times1}{(r-x)^2}$ or, $\frac{q_1}{x^2} = \frac{q_2}{(r-x)^2}$

or, $\frac{1\times10^{-6}}{x^2} = \frac{4\times10^{-6}}{(0.12-x)^2}$ or, $\frac{1}{x^2} = \frac{4}{(0.12-x)^2}$

or, $\frac{1}{x} = \frac{2}{(0.12-x)}$ or, $2x = 0.12 - x$

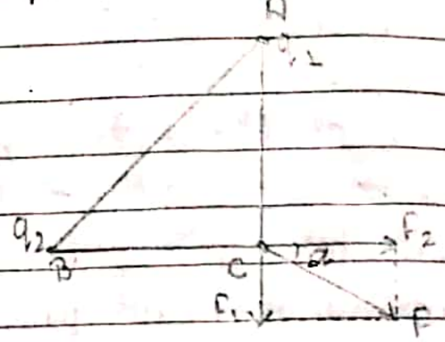
or, $3x = 0.12$

$\therefore x = 0.04\,m$

Thus, the point where net force acting on the unit positive charge is zero lies at a distance of 0.04m from the first charge $(1\,\mu C)$.

^{-4}C

5. Three equal charges of 4.0×10^{-7} C are located at the corner of a right-angled triangle whose sides are 6 cm, 8 cm & 10 cm respectively. Find the force exerted on the charge located at a 90° angle.



Soln: Given:

$q_1 = q_2 = q_3 = 4 \times 10^{-7}$ C

$BC = 6cm = 0.06m$

$AC = 8cm = 0.08m$

$AB = 10cm = 0.10m$.

$F(\text{at } C) = ?$

Suppose $\triangle ABC$ is a right-angled triangle so that $\angle C = 90°$

Thus, $AB^2 = AC^2 + BC^2$

Now, the force exerted by charge q_1 at point A to the charge q_2 at point C is

$$F_1 = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{(AC)^2} = \frac{9 \times 10^9 (4 \times 10^{-7})^2}{(0.08)^2} = 0.225 N \text{ along } \overrightarrow{AC}$$

Similarly, the force exerted by charge q_3 at point B to the charge q_2 at point A is

$$F_2 = \frac{1}{4\pi\epsilon_0} \frac{q_2 q_3}{(BC)^2} = \frac{9 \times 10^9 (4 \times 10^{-7})^2}{(0.06)^2} = 0.4 N \text{ along } \overrightarrow{BC}$$

Also, the angle between the two forces F_1 & F_2 $(\theta) = 90°$

Thus, the magnitude of the resultant force is given by

$$F = \sqrt{F_1^2 + F_2^2 + 2F_1F_2\cos\theta} = \sqrt{F_1^2 + F_2^2 + 2F_1F_2\cos 90°}$$

$$= \sqrt{F_1^2 + F_2^2 + 0} = \sqrt{(0.225)^2 + (0.4)^2 + 0}$$

$\therefore F = 0.459 N$

If α be the angle made by the resultant force F with F_2, then

$$\tan\alpha = \frac{F_1}{F_2} = \frac{0.225}{0.4}$$

$\therefore \alpha = 29.4°$

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