Unit-1
Chapter-1 ELECTROSTATICS

Electrostatics : The study of Electric forces, Electric field and electric Potential when charges are at rest is Electrostatics

Electric charge :- The force experienced by matter when it is placed near other matter is due to "Electric charge"

- → Electric charge is a Scalar Quantity
- → Dimensional formula → [AT]
- → SI Unit → Coulomb
- → 1 Coulomb = 3×10^{9} Stat Coulomb
- → Types of Charges :-

Positive : Proton	Negative - Electron	Neutral :- Neutron
charge = $+1.6 \times 10^{-19}$ C	charge = -1.6×10^{-19} C	charge - Zero
mass = 1.672×10^{-27} kg	mass = 9.1×10^{-31} kg	Mass = 1.674×10^{-27} kg

→ Neutron is heaviest among these.

Behaviour of Charges :

~ Similar charges always repel each other

$$\oplus \longleftrightarrow \oplus$$

↓

Repel

~ Opposite charges always attract each other.

$$\oplus \quad \ominus$$

Properties :

① Additivity Property :

The total charge of a system is equal to sum of charges present in the system i.e

$$Q_{Total} = q_1 + q_2 + \cdots + q_n$$

For Example :-

A system contains $-2q, -7q, +4q$ charge

then $Q_{Total} = -2q - 7q + 4q = -5q$

② Conservation of charge :

Total charge of a system always remains constant

$${}_{92}U^{238} \longrightarrow {}_{90}Th^{234} + {}_{2}He^{4}$$

③ Quantisation of Charge :-

Only Integral No. of charges always remains constant can be transferred from one body to another i.e fraction of charge can never be transferred.

$$\boxed{Q = \pm ne}$$

Q = Total charge
n = No. of e⁻s
e = Charge on e⁻s

Ques Is a charge of 4.5×10^{-19} C possible?

$Q = 4.5 \times 10^{-19}$ C $\qquad e = 1.6 \times 10^{-19}$ C

$$n = \frac{Q}{e} = \frac{4.5 \times \cancel{10^{-19}}}{1.6 \times \cancel{10^{-19}}} = 2.8$$

But according the quantisation $n \neq 2.8$. So, charge of 4.5×10^{-19} is Not Possible.

Ques Calculate the total charge and No. of e⁻s, in a cup of 100 CC of H_2O.

Sol Molecular Weight of Water = 18 ; Mass of 100 cm³ of H_2O = 100 gm

∴ No. of molecules in 18 gm of Water $= 6.023 \times 10^{23}$

No. of molecules in 1 gm of water $= \frac{6.023 \times 10^{23}}{18}$

So, Each Molecule of Water Contain 10 e⁻s

$$\left[\begin{matrix} H_2 & O \\ \Downarrow & \Downarrow \\ 1 \times 2 + & 8 \end{matrix} = 10\right]$$

So, total 'n' $= \frac{6.023 \times 10^{23} \times 100}{18} \times 10$

$n = \underline{\underline{0.33 \times 10^{26}}}$

∴ Total charge ⇒ $Q = ne$

$= 0.33 \times 10^{26} \times 1.6 \times 10^{-19}$

$= \underline{\underline{526 \times 10^{4}}}$

COULOMB'S LAW :-

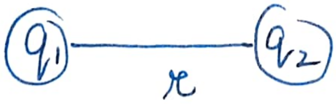
The force of interaction b/w the charges given by

① directly Proportional to product of charges

i.e $F \propto q_1 q_2$

(ii) ~~&~~ inversely proportional to sq. dis. b/w them.

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



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

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

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

In SI System

$$k = 9\times10^{9}\ Nm^{2}C^{-2}$$ $$\left[k = \frac{1}{4\pi\epsilon_0}\right]$$

where

ϵ_0 → Epsilon Not
↳ Electrical Permitivity in Vaccum.

Electrical Permittivity (ϵ_0)

It is a parameter which determines how much electric field and force affected by medium.

$$\epsilon_0 = 8.85\times10^{-12}\ N^{-1}m^{-2}C^{2}$$

Relative Electrical Permittivity / Dielectric Constant (K)

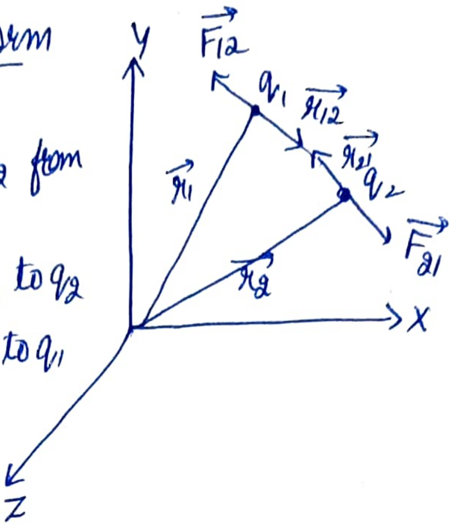
The ratio of force in vaccum to the force b/w the charge in medium.

$$\frac{F_0}{F_m} = \frac{\frac{1}{\cancel{4\pi}\epsilon_0}\frac{\cancel{q_1q_2}}{\cancel{r^2}}}{\frac{1}{\cancel{4\pi}\epsilon}\frac{\cancel{q_1q_2}}{\cancel{r^2}}} = \frac{\frac{1}{\epsilon_0}}{\frac{1}{\epsilon}} = \frac{\epsilon}{\epsilon_0} = K$$

$$\boxed{\frac{F_0}{F_m} = \frac{\epsilon}{\epsilon_0} = K}$$

- Dielectric Constant is a unit less Quantity
- $K = 1$ (Air)
- $K = \infty$ (Metal)
- $K = 81$ (Water)

Coulomb's law in Vector form



Let

q_1, q_2 → charges placed at r_1, r_2 from origin

$\vec{r}_{12} = \vec{r}_2 - \vec{r}_1$ = Dis. from q_1 to q_2

$\vec{r}_{21} = \vec{r}_1 - \vec{r}_2$ = Dis. from q_2 to q_1

$\vec{F}_{12}$ = forces on q_1 due to q_2

$\vec{F}_{21}$ = forces on q_2 due to q_1

from Coulomb's law,

$$\vec{F}_{12} = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{(r_{21})^2}(\hat{r}_{21}) = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{(r_{21})^3}\vec{r}_{21} \quad \text{— ①} \quad \left[\because \hat{r}_{21} = \frac{\vec{r}_{21}}{r_{21}}\right]$$

$$\vec{F}_{21} = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{(r_{12})^2}(\hat{r}_{12}) = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{(r_{12})^3}\vec{r}_{12} \quad \text{— ②} \quad \left[\because \hat{r}_{12} = \frac{\vec{r}_{12}}{r_{12}}\right]$$

As $\boxed{\vec{r}_{12} = -\vec{r}_{21}}$ and $\boxed{(r_{12})^3 = (r_{21})^3}$

∴ Eq^n ② becomes

$$\vec{F}_{21} = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{(r_{21})^3}(-\vec{r}_{21}) \quad \text{— ③}$$

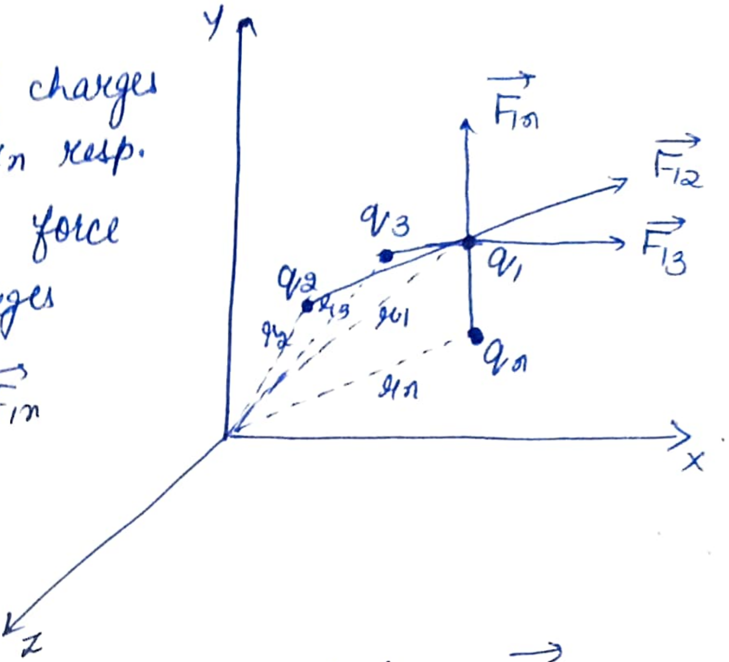
from eq^n ① and ③

$$\boxed{\vec{F}_{12} = -\vec{F}_{21}}$$

which means action & reaction are equal and opposite. Hence Coulomb's law follows Newton's 3rd law of Motion also.

Superposition Principle for Coulomb's law :-

Let $q_1, q_2 - - - q_n$ no. of charges placed at $r_1, r_2 - - - r_n$ resp. We have to find total force on 'q' due to all charges



$$\vec{F}_{net} = \vec{F}_{12} + \vec{F}_{13} + - - - + \vec{F}_{1n}$$

$$\vec{F}_{net} = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{(r_{21})^3}\vec{r}_{21} + \frac{1}{4\pi\epsilon_0}\frac{q_1 q_3}{(r_{31})^3}\vec{r}_{13} + - - - + \frac{1}{4\pi\epsilon_0}\frac{q_1 q_n}{(r_{n1})^3}\vec{r}_{n1}$$

$$\boxed{\vec{F}_{net} = \frac{q_1}{4\pi\epsilon_0}\sum_{i=2}^{n}\frac{q_i}{(r_{i1})^3}\vec{r}_{i1}}$$

Distribution of Charges

① **Linear charge Distribution (λ)**

The distribution of charges is over length of Conductor.

$$\lambda = \frac{q}{length} = \frac{Coulomb}{metre} = Cm^{-1}$$

② **Surface charge Distribution (σ)**

The distribution of charges is over surface of conductor

$$\sigma = \frac{q}{Area} = \frac{Coulomb}{(metre)^2} = Cm^{-2}$$

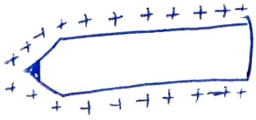
③ **Volume Charge Distribution (ρ)**

The distribution of charges is over volume of conductor

$$\rho = \frac{q}{volume} = \frac{Coulomb}{(metre)^3} = Cm^{-3}$$

→ Smaller the length, area and Volume, greater would be density of charge

→ A metallic pen is charged uniformly, maximum charge density would be at its 'Nib' because it have minimum area.



Electric field : The space around a charged body in which force of interaction can be experienced by another charge is Electric field.

Source Charge : A charge which produces electric field is source charge.

Test charge :- A very small electric charge which act as 'detector' is Test charge.

Electric field Intensity ($\vec{E}$) : Electrostatic force per unit test charge is 'Electric field Intensity'

→ Electric field Intensity $(\vec{E}) = \frac{\text{Force } (F)}{\text{Test charge}(q_0)} = \frac{\text{Newton}}{\text{coulomb}}$

→ It is a vector Quantity whose direction is in the direction of force.

Note :-

Electric field Intensity $(\vec{E}) = \frac{\text{Electric Potential }(V)}{\text{length }(l)} = Vm^{-1}$

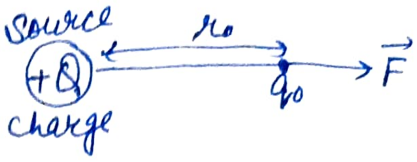
↳ Electric field Intensity is equivalent to 'Potential Gradient'

↳ Weight of charged particle is balanced as

$F = mg$ and $F = qE$

$$\boxed{mg = qE}$$

Electric Field Intensity due to a Point Charge :-



Let $Q \rightarrow$ source charge

$q_0 \rightarrow$ Test charge

$r \rightarrow$ separation b/w source & test charge

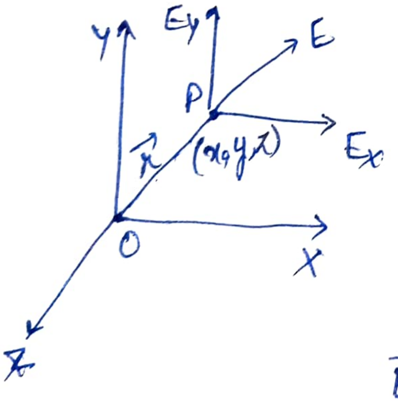
∴ from Coulomb's law;

$$F = \frac{1}{4\pi\epsilon_0}\frac{Q q_0}{r^2}$$

and Electric field Intensity $(E) = \frac{F}{q_0} = \frac{\frac{1}{4\pi\epsilon_0}\frac{Q \cancel{q_0}}{r^2}}{\cancel{q_0}} = \frac{1}{4\pi\epsilon_0}\frac{Q}{r^2}$

∴ Electric field Intensity at a point depend only on source charge and separation b/w charge but not on test charge

Rectangular Components of Electric Field Intensity :



Let $Q \rightarrow$ source charge

$\vec{r} = x\hat{i} + y\hat{j} + z\hat{k}$

$r = |\vec{r}| = (x^2 + y^2 + z^2)^{1/2}$

∴ Electric field Intensity can be given as:

$$\vec{E} = \frac{1}{4\pi\epsilon_0}\frac{Q}{((x^2+y^2+z^2)^{1/2})^2}\hat{r}$$

$$\vec{E} = \frac{1}{4\pi\epsilon_0}\frac{Q}{((x^2+y^2+z^2)^{1/2})^2}\frac{\vec{r}}{|r|}$$

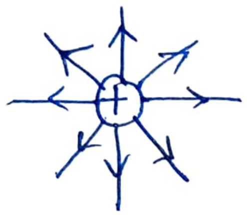
$$\boxed{\vec{E} = \frac{1}{4\pi\epsilon_0}\frac{Q\,(x\hat{i}+y\hat{j}+z\hat{k})}{(x^2+y^2+z^2)^{3/2}}}$$

$\vec{E}_x = \frac{1}{4\pi\epsilon_0}\frac{Qx\hat{i}}{(x^2+y^2+z^2)^{3/2}}$ $\vec{E}_y = \frac{1}{4\pi\epsilon_0}\frac{Qy\hat{j}}{(x^2+y^2+z^2)^{3/2}}$ $\vec{E}_z = \frac{1}{4\pi\epsilon_0}\frac{Qz\hat{k}}{(x^2+y^2+z^2)^{3/2}}$

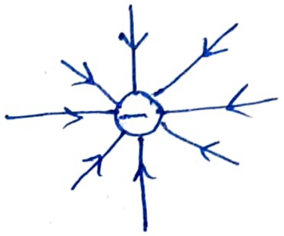
Electric field lines & Properties

Presentation of electric field is 'Electric field lines'

① For Positive charge ② For Negative charge

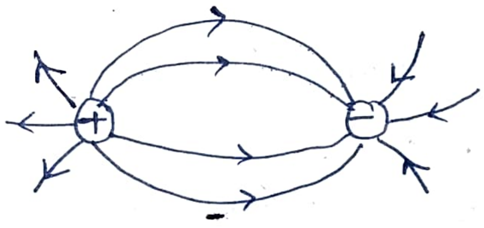


$q>0$



$q<0$

② The electric field lines of force begins from positive charge and ends on negative charge.



③ These field lines do not form closed loops because they travel only from +ve to -ve charge

④ Two electric field lines never intersect each other because if it happens then similar charge would attrach each other and a single line would have two different direction which is not possible.

⑤ Tangent to Electric field line give direction of Electric field.

⑥ The electric field lines are always ⊥r to the Conductor

⑦ The electric field Intensity is more near the charge

Electric Dipole :-

A pair of equal and opposite charges separated by small distance is an "electric dipole"

Electric Dipole Moment ($\vec{P}$) : The product of magnitude of either charge and distance b/w them is 'Electric dipole Moment'

$$\boxed{\vec{P} = q \times 2a}$$

↳ SI unit of dipole moment is 'Coulomb metre'

↳ CGS unit of dipole moment is 'Stat Coulomb Centimetre'

Polar Molecule :-

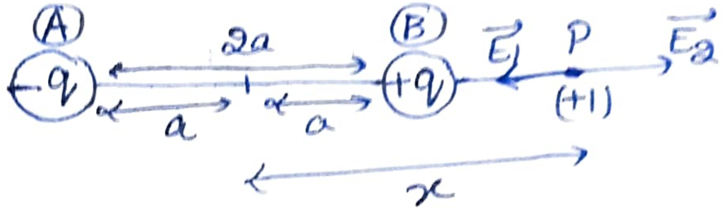
If positive and Negative charge doesnot coincide at centre is "Polar Molecule"

~ Polar Molecules have "Permanent dipole Moment"

Non- Polar Molecule :-

If positive and negative charges are coincide at the Centre of molecules & have zero dipole moment is Non Polar Molecule.

Electric field Intensity at Point on Axial line of an electric dipole :



Let,

AB → An electric dipole of length '2a'

At point 'P' ; (+1) test charge is placed

$\vec{E_1}$ → Electric field intensity b/w point P and A

$\vec{E_2}$ → Electric field intensity b/w point P and B

$$\therefore \boxed{E_1 = \frac{-q}{4\pi\epsilon_0 (x+a)^2}}$$

$$\boxed{E_2 = \frac{+q}{4\pi\epsilon_0 (x-a)^2}}$$

Net electric field Intensity at point 'P' due to both charge

i.e $E = E_1 + E_2$

$$= \frac{-q}{4\pi\epsilon_0 (x+a)^2} + \frac{q}{4\pi\epsilon_0 (x-a)^2}$$

$$= \frac{q}{4\pi\epsilon_0}\left[\frac{-1}{(x+a)^2} + \frac{1}{(x-a)^2}\right]$$

$$E = \frac{q}{4\pi\epsilon_0}\left[\frac{-(x-a)^2+(x+a)^2}{(x^2-a^2)^2}\right]$$

$$= \frac{q}{4\pi\epsilon_0}\left[\frac{-(x^2+a^2-2xa)+(x^2+a^2+2xa)}{(x^2-a^2)^2}\right]$$

$$= \frac{q}{4\pi\epsilon_0}\left[\frac{\cancel{-x^2}\cancel{-a^2}+2xa+\cancel{x^2}+\cancel{a^2}+2xa}{(x^2-a^2)^2}\right]$$

$$= \frac{q}{4\pi\epsilon_0} \times \frac{4xa}{(x^2-a^2)^2}$$

$$E = \frac{q}{4\pi\epsilon_0}\,\frac{2x\times 2a}{(x^2-a^2)^2} = \frac{P\times 2x}{4\pi\epsilon_0(x^2-a^2)^2}$$

#$\boxed{E = \frac{P\times 2x}{4\pi\epsilon_0(x^2-a^2)^2}}$ —— Ⓐ

Special case :-

If dipole length is very small i.e $x >> a$ So, a^2 can be neglected and eqⁿ Ⓐ can be given as:

$$E = \frac{P\times 2x}{4\pi\epsilon_0(x^2-0)^2} = \frac{2Px}{4\pi\epsilon_0 x^{\cancel{4}3}} = \frac{2P}{4\pi\epsilon_0 x^3}$$

#$\boxed{E = \frac{2P}{4\pi\epsilon_0 x^3}}$