UNIT - 1
ELECTRO STATICS

(Marks - 8

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Frictional Electricity :→

Electrostatics is the study of electric charges at rest.

Whenever two bodies are rubbed wi each other, heat energy is produced due to forc of friction b/w the two bodies. Due to this hea electrons get transferred from one body (having value of Ionization Energy) to the other body h higher value of I.E. Thus both the bodies acq charges. Thus electrostatics is also named frictional electricity or static electricity.

Two Kinds of Charges :→

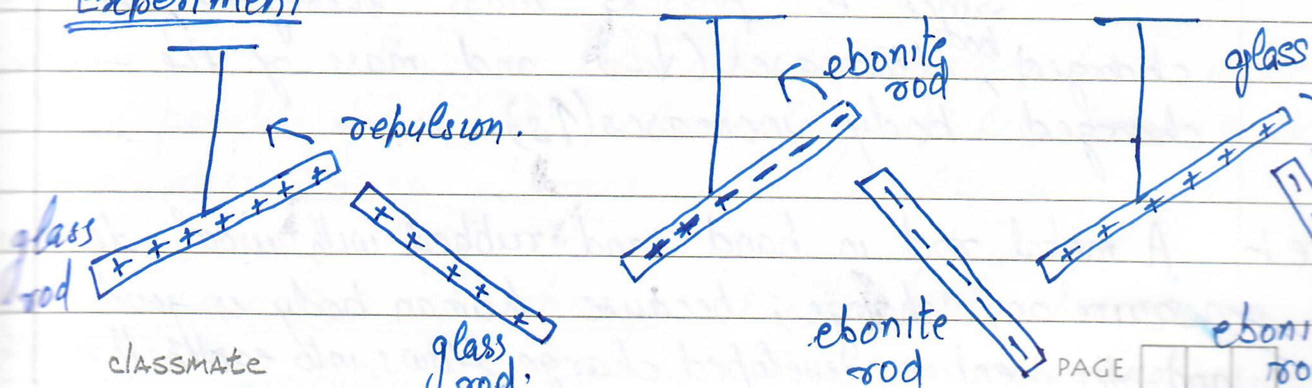
When two bodies are rubbed with ea other, transfer of e̅s takes place. A body whi looses e̅s acquires +ve charge w/a the bod which gains charge acquires -ve charge.

eg. when glass rod is rubbed with cloth, then glass rod acquires +ve charge w silk cloth acquires -ve charge.

Similarly when ebonite rod is rubbed fur then ebonite rod acquires -ve charge and fur acquires +ve charge.

Like charges repel each other w/a unl charges attract each other.

Experiment



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When a glass rod rubbed with silk cloth is brough[t] near another freely suspended glass rod rubbed w[ith] silk then both rods repell each other

IIly when a ebonite rod (or plastic rod) rubbed with fur (or silk) is brought near to a[nother] such ebonite rod then again both the rods repel each other

But when a ~~gl~~ ebonite rod rubbed [with] fur is brought near a freely suspended glass [rod] rubbed with silk then both rods attract eac[h] other.

Thus we can say that like charge rep[el] and unlike charges attract each other. This statement is also k/a fundamental law of electro[statics]

Cause of electrostatics ↦

When two bodies are rubbed with each other then due to force of friction, heat en[ergy] is produced. Thus e^-s get transferred from a bod[y] having lower work function (or lower I.E) to the bod[y] having higher work function (or higher I.E). The body which looses e^-s acquire +ve charge and is k/a vilerous body and where as the body which gain[s] e^-s acquire −ve charge and is k/a resionou[s] body.

Since e^-s possess mass therefore mass of the +v[e] charged body decreases (↓s) and mass of the −vely charged body increases (↑s).

Note :- A metal rod in hand and rubbed with wool does n[ot] acquire any charge, because human body is good con[ductor] and the entire developed charge flows into earth throug[h]

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~~Basic~~ properties of electric charges ↦

1. Charge on any body does not varies with velocity ... mass varies as per :-

$$m = \frac{m_0}{\sqrt{1-\frac{u^2}{c^2}}}.$$

2. Charges are additive in nature ie they can be added algebraically.

eg $\boxed{+2C \quad +3C} = +5C$ $\boxed{+2C \quad -3C} = -1C.$

3. Charge is quantized in nature. ie any body possess charge equals to integral multiple of charge on one e^- ie $\boxed{q = \pm ne}$ where n is any integer

and $e = -1.6 \times 10^{-19}$ C.

Cause of quantization of charge is that the charge of any body is due to transfer of integral number of e^-s from one body to another body.

eg when 10 e^-s will transfer from one body to other then one body will acquire +10e charge and other will acquire −10e charge. And it is never possible that $10\frac{1}{2}$ es get transferred.

However recent discoveries have indicated the ~~parcles~~ ~~particles~~ elementary p'cles ~~known~~ k/a quarks having charges e/3 & 2e/3.

4. Conservation of charges ↦ The total charge on an isolated system is always conserved.

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eg. (a) when a glass rod is rubbed with silk cloth then glass rod acquires +ve charge w/q silk cloth acquires equal -ve charge. Therefore total charge before and after rubbing remain same (here zero)

(b) In pair production, a γ ray photon breaks up to produce an electron and positron. Thus total charge before and after pair production remains same

$$\gamma \longrightarrow e^{-1} + e^{+1}$$

charge 0 (neutral) $\rightarrow -1e + 1e \; (0)$

(c) In ~~anhilation of~~ annihilation of matter, an electron and positron destroy each other to produce γ ray photon.

$$e^{-1} + e^{+} \longrightarrow \gamma$$

charge $(0) \longrightarrow (0)$

(d) In all types of nuclear transformation the total charge before and after transformation remains same. eg.

$$_{92}U^{235} + {_0}n^1 \rightarrow {_{36}}Kr^{92} + {_{56}}Ba^{141} + 3{_0}n^1 + \text{Energy}$$

Charge $92 + 0 \longrightarrow 36 + 56 + 0.$

ie $92 \longrightarrow 92.$

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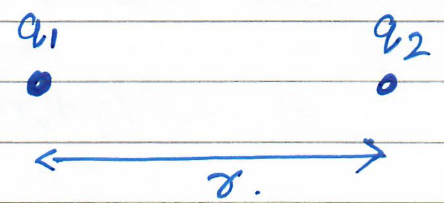
Coulomb's Law of Electric forces ↦

According to coulomb's the force of attraction or repulsion b/w two char is directly proportional to the product of char and inversly proportional to the square of distan b/w them.

Consider two charges q_1 & q_2 separa in vacuum by a distance r then force of a or repulsion b/w them is

$$F \propto q_1 q_2$$

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



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

$$\Rightarrow \quad F = K \frac{q_1 q_2}{r^2}$$

wher $K = \frac{1}{4\pi\epsilon_0}$ is constant of proportionality.
and ϵ_0 is electrical permitivity of the vacuum free space.

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

where $\frac{1}{4\pi\epsilon_0} = 9 \times 10^9 \, Nm$

Units of Charge ↦

we know that (wkt)

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

if $q_1 = q_2 = 1C$ and $r = 1m$

then $F = 9 \times 10^9 \, Nm^2 C^{-2} \times \frac{1C \times 1C}{1m^2}$

$$\Rightarrow F = 9 \times 10^9 N.$$

Thus charge is said to be 1C if it attract or repell an equal charge placed at a distance of 1m in vacuum with a force of 9×10^9 N.

In cgs system, the unit of charge is one statcoulomb or electrostatic unit of charge ~~and 1 esu of charge or 1 statcoulomb = 3×10^9 C~~

$$1 \text{ Coulomb} = 3\times10^9 \text{ statcoulomb} \; \cancel{\text{or (esu)}}$$

and electromagnetic unit of charge as abcoulomb and $1 \text{ Coulomb} = \frac{1}{10}$ emu of charge $= \frac{1}{10}$ abcolomb

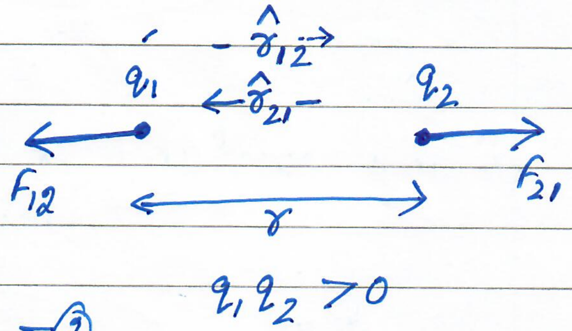
~~Colou~~

Coulomb's law in vector form:→

Consider two charges q_1 and q_2 so that $q_1 \times q_2 > 0$ separated by a distance r as shown. Let $\vec{F}_{12}$ is the force exerted by q_2 on q_1 and F_{21} " " " " " q_1 on q_2

Then from Coulomb's law :-

$$\vec{F}_{12} = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r^2} \cdot \hat{r}_{21} \quad \text{—①}$$



~~$\text{IIly } \vec{F}_{21} = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r^2}$~~

$$\text{IIly } \vec{F}_{21} = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r^2} \hat{r}_{12} \quad \text{—②}$$

But $\hat{r}_{12} = -\hat{r}_{21}$

Thus eqn no ② becomes

$$\vec{F}_{21} = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r^2} (-\hat{r}_{21})$$

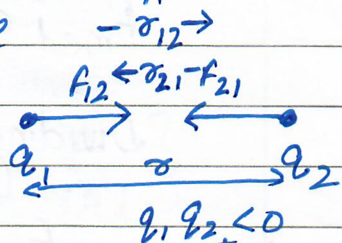
$$\Rightarrow \vec{F}_{21} = -\frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r^2} (\hat{r}_{21})$$

$$\Rightarrow \boxed{\vec{F}_{21} = -\vec{F}_{12}}$$ ~~from~~ {using eqn ①}

Thus force exerted by two charges on each other is equal and opposite.

If $q_1 q_2 < 0$ ie $q_1 q_2 = -ve$

even then $\vec{F}_{21} = -\vec{F}_{12}$



but the force will be attractive in nature

Note:→ $q_1 q_2 > 0 \Rightarrow q_1 q_2 = +ve$ ie either both charges are +ve or both are −ve.

$q_1 q_2 < 0 \Rightarrow q_1 q_2 = -ve$ ie charges are opposite in nature.

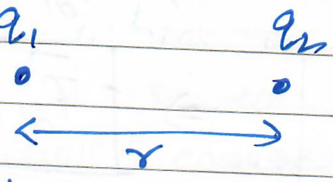
Note ↦ Since coulomb's force act along the line joining the centre of two charges therefore it is also called central force.

Dielectric constant (K) or relative permitivity (ϵ_r) ↦
Dielectric constant or relative permitivity of a medium is defined as (d/a) the ratio of permitivity of the medium to the permitivity of the free space.

ie $\boxed{K \text{ or } \epsilon_r = \frac{\epsilon}{\epsilon_0}.}$ or $\epsilon = K\epsilon_0$.

Consider two charges q_1 ~~q_2~~ and q_2 separated by a distance r in free space. The force b/w them is given as

$$F_0 = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r^2} \quad \text{— (1)}$$



if these two charges are separated by the same distance in med. then

$$F_{med} \text{ or } F_m = \frac{1}{4\pi\epsilon} \frac{q_1 q_2}{r^2} \quad \text{— (2)}$$

Dividing (1) by (2) we get

$$\frac{F_0}{F_m} = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r^2} \times \frac{4\pi\epsilon}{1} \times \frac{r^2}{q_1 q_2}$$

$$\Rightarrow \frac{F_0}{F_m} = \frac{\epsilon}{\epsilon_0} = K \text{ or } \epsilon_r .$$

thus $\boxed{\epsilon_r \text{ or } K = \frac{F_0}{F_m}}$

Thus dielectric constant or relative permittivity may also be d/a the ratio of force of attraction or repulsion b/w the two charges separated by certain distance in free space to the force of attraction or repulsion b/w the same two charges separated by the same distance in medium.

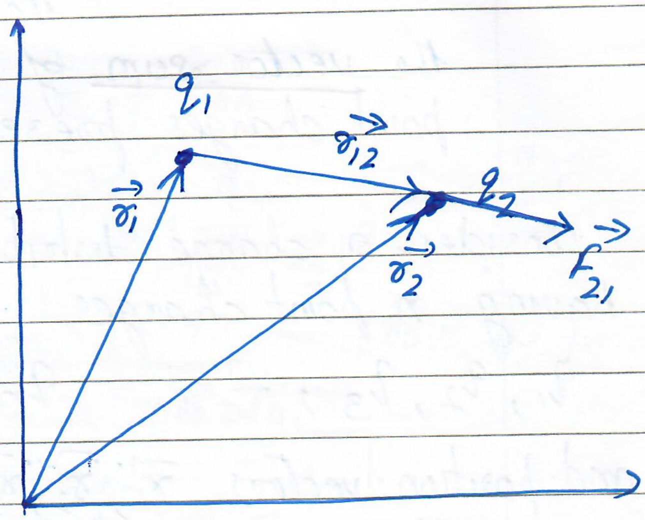
since $K = \dfrac{F_0}{F_m}$. | or $\epsilon_r = \dfrac{F_0}{F_m}$

$\therefore F_m = \dfrac{F_0}{K}$ | $\Rightarrow F_m = \dfrac{F_0}{\epsilon_r}$

$\Rightarrow F_m = \dfrac{1}{4\pi\epsilon_0 \ldots} \dfrac{q_1 q_2}{\ldots}$ | $\Rightarrow F_m = \dfrac{1}{4\pi\epsilon_0 \ldots} \dfrac{q_1 q_2}{\ldots}$

Coulombs law in position vector form ↦ $q_1 q_2 > 0$

Consider two charges q_1 & q_2 having position vectors (PVs) $\vec{r}_1$ & $\vec{r}_2$ respectively.



Thus from coloumbs law the force exerted by q_1 on q_2 is

$$\vec{F}_{21} = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{|\vec{r}_{12}|^2}\hat{r}_{12}$$

$$\Rightarrow \vec{F}_{21} = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{|\vec{r}_{12}|^2} \times \frac{\vec{r}_{12}}{|\vec{r}_{12}|} \qquad \left\{ \because \hat{A} = \frac{\vec{A}}{|\vec{A}|} \right\}$$

$$\Rightarrow \vec{F}_{21} = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{|\vec{r}_{12}|^3}\vec{r}_{12} \quad \text{—} (1)$$

from Δ law of vector addition.

$$\vec{r}_2 = \vec{r}_1 + \vec{r}_{12}$$

$$\Rightarrow \vec{r}_{12} = \vec{r}_2 - \vec{r}_1$$

Thus eqn (1) becomes.

$$\vec{F}_{21} = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{|\vec{r}_2 - \vec{r}_1|^3}(\vec{r}_2 - \vec{r}_1) \quad \text{—} (2)$$

||ly force exerted by q_2 on q_1 is

$$\vec{F}_{12} = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{|\vec{r}_{21}|^2}\hat{r}_{21}$$

$$\therefore \text{||ly } \vec{F}_{12} = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{|\vec{r}_1 - \vec{r}_2|^3}(\vec{r}_1 - \vec{r}_2) \quad \text{—} (3)$$

from (2) & (3)

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

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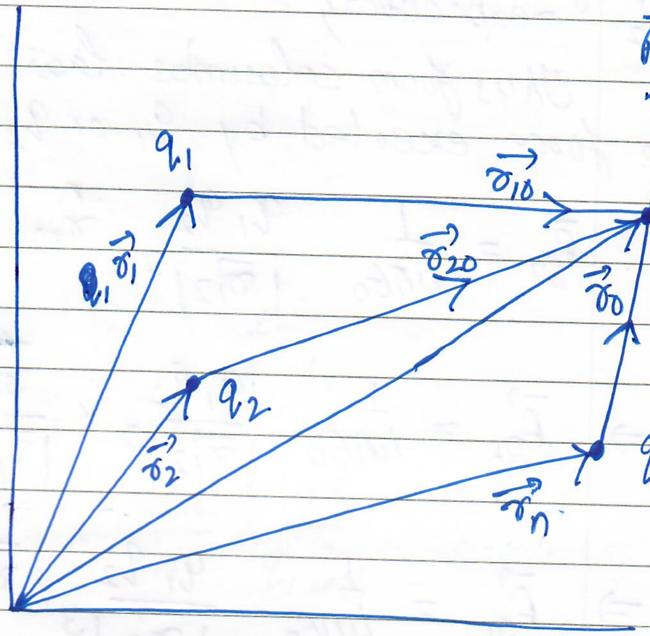
Superposition principle ↦ According to superposition principle the net force on a given charge [is] the vector sum of all the forces exerted by all point charges present in the charge distribution.

Consider a charge distribution having n point charges, $q_1, q_2, q_3, \ldots\ldots q_n$ and position vectors $\vec{r}_1, \vec{r}_2, \vec{r}_3, \ldots\ldots \vec{r}_n$ respectively.



The force exerted by q_1 on any given charge q_0 having PV $\vec{r}_0$ is given as

$$\vec{F}_{01} = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_0}{|\vec{r}_{10}|^2}\hat{r}_{10}$$

$$\Rightarrow \vec{F}_{01} = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_0}{|\vec{r}_{10}|^3}\vec{r}_{10} \qquad \left\{\because \hat{A} = \frac{\vec{A}}{|\vec{A}|}\right\}$$

$$\Rightarrow \vec{F}_{01} = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_0}{|\vec{r}_0 - \vec{r}_1|^3}(\vec{r}_0 - \vec{r}_1) \qquad \{\because \Delta \text{ law of vector addition}\}$$

$$\text{||ly } F_{02} = \frac{1}{4\pi\epsilon_0}\frac{q_2 q_0}{|\vec{r}_0 - \vec{r}_2|^3}(\vec{r}_0 - \vec{r}_2)$$

$$\text{||ly } \vec{F}_{0n} = \frac{1}{4\pi\epsilon_0}\frac{q_n q_0}{|\vec{r}_0 - \vec{r}_n|^3}(\vec{r}_0 - \vec{r}_n)$$

Thus from superposition principle net

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force acting on the test charge q_0 due charge distribution is

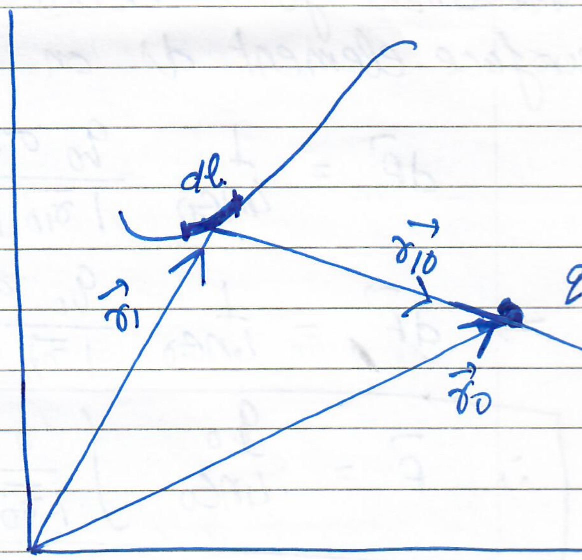
$$\vec{F} = \vec{F}_{01} + \vec{F}_{02} + - - - - + \vec{F}_{0n}$$

$$\Rightarrow \vec{F} = \frac{q_0}{4\pi\epsilon_0}\left[\frac{q_1}{|\vec{r}_0-\vec{r}_1|^3}(\vec{r}_0-\vec{r}_1) + \frac{q_2}{|\vec{r}_0-\vec{r}_2|^3}(\vec{r}_0-\vec{r}_2) + ------ + \frac{q_n}{|\vec{r}_0-\vec{r}_n|^3}(\vec{r}_0-\vec{r}_n)\right]$$

$$\boxed{\Rightarrow \vec{F} = \frac{q_0}{4\pi\epsilon_0}\sum_{i=1}^{n}\frac{q_i}{|\vec{r}_0-\vec{r}_i|^3}(\vec{r}_0-\vec{r}_i)}$$

Force on a given charge due continuos charge distribu

(a) Due to continuous line distribution of charge ↦



Consider a continuous line distribution of charge having linear charge density λ (charge per unit length)

Consider a small length element dl having charge λdl and having PV $\vec{r}_1$ as shown.

Thus force exerted by small length element dl on a given charge q_0 having PV $\vec{r}_0$ is given as.

$$d\vec{F} = \frac{1}{4\pi\epsilon_0}\frac{q_0\lambda dl}{|\vec{r}_{10}|^2}\hat{r}_{10}$$

$$\Rightarrow d\vec{F} = \frac{1}{4\pi\epsilon_0}\frac{q_0\lambda dl}{|\vec{r}_0-\vec{r}_1|^3}(\vec{r}_0-\vec{r}_1)$$

Thus force due to entire line distribution of charge

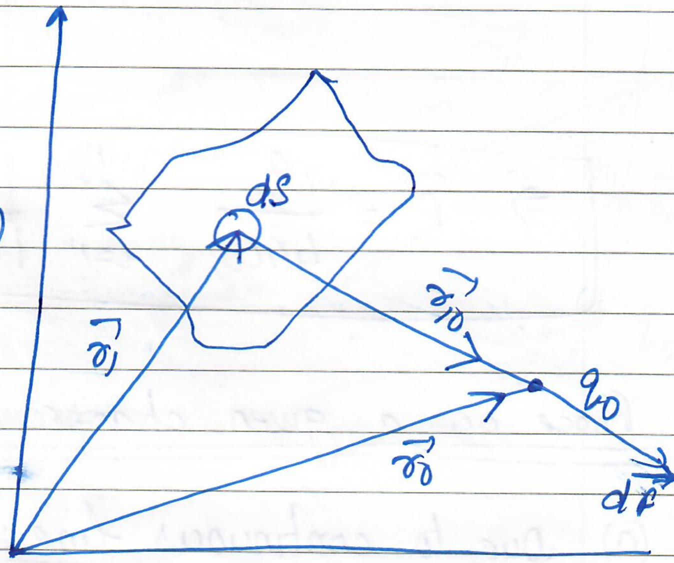
Thus $\vec{F} = \int d\vec{F}$

$$\boxed{\Rightarrow \vec{F} = \frac{q_0}{4\pi\epsilon_0}\int \frac{\lambda\, dl}{|\vec{r_0}-\vec{r_1}|^3}(\vec{r_0}-\vec{r_1})}$$

(b) Due to continuous surface distribution of charges

Consider a continuous surface distribution of charge having surface charge density σ (charge per unit surface area)

Consider a small surface element ds having charge σds and pv $\vec{r_1}$ as shown.



~~Fo~~ Small force exerted by surface element ds on a given charge q_0 having pv $\vec{r_0}$

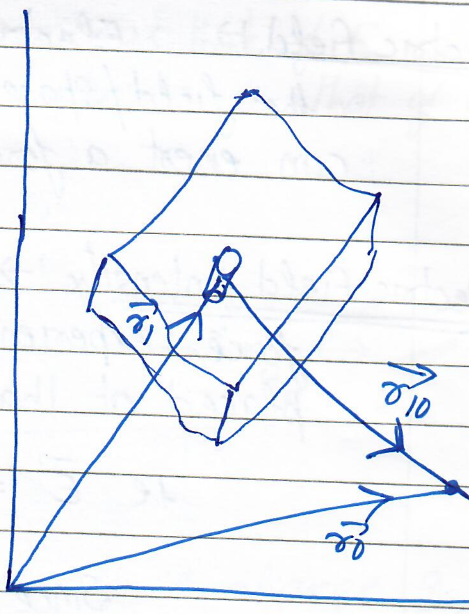
$$d\vec{F} = \frac{1}{4\pi\epsilon_0}\frac{q_0\,\sigma ds}{|\vec{r_{10}}|^2}\hat{r}_{10}$$

$$\Rightarrow d\vec{F} = \frac{1}{4\pi\epsilon_0}\frac{q_0\,\sigma ds}{|\vec{r_0}-\vec{r_1}|^3}(\vec{r_0}-\vec{r_1})$$

$$\boxed{\therefore \vec{F} = \frac{q_0}{4\pi\epsilon_0}\int \frac{\sigma\, ds}{|\vec{r_0}-\vec{r_1}|^3}(\vec{r_0}-\vec{r_1})}$$

(c) Due to continuous volume distribution of charge:-

Consider a continuous volume distribution of charge having volume charge density ρ (charge per unit volume) consider a small volume element dV having charge ρdV and PV $\vec{r_1}$ as shown.



Thus small force exerted by by small volume element on a given charge q_0 having PV $\vec{r_0}$ is.

$$d\vec{F} = \frac{1}{4\pi\epsilon_0} \frac{q_0 \rho dV}{|\vec{r_{10}}|^2} \hat{r_{10}}$$

$$\Rightarrow d\vec{F} = \frac{1}{4\pi\epsilon_0} \frac{q_0 \rho dV}{|\vec{r_0} - \vec{r_1}|^3} (\vec{r_0} - \vec{r_1})$$

$$\therefore \vec{F} = \frac{q_0}{4\pi\epsilon_0} \int \frac{\rho dV}{|\vec{r_0} - \vec{r_1}|^3} (\vec{r_0} - \vec{r_1})$$