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[Ch-01] Electrostatics

- **Electric charge :** $\boxed{1C = 3 \times 10^9 \text{ esu of charge}}$
- Charge is an intrinsic property of matter which gives rise to electric force b/w various objects.

- Symbol → q or Q
- S.I Unit → Coulomb (C)

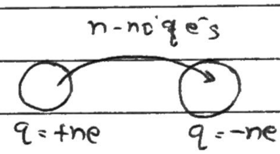
Dimension, $Q = i \times t$
$= [AT]$.

[Scalar Quantity]

- Types of Charge → +ve and −ve.
- Like charges repel each other and unlike charges attract each other.

Property of Charge

1) charge is transferable.



2) Charge is associated with mass.
(No charge can exist without mass.)

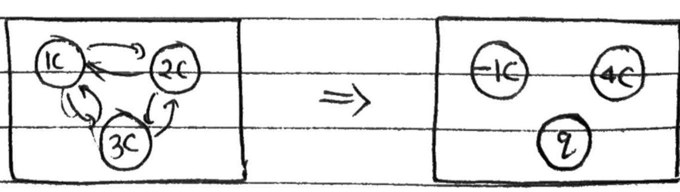
3) charge is invariant (do not vary with speed of body).
{Mass increases with velocity}

4) Conservation of charge : Charge can neither be created nor destroyed but only be transferred from one body to another. { Pair production m charge bnte hai pr net charge 0 hai
$\gamma + \gamma \rightarrow e^- + e^+$ }

OR

The total charge of an isolated system remains constant.

Isolated system



$1+2+3 = -1+4+q$
$6 = 3+q$
$q = 3C$

Quantisation → Available in fixed amount.

Quantisation of Charge

i) The smallest charge which exists independently is charge on electron.

$$1e^- = 1.6 \times 10^{-19} C \quad \text{(fundamental Charge)}$$

ii) Charge always exist in Integral multiple of fundamental charge.

$1e^-, 2e^-, 3e^-, 4e^- \ldots\ldots ne$

$-1e^-, -2e^-, -3e^-, -4e^-, \ldots\ldots ne$

$$Q = \pm ne$$

Q → Charge, n → Integer, e → Charge on e^-

Q- Can a charge $8 \times 10^{-19} C$ be given to a body ?

$Q = \pm ne$

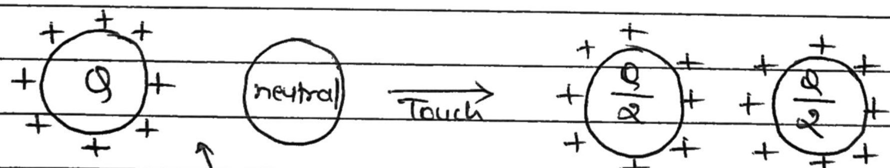
$8 \times 10^{-19} = n \times 1.6 \times 10^{-19}$

$n = \frac{80}{16} = 5$ (integer) ∴ Given charge Exists

Methods of Charging

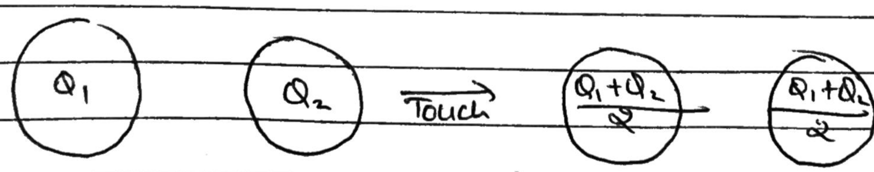
1) Charging by conduction : Direct contact.

(1)



Identical

(2)

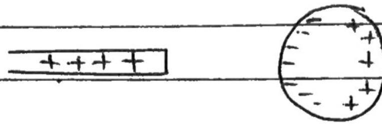


• charging by friction :-

⇒ Glass Rod + silk Cloth ⟶ Glass rod (+ve charge) + silk Cloth (−ve charge)

⇒ Ebonite rod (rubber) + Animal fur (wool) ⟶ Ebonite rod (−ve charge) + (+ve charge)

2) Charging by Induction : without contact.

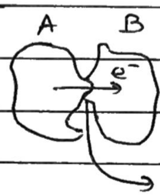


nearer end → opp. charge
farther end → same charge

overall charge = 0 .

3) Charging by Friction

If n e-s transfers from A to B

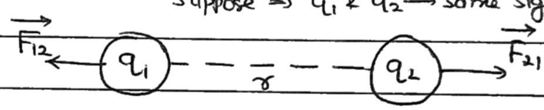


A : $q = +ne$
B : $q = -ne$

→ Rubbing → Thermal Energy → some outer e⁻ falls from one body to another

Coulomb's law

Suppose ⇒ q_1 & q_2 → same sign



1) $\vec{F_{12}} = -\vec{F_{21}}$

2) $F = \frac{kq_1q_2}{r^2}$ → without sign
↳ direcn decide

3) $k = \frac{1}{4\pi\varepsilon}$ ε → permittivity of medium.
$\varepsilon\uparrow$ $k\downarrow$ $F\downarrow$

4) for air / free space / vacuum

$k = \frac{1}{4\pi\varepsilon_0}$ ε_0 → absolute permittivity
↳ minimum value of ε

ε → min → air/vacuum ⇒ F → maximum in air

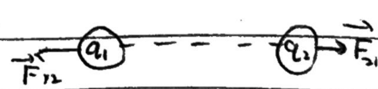
$\varepsilon_0 = 8.85 \times 10^{-12}\ C^2/Nm^2$

air / vacuum

$$k = 9 \times 10^9\ Nm^2/C^2$$

F → max in air/vacuum

5) F acts along line joining two charge.
(central force)



NOTE: Repulsion is sure test of electrification.
It mean if two objects repels each other then they must be charged object.

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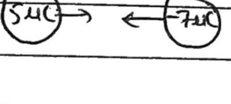
6) Coulomb's law valid for point charge only.
7) Coulomb's law valid for stationary charges.
8) F follows inverse square law $F \propto \frac{1}{r^2}$

9) ~~Work do~~ Electrostatic force is a conservative force
- work done depends only on initial & final position & do not depend on path.
- work done in a round trip by electrostatic force is zero.

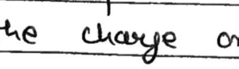
Q-> The charges on two spheres are $+7\mu C$ and $-5\mu C$, resp. They experience a force F. If each of them is given an additional charge of $-2\mu C$, then new force attraction will be

~~a)~~ F (b) F/2
c) $F/\sqrt{3}$ (d) 2F



$$F = \frac{k(7)(5)}{r^2} = \frac{35k}{r^2}$$

$-2\mu C$ given to each.



$$F' = \frac{k(5)(7)}{r^2} = \frac{35k}{r^2} = F$$

Q-> A charge Q is divided into two parts such that the electrostatic force between two parts is maximum. Find the charge on each part.

a) $\frac{Q}{4}, \frac{3Q}{4}$ (c) $\frac{Q}{5}, \frac{4Q}{5}$

~~b)~~ $\frac{Q}{2}, \frac{Q}{2}$ (d) $\frac{Q}{3}, \frac{2Q}{3}$

Yad rkhna -> [Aadha Aadha krne pr hi force maximum hoti h!]

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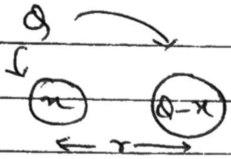

$$F = \frac{K(Q-x)x}{r^2}$$

F → Maxima

y → Maximum, $\frac{dy}{dx} = 0$

F → Maximum, $\frac{dF}{dx} = 0$

$$\frac{d\left[\frac{K(Q-x)x}{r^2}\right]}{dx} = 0$$

$$\frac{d[(Q-x)x]}{dx} = 0$$

$$\frac{d(Qx - x^2)}{dx} = 0$$

$$Q - 2x = 0$$

$$Q = 2x$$

$$x = \frac{Q}{2}$$

Q- Two point charges A and B, having charges +Q and −Q resp, are placed at certain distance apart and force acting b/w them is F. If 25 % charge of A is transferred to B, then force b/w the charges becomes :

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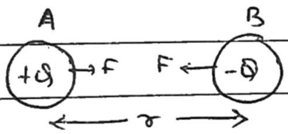
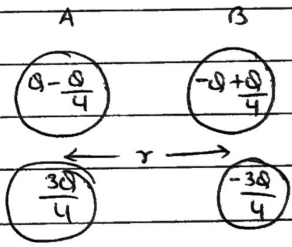
(A) $\frac{16F}{9}$ (b) $\frac{4F}{3}$

(C) F ~~(d)~~ $\frac{9F}{16}$



⟹ 25 % charge of A transfers to B.



$$F = \frac{KQ^2}{r^2}$$

$$F' = \frac{K\left(\frac{3Q}{4}\right)\left(\frac{3Q}{4}\right)}{r^2}$$

$$= \frac{9}{16}\frac{KQ^2}{r^2}$$

$$\boxed{F' = \frac{9}{16}F}$$

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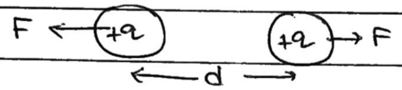
Q- Two positive ions, each carrying a charge q, are separated by a distance d. If F is the force of repulsion b/w the ions, the no of electrons missing from each Ion will be (e being the charge on an electron) (2010)

a) $\frac{4\pi\epsilon_0 F d^2}{e^2}$ (b) $\sqrt{\frac{4\pi\epsilon_0 F e^2}{d^2}}$

~~c)~~ $\sqrt{\frac{4\pi\epsilon_0 F d^2}{e^2}}$ (d) $\frac{4\pi\epsilon_0 F d^2}{q^2}$



$q = +ne$

$$F = \frac{kq^2}{d^2}$$

$$F = \frac{1}{4\pi\epsilon_0 . d^2} n^2 e^2 \Rightarrow \frac{F . 4\pi\epsilon_0 d^2}{e^2} = n^2$$

$$\boxed{\sqrt{\frac{4\pi\epsilon_0 . F d^2}{e^2}} = n}$$

Comparison with Law of Gravitation

$F_e = \frac{k q_1 q_2}{r^2}$ $F_G = \frac{G m_1 m_2}{r^2}$

Similarity :

- both follows $F \propto \frac{1}{r^2}$ (inverse sq. law)
- Acts along Line joining centres of bodies (central forces)

Differences :

• G is universal constant. $G = 6.67 \times 10^{-11}\ Nm^2/kg^2$	• k depends on medium air/vacuum $k = 9 \times 10^9\ Nm^2/C^2$
• F_G is attractive only	• F_e can be attractive or repulsive

Q- Find the ratio of electrostatic force to gravitational force b/w two electrons kept in free space

$1e^- = 1.6 \times 10^{-19}$ C $m_e = 9.1 \times 10^{-31}$ kg

$k = 9 \times 10^{9}$ Nm^2/C^2 $G = 6.67 \times 10^{-11}$ Nm^2/kg^2

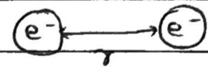
a) 10^{12}

b) 10^{24}

c) 10^{32}

~~d)~~ 10^{42}

$\frac{F_e}{F_G} = ?$



$$\frac{F_e}{F_G} = \frac{\frac{kq_1q_2}{r^2}}{\frac{Gm_1m_2}{r^2}} = \frac{9 \times 10^9 \times e^2}{6.67 \times 10^{-11} \times m^2}$$

$$= \frac{9 \times 10^9 \times (1.6 \times 10^{-19})^2}{6.67 \times 10^{-11} \times (9.1 \times 10^{-31})^2}$$

$\approx 10^{42}$

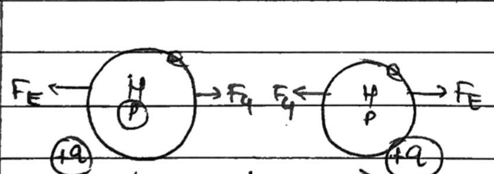
Q- Suppose the charge of a proton and an electron differ slightly. One of them is $-e$, the other is $(e + \Delta e)$. If the net of electrostatic force and gravitational force between two hydrogen atoms placed at a distance d (much greater than atomic size) apart is zero, then Δe is of the order of [Given mass of hydrogen $m_h = 1.67 \times 10^{-27}$ kg]. (2017)

a) 10^{-23} C ~~(b)~~ 10^{-37} C

c) 10^{-47} C (d) 10^{-20} C

electron $= -e$

proton $= e + \Delta e$



Net charge on H-atom $= -e + e + \Delta e$

$q = \Delta e$

Given: net force is zero,

$F_e = F_G$

$\frac{kq^2}{d^2} = \frac{Gm^2}{d^2}$

$9 \times 10^9 \times (\Delta e)^2 = 6.67 \times 10^{-11} \times (1.67 \times 10^{-27})^2$

$9 \times 10^9 \times (\Delta e)^2 = 6.67 \times 10^{-11} \times (1.67 \times 10^{-27})^2$

$9 \times 10^9 \times (\Delta e)^2 = 6.67 \times 10^{-11} \times (1.67)^2 \times 10^{-54}$

$10^{10} \cdot (\Delta e)^2 = 6.67 \times (1.67)^2 \times 10^{-65}$

$(\Delta e)^2 \approx 6.67 \times (1.67)^2 \times 10^{-75}$

$\Delta e \approx 2.5 \times 1.67 \times 10^{-37.5}$

$\boxed{\tan\theta \propto \frac{1}{mg}}$ $\Rightarrow$ $\tan\theta \downarrow \propto \frac{1}{m\uparrow}$ (mass zyada θ kam)

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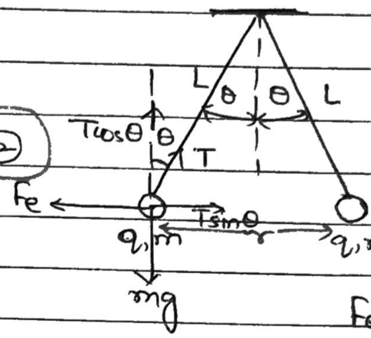
Q- Two identical small charged spheres, each having a mass 'm', hang in equilibrium as shown. The length of each string is l, and the ~~magnitude~~ angle made by any string with the vertical is θ. Find the magnitude of charge on each sphere.

Equilibrium: Net force = 0

$F_{net\,x} = 0$ | $F_{net\,y} = 0$

$T\sin\theta = F_e$ — (1) | $T\cos\theta = mg$ — (2)



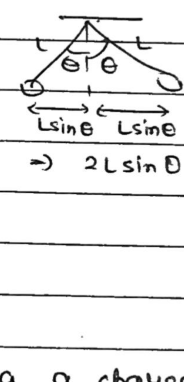
$F_e = \frac{kq^2}{r^2}$

(1) ÷ (2),

$$\tan\theta = \frac{F_e}{mg}$$

$$\tan\theta = \frac{kq^2}{r^2 \cdot mg}$$

$$\Rightarrow \quad q^2 = \frac{mg\,r^2 \tan\theta}{k}$$



$\Rightarrow 2L\sin\theta$

$$q^2 = 4\pi\epsilon_0 \cdot mg\,(2L\sin\theta)^2 \tan\theta$$

$$q^2 = 4\pi\epsilon_0 \cdot 4L^2\sin^2\theta\; mg\tan\theta$$

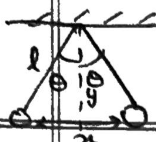
$$\boxed{q = \sqrt{16\pi\epsilon_0\, mg L^2 \sin^2\theta \tan\theta}}$$

Q- Two small spherical balls each carrying a charge $q = 10\,\mu C$ are suspended by two insulating threads of equal lengths 1 m each, from a point fixed in the ceiling. It is found that in equilibrium threads are separated by an angle $60°$ b/w them, as shown in the fig. What is the Tension in the threads :- (Given, $\left(\frac{1}{4\pi\epsilon_0}\right) = 9\times10^9\ Nm/C^2$)

(a) 18 N ~~(b)~~ 1.8 N

(c) 0.18 N (d) None of these

Key point :



If θ is very small,

Tan θ ≈ sin θ ≈ θ

$$x^3 = \frac{kq^2(2y)}{mg} = \frac{kq^2(2l)}{mg}$$

$\Rightarrow x^3 \propto q^2$

$\propto y$

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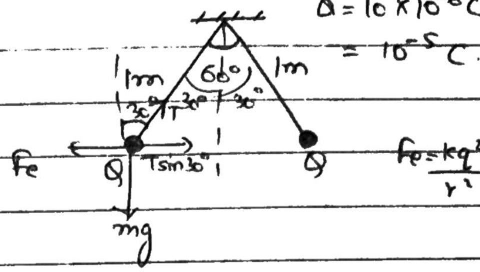


$Q = 10 \times 10^{-6} C$

$= 10^{-5} C$

$F_e = \frac{kq^2}{r^2}$

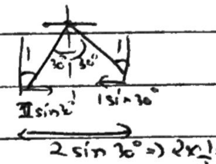
$T \sin 30° = F_e$

$$T \times \frac{1}{2} = \frac{kq^2}{r^2}$$

$$T \times \frac{1}{2} = \frac{9 \times 10^9 \times (10^{-5})^2}{(1)^2}$$

$T = 18 \times 10^{-1}$

$T = 1.8$ N



$2 \sin 30° \Rightarrow 2 \times \frac{1}{2} = 1$

Q- Two pith balls carrying equal charges are suspended from a common point by strings of equal length, the equilibrium separation b/w them is r. Now the strings are rigidly clamped at half the height. The equilibrium separation b/w the balls now become (2013)

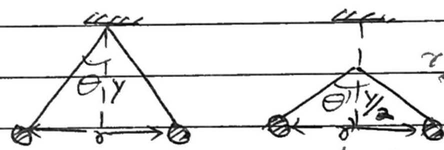
Key point: $x^3 \propto y$

a) $\left(\frac{1}{\sqrt{2}}\right)^2$

b) $\frac{r}{\sqrt[3]{2}}$

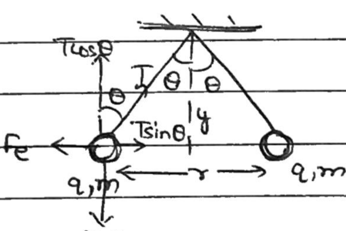
c) $\left(\frac{2r}{\sqrt{3}}\right)$

d) $\left(\frac{2r}{3}\right)$



$r^3 \propto y$

$$\left(\frac{r_1}{r_2}\right)^3 = \frac{y}{y/2}$$



$T \sin\theta = F_e$

$T \cos\theta = mg$

$\therefore \tan\theta = \frac{F_e}{mg}$

Case I : $\tan\theta = \frac{F_e}{mg}$

$$\frac{r}{2y} = \frac{kq^2}{r^2 mg} \quad \text{--- (1)}$$

Case II : $\tan\theta' = \frac{F_e}{mg}$

$$\frac{r'}{y} = \frac{kq^2}{r'^2 \cdot mg} \quad \text{--- (2)}$$

$\Rightarrow$ from (1) & (2)   (2) ÷ (1)

$$\frac{r}{2y} = \frac{2r'}{2y}$$

$$\frac{\frac{r'}{y}}{\frac{r}{2y}} = \frac{\frac{kq^2}{r'^2 mg}}{\frac{kq^2}{r^2 mg}}$$

$$\frac{2r'}{r} = \frac{r^2}{r'^2}$$

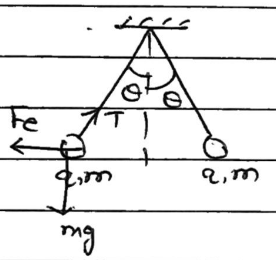
$$2r'^3 = r^3$$

$$r'^3 = \frac{r^3}{2}$$

$$r' = \frac{r}{(2)^{1/3}} = \frac{r}{\sqrt[3]{2}}$$

Summary

Learn ~~this~~

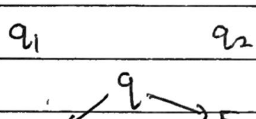


$$\tan\theta = \frac{F_e}{mg}$$

$$T = \sqrt{F_e^2 + mg^2}$$

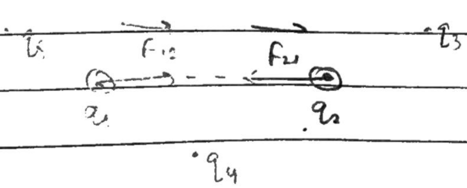
Principle of superposition

- If there are 3 or more charges, then net force on any one charge is vector sum of all forces on it due to remaining charges.



$$F_{net} = \vec{F_1} + \vec{F_2}$$

Note: The force between any two charges is unaffected by the presence of third charge.



Conclusion

1. F_{12} & F_{21} will remain constant
2. Net force on q_1 & q_2 may ↑es or ↓es.

Q- 

Attraction

$q_1 q_2 \to$ (−ve)

~~a) $q_1 q_2 < 0$~~
b) $q_1 q_2 > 0$
c) $q_1 q_2 = 0$
d) Data Insuff.

$q_1 \quad q_2 \quad q_3 \quad q_4 \quad q_5 \quad q_6 \; \ldots\ldots \quad q_n$.

net force on
n^{th} charge $= \vec{F_n} = \vec{F_{n_1}} + \vec{F_{n_2}} + \vec{F_{n_3}} + \ldots\ldots$

Q. A charge q_1 exerts some force on a second charge q_2. If a third charge q_3 is brought near q_2, then the force exerted by q_1 on q_2

a) decreases
b) increases
~~c)~~ remains the same
d) increases, if q_3 is of same sign as q_1 and decreases, if q_3 is of opp. sign as q_1.

$q_1 \qquad q_2 \longrightarrow F_{21}$
$\qquad\qquad q_3$

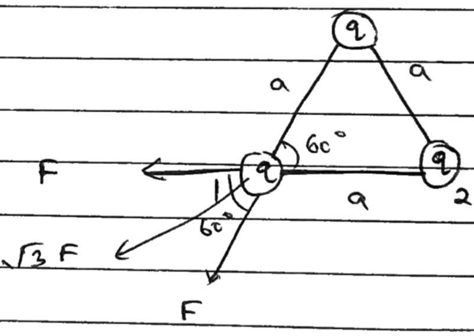
Q- Three equal charges (q) are placed at the corners of an equilateral triangle. The force on any charge is ;

a) $\dfrac{3kq^2}{a^2}$

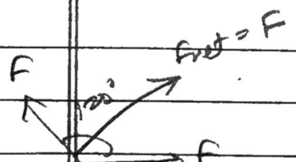
~~b)~~ $\dfrac{\sqrt{3}\,kq^2}{a^2}$

c) $\dfrac{\sqrt{3}\,kq^2}{a^3}$

d) $\dfrac{\sqrt{3}\,kq}{a^2}$



∴ Net force on 1 :
$= \sqrt{3}\,F$
$= \dfrac{\sqrt{3}\,kq^2}{a^2}$



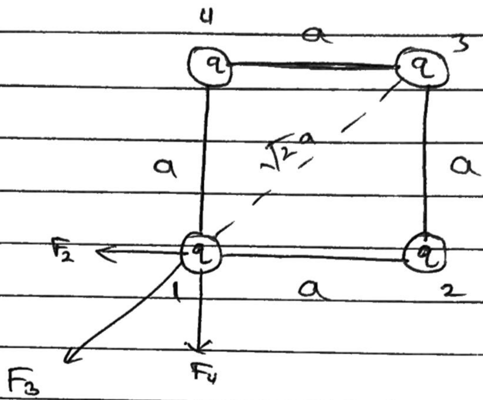
Q. Four equal point charges each 'q' are placed on the four corners of a square of side 'a'. Calculate the force on any one of the charges.

a) $\frac{kq^2}{a^2}(2+\sqrt{2})$

b) $\frac{kq^2}{a^2}\left(2+\frac{1}{\sqrt{2}}\right)$

~~c)~~ $\frac{kq^2}{a^2}\left(\sqrt{2}+\frac{1}{2}\right)$

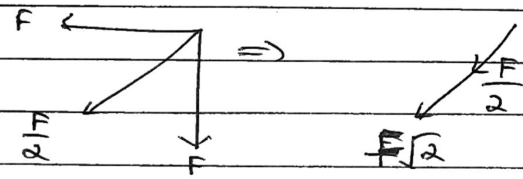
d) None of these



$$F_2 = \frac{kq^2}{a^2} = F$$

$$F_4 = \frac{kq^2}{a^2} = F$$

$$F_3 = \frac{kq^2}{(\sqrt{2}a)^2} = \frac{kq^2}{2a^2} = \frac{F}{2}$$



$\therefore$ Net force $= \frac{F}{2} + F\sqrt{2}$

$$= \frac{kq^2}{a^2}\left(\frac{1}{2}+\sqrt{2}\right)$$

Attraction can be b/w +ve & neutral charge but repulsion only b/w same charges.

1) cgs unit : $1\,C = 3\times10^9$ stat. C

$1\,C = 3\times10^9$ esu & $\boxed{1\,C = \frac{1}{10}\,emu}$

$K = 1$ (for air/vacuum)

$K = \infty$ (for metals)

2) $\boxed{\frac{F_{Air}}{F_{med}} = K = \varepsilon_r}$ $\boxed{\frac{F_0}{F_m} = \frac{\varepsilon_m}{\varepsilon_0} = \varepsilon_r \text{ or } K} \Rightarrow \varepsilon_m = \varepsilon_r \cdot \varepsilon_0$ $1 \le K \le \infty$

3) Condition for the force to be identical b/w two point charges separated by two diff. mediums.

$$\boxed{K_1 r_1^2 = K_2 r_2^2}$$

If 1^{st} medium is air $\Rightarrow (K_1 = 1)$

$$\boxed{r_{Air} = \sqrt{K_{med}}\cdot r_{med}}$$

$$F = \frac{Kq_1q_2}{(r - t + \sqrt{K}t)^2}$$

$$E_{ax} = \frac{2pr}{4\pi\varepsilon_0(r^2-a^2)}\hat{p}$$

$$E_{eq} = -\frac{p}{4\pi\varepsilon_0(r^2+a^2)^{3/2}}$$

4) Electric field intensity at line joining two charges :-

$$\boxed{x = \left[\frac{\sqrt{\text{smaller charge}}}{\sqrt{\text{Bigger charge}} - \sqrt{\text{Smaller charge}}}\right]a}$$

5) Electric field intensity due to distributed charge $= \boxed{E = \frac{2K\lambda}{r} = \frac{\lambda}{2\pi\varepsilon_0 r}}$

6) Electric field intensity due to an arc of charge at its centre :

$$\boxed{E_{centre} = \int dE = \frac{2K\lambda}{R}\frac{\sin\theta}{2}}$$

for semicircular arc, $\theta = 180°$

$$\boxed{E_{centre} = \frac{2K\lambda}{R}}$$

7) Electric field intensity due to a ring of charge at a distance 'x' from the centre on the axis of the Ring :

$$\boxed{E_{axis} = \frac{KQx}{(R^2+x^2)^{3/2}}}$$

$\frac{dE}{dx} = 0$ $\boxed{x = \frac{\pm R}{\sqrt{2}}}$ E max.

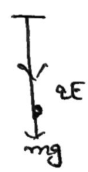
(ii) Time period of SHM of a charge q released very close to the centre of the ring :

$$\boxed{T = 2\pi\sqrt{\frac{4\pi\varepsilon_0 m R^3}{Qq}}}$$

8) Effect of simple pendulum placed in External Magnetic field.

$$T = 2\pi\sqrt{\frac{l}{g_{eff}}}$$

Case I : Pendulum oscillates vertically downward



$mg_{eff} = mg + qE$

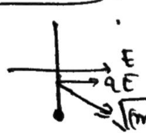
$g_{eff} = g + \frac{qE}{m}$, $\boxed{T = 2\pi\sqrt{\frac{l}{g + \frac{qE}{m}}}}$

Case II : Pendulum rotates in vertical upward.

$mg_{eff} = mg - qE$

$g_{eff} = g - \frac{qE}{m}$ $\boxed{T = 2\pi\sqrt{\frac{l}{g - \frac{qE}{m}}}}$

Case III : If Pendulum is placed in a horizontal electric field.



$\sqrt{(mg)^2 + (qE)^2} = mg_{eff}$

$$g_{eff} = \sqrt{g^2 + \left(\frac{qE}{m}\right)^2}, \quad \boxed{T = 2\pi\sqrt{\frac{l}{\sqrt{g^2 + \left(\frac{qE}{m}\right)^2}}}}$$

9) $\omega = \sqrt{\frac{PE}{I}}$ $\quad T = 2\pi\sqrt{\frac{I}{PE}}$

10) Integral form of Relaⁿ b/w Potential diff. & electric field.

$$V_A - V_B = \int_{x_a}^{x_b} E_x dx + \int_{y_a}^{y_b} E_y dy + \int_{z_a}^{z_b} E_z dz$$

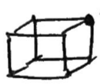
If potential is given, & Electric field is to be calculated :-

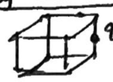
$$\vec{E} = -\left(\frac{\partial V}{\partial x}\hat{i} + \frac{\partial V}{\partial x}\hat{j} + \frac{\partial V}{\partial x}\hat{k}\right) \qquad \vec{E} = -\nabla V$$

11) Gauss

(How many cubes needed to cover charge)

(i)  on surface $\quad \phi = \frac{q}{2\epsilon_0}$

(ii)  $\quad \phi = \frac{q}{8\epsilon_0}$

(iii)  $\quad \phi = \frac{q}{4\epsilon_0}$

→ A charge Q is placed at corner of cube of length L. The electric flux link to one of the face not touching the charge Q is $\frac{Q}{24\epsilon_0}$

12) Electric field & Potential diff. due to infinitely long charge,

$E = \frac{\lambda}{2\pi\epsilon_0 r} = \frac{2K\lambda}{r}$ $\quad V_A - V_B = 2K\lambda \ln\frac{b}{a}$

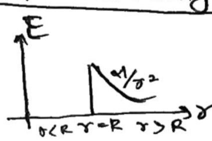
(ii) electric field & potential diff. due to a sheet of charge

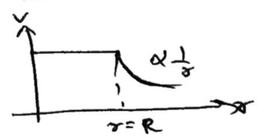
$E = \frac{\sigma}{2\epsilon_0}$ $\quad V_A - V_B = \frac{\sigma}{\epsilon_0}(b-a)$

E due to conducting sheet = $\frac{\sigma}{\epsilon_0}$
non-conducting sheet = $\frac{\sigma}{2\epsilon_0}$

(iii) Electric field & potential at all points due to hollow conducting, hollow non-conducting, solid conducting,

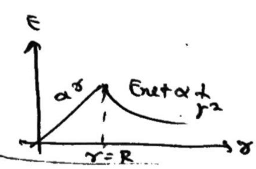
	Outside ($r>R$)	Surface ($r=R$)	Inside ($r<R$)
electric field	$E_{out} \propto \frac{KQ}{r^2}$	$E_{surf.} = \frac{KQ}{R^2}$	$E_{in} = 0$
potential	$V_{out} \propto \frac{KQ}{r}$	$V_{surf.} = \frac{KQ}{R}$	$V_{in} = V_{surface}$

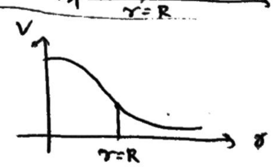




(iv) Electric field & potential at all points due to solid non-conducting sphere,

	outside ($r>R$)	Surface ($r=R$)	Inside ($r<R$)
	$E_{net} = \frac{KQ}{r^2}$	$E = \frac{KQ}{R^2}$	$E_{in} = \frac{KQr}{R^3}$ or $E = \frac{\rho r}{3\epsilon_0}$
potential	$V_{out} = \frac{KQ}{r}$	$V_{surf.} = \frac{KQ}{R}$	$V_{centre} = \frac{3}{2}\frac{KQ}{R}$; $V_{centre} = \frac{3}{2}V_{surface}$





13) Electric field at random position

$E_{net} = \frac{Kp}{r^3}\sqrt{1+3\cos^2\theta}$ $\quad \alpha = \tan^{-1}\left[\frac{\tan\theta}{2}\right]$

14) ⊥ dist. of charge q in uniform E after travelling distance x is $y = \frac{qEx^2}{2mv^2}$