11 Electrostatics

Electric Charge

- Like mass, the electric charge is also fundamental and intrinsic property of matter.
- Electric Charge is scalar quantity. It has two types

  (i) Positive Charge (ii) Negative charge
- If electron is removed from the body, it becomes positively charged and its mass is slightly decreased.
- When the body gain the electron, it becomes negatively charged and mass is slightly increased.
- The change in mass of the body = $n\text{m}_e = \frac{Q}{e}\text{m}_e$.

  Where $\text{m}_e = 9.1 \times 10^{-31}$ kg.

Units of Electric Charge and Relation Between Them

SI Unit $\rightarrow$ Coulomb (C)

CGS Unit $\rightarrow$ 1 Stat C or 1 esu of charge

CGS Unit $\rightarrow$ 1 ab C or 1 emu of charge

Relation : $1\text{ C} = 3 \times 10^9 \text{ Stat C} = \frac{1}{10}\, ab\text{ C}$

- Practical units of charge

  (i) amp $\times$ hr = 3600 C

  (ii) 1 faraday = 96,500 C
- The smallest unit of electric charge $\rightarrow$ Stat Coulomb
- The biggest unit of electric charge $\rightarrow$ Faraday
- The dimensional formula of electric charge $\rightarrow$ T^1A^1 or Q^1
- The minimum magnitude of electric charge on any body is $e = 1.60217733 \times 10^{-19}$ C. It is known as basic or fundamental charge.
- The number of electrons in 1 C negative charge is $n = 6.25 \times 10^{18}$
- The presence of electric charge can be detected by electroscope

Quantization of electric Charge

Magnitude of all charges found in nature are in integral multiple of a fundamental charge.

$Q = ne$ Where n = integer and $e = 1.6 \times 10^{-19}$ C

- Protons and neutrons consists of fundamental particle known as Quarks.

  It has two types : (i) Up quark $(u) \to +\frac{2}{3}e$ (ii) Down quark $(d) \to -\frac{1}{3}e$

- Composition of proton : *uud*

  Composition of neutron : *udd*

- If any body consists n_1 number of proton and n_2 number of electron then total charge on it is $Q = (n_2 \sim n_1)e$

Conservation of Electric Charge

- The algebraic sum of electric charges in an electrically isolated system always remains constant irrespective of any process taking place.
- In every chemical or nuclear reaction, the total charge before and after the reaction remains constant.

e.g. Pair Production : $2\gamma \text{ rays} \to {}_{-1}e^0 + {}_{+1}e^0$

Nuclear reaction : ${}_{92}U^{238} \to {}_{90}Th^{234} + {}_{2}He^4$

$${}_0n^1 \to {}_1P^1 + {}_{-1}e^0$$

Electrostatic Induction :

Body can be charged by the following methods :

(1) By Friction :

When two bodies are rubbed together, equal and opposite charges are produced on both the bodies.

- In the method of Friction, when an electron is transfer from one body to another body, the body which loss the electron becomes positively charged and its mass is reduced. While the body which gain the electron becomes negatively charged and its mass is increased.
- The pair of charged body :

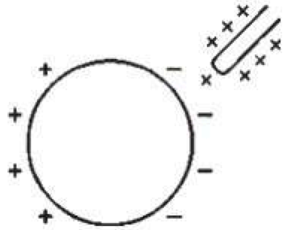
FGW	*PASER*
(+)	(−)

- F = Fur, G = Glass, W = Wool
- P = Plastic, A = Amber, S = Silk, E = Ebonite,

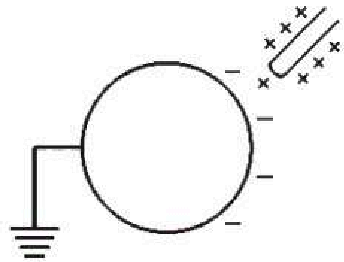
  R = Rubber

(2) By Induction :

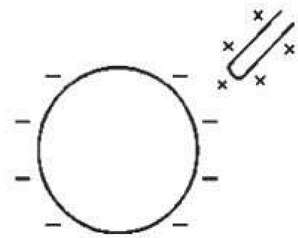
If a charged body is brought near a neutral body, opposite charge is induced at the near end and similar charge at the farther end on neutral body.



Charging substance brought near to uncharged substance



Charged substance connected to the Earth (Earthing)



Disconnecting charged substance from the earth

- Maximum induced charge $Q' = \pm Q\left[1-\frac{1}{K}\right]$ Where $K =$ di-electric constant of chargeless substance.

(3) By Conduction :

When two identical bodies, one of them is charged and the other is neutral, brought in contact, the charge is distributed half-half on them. Hence the neutral body is charged.

- If the two sphere of radius R_1 and R_2 and total charge Q, brought in contact and then separate the charge on them is :

$$q_1 = \frac{QR_1}{R_1+R_2} \text{ and } q_2 = \frac{QR_2}{R_1+R_2}$$

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(1) A copper sphere of mass 2.0 g contains about 2×10^{22} atoms. The charge on the nucleus of each atom is 29e. If the charge on sphere is $+2\mu C$ then fraction of electrons removed is __________.

(A) 5.8×10^{23} (B) 1.25×10^{13} (C) 6.28×10^{23} (D) 2.16×10^{-11}

(2) A substance of mass 1 g consists of 5×10^{21} molecules. If from 0.01 % molecules of the substance 1 electron is removed, then total electric charge on the substance is __________ C.

(A) + 0.08 (B) + 0.8 (C) – 0.08 (D) – 0.8

(3) Total charge on 75 kg electrons is __________ C.

(Mass of electron, $m_e = 9\times10^{-31}$ kg)

(A) -1.25×10^{13} (B) -6.25×10^{18} (C) -1.33×10^{13} (D) -1.6×10^{19}

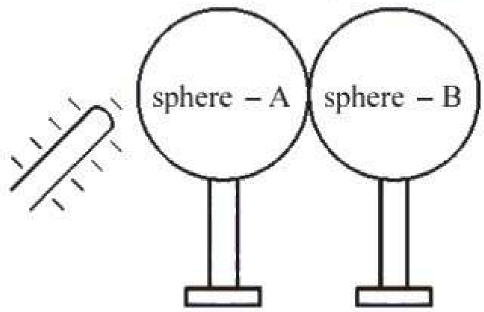
(4) Calculate negative charge in 100 g of water.

(A) 1.33×10^{13} C (B) 5.34×10^{6} C (C) 6.25×10^{18} C (D) 2.55×10^{8} C

(5) If 10^{10} electrons are incident on a substance per second, then what time would be taken by it to get total 1 C electric charge ?

(A) 20 Days (B) 20 Years (C) 2 Hours (D) 2 Days

(6) Two chargeless sphere A and B are in contact with each other. As shown in figure, a negatively charged rod is brought near without contact to sphere. Now, if sphere A and B are slightly separated and the rod is removed, the charge on sphere A and sphere B is ____________ .



(A) positive and positive (B) A Positive and B Negative

(C) Negative and Negative (D) A Negative and B Positive

(7) Sphere having radius 2 cm has $40\mu C$ charge and other sphere having radius 3 cm has $20\mu C$ charge. If they are connected with a conducting wire, the charge move from sphere of radius 2 cm to sphere of radius 3 cm is ____________.

(A) $24\mu C$ (B) $72\mu C$ (C) $16\mu C$ (D) $32\mu C$

Ans. : 1 (D), 2 (A), 3 (C), 4 (B), 5 (B), 6 (B), 7 (C)

Coulomb's Law :

In 1785 a scientist Charles Augustin Coulomb gavea the law to find out the electric force between two point charges.

'The electric force between two stationary point charges is directly proportional to the product of their charges and inversely proportional to the square of the distance between them.'

$$F \alpha \frac{q_1 q_2}{r^2} \Rightarrow \boxed{F = k\frac{q_1 q_2}{r^2}}$$

Where k is proportionality constant it is known as Coulomb's constant. Its value depends upon two factors :

(i) Unit system (ii) Medium in which the charge is placed.

- **SI System :** $k = \frac{1}{4\pi \epsilon_0} = 9 \times 10^9 \ Nm^2 C^{-2}$

  CGS System : $k = 1$

  Where ϵ_0 = permitivity of free space = $8.85 \times 10^{-12} \ C^2 N^{-1} m^{-2}$

- **Another unit of is** ϵ_0 **:** farad / metre

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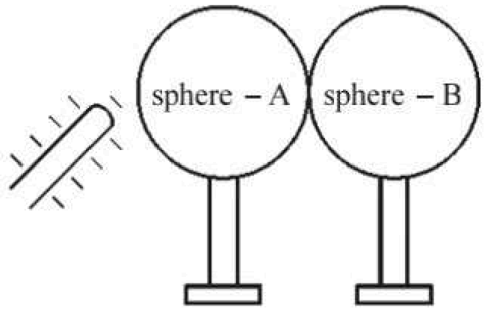

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- **Relative Permittivity $(\in_r)$ Or Dielectric Constant (K) :**

Dielectric constant of medium $K = \dfrac{\text{Permittivity of medium } (\in)}{\text{Permittivity of vaccum } (\in_0)}$

$$K = \in_r = \frac{\in}{\in_0}$$

- **Coulomb's Law In Terms of dielectric constant (K) :**

When two charges are put in a medium, the electric force between them

$$F_m = \frac{1}{4\pi \in} \frac{q_1 q_2}{r^2}$$

$$\text{But } \frac{\in}{\in_0} = K \Rightarrow \in = K \in_0$$

$$F_m = \frac{1}{4\pi \in_0 K} \frac{q_1 q_2}{r^2}$$

$$\text{Therefore } F_m = \frac{F}{K}$$

- For Insulator (dielectric substances) $K > 1$ thus, $F_m < F$
- In vacuum $K = 1$, For air $K = 1.0006 = 1$
- For Conductor $K = \infty$

Vector form of Coulomb's law :

- The electric force on q_1 due to q_2 is $\vec{F}_{12} = \dfrac{kq_1q_2}{|\vec{r}_1 - \vec{r}_2|^3}\left(\vec{r}_1 - \vec{r}_2\right)$

- The electric force on q_2 due to q_1 is $\vec{F}_{21} = \dfrac{kq_2q_1}{|\vec{r}_2 - \vec{r}_1|^3}\left(\vec{r}_2 - \vec{r}_1\right)$

Important points of Coulomb's law

- The coulombian force acting between two charges is mutually interactive. The force acting between two charges is equal in magnitude and opposite in direction. The ratio of electric force between charges q_1 and q_2 is 1:1.

- Coulomb's law agrees with Newton's Third law. $\vec{F}_{12} = -\vec{F}_{21}$

- Coulomb's law is applicable for the distance more than 10^{-15} m (nuctear distance) and it can be applied for the point charges only.

- If $q_1q_2 > 0$ then two charges repel each other and if $q_1q_2 < 0$ then they attract each other.
- Charge Q is divided in charges q_1 and q_2 and if the force acting between them is maximum then $q_1 = q_2 = \frac{Q}{2}$.
- When a material medium of dielectric constant K is placed between the charges, the force between them becomes $\frac{1}{K}$ of the force between them in vacuum. $F_m = \frac{F}{K}$
- If a dielectric medium of dielectric constant K and thickness t is partially filled between the charges q_1 and q_2 which are at a distance r then the electric force between them is. $F = \frac{kq_1q_2}{\left(r-t+t\sqrt{K}\right)^2}$
- The coulombian force acting between two charges is not influenced by the presence of a third charge. Hence, the coulombian force is called a two body force.
- If two point charge q_1 and q_2 are separated with medium of thickness $t_1, t_2, \ldots. t_n$ and dielectric constant $K_1, K_2, \ldots. K_n$ respectively then the electric force between them is.

$$F = \frac{kq_1q_2}{\left[\sum_{i=1}^{n} \sqrt{K_i}\ t_i\right]^2}$$

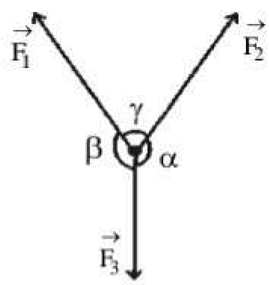
In above case, if the distance between two charge is taken t then equivalent dielectric constant.

$$K = \left[\frac{\sum_{i=1}^{n} \sqrt{K_i}\ t_i}{\sum_{i=1}^{n} t_i}\right]^2$$

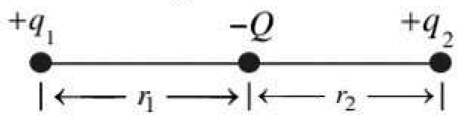
- If the force between two charges at distance r_1 is F_1 and at distance r_2 is F_2 then $F_1r_1^2 = F_2r_2^2$.
- If the force in medium of dielectric constant K_1 is F_1 and in dielectric constant K_2 is F_2 than $F_1K_1 = F_2K_2$.
- If two identical sphere carry charge q_1 and q_2 and force acting between them is F. They are brought in contact and then separated then the force acting between them is $F' = \frac{(q_1+q_2)^2}{4q_1q_2}F$.
- A sphere of mass m, atomic number Z and atomic mass A has electric charge $q = \frac{(\%Ze)\ N_A m}{A}$ where N_A = Avogadro's number

Principle of equilibrium of electric forces :

- To solve some questions of electrostatic, Lami's theorem is very useful. According to this theorem, if three forces are in equilibrium, as shown in figure, it means that $\vec{F_1} + \vec{F_2} + \vec{F_3} = 0$ then,



$$\frac{F_1}{\sin\alpha} = \frac{F_2}{\sin\beta} = \frac{F_3}{\sin\gamma}$$

- 

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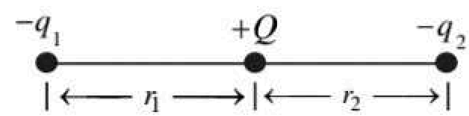


As shown in figure, charges are placed on one line. q_1 and q_2 are like charges while Q is unlike charge then,

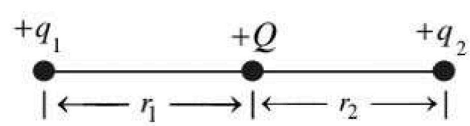
- When the force on q_1 is zero then $\frac{q_2}{Q} = \frac{(r_1 + r_2)^2}{r_1^2}$

- When the force on q_2 is zero then $\frac{q_1}{Q} = \frac{(r_1 + r_2)^2}{r_2^2}$

- When the force on Q is zero then $\frac{q_2}{q_1} = \frac{r_2^2}{r_1^2}$

- If all three charges are like charges then condition for equilibrium of Q is,

$$\boxed{\frac{q_1}{q_2} = \frac{r_1^2}{r_2^2}}$$



- **The magnitude of distance for the same magnitude of force in vacuum and medium**

$$F_{vacuum} = F_{medium}$$

$$\frac{1}{4\pi\epsilon_0}\frac{q_1q_2}{r^2} = \frac{1}{4\pi\epsilon_0 K}\frac{q_1q_2}{r'^2}$$

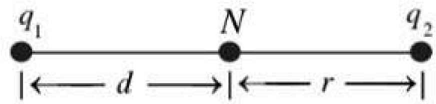
$$\boxed{\Rightarrow r' = \frac{r}{\sqrt{K}}}$$

- **Null points or neutral points due to charge q_1 and q_2 at distance r :**
  - If the neutral point is at the distance d from the charge q_1 then,

$$\boxed{d = \frac{r}{\sqrt{\frac{q_2}{q_1}} \pm 1}} \quad (\text{If } q_2 > q_1)$$

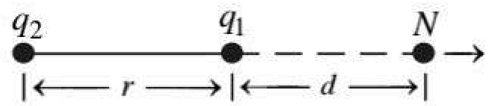
  - If both the charges are identical then,

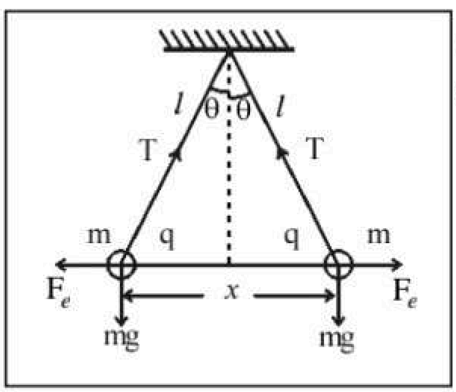
$$d = \frac{r}{\sqrt{\frac{q_2}{q_1}} + 1}$$



  - If both the charges are unidentical then,

$$d = \frac{r}{\sqrt{\frac{q_2}{q_1}} - 1}$$





As shown in figure if the spheres of mass m are charged with charge q then

$$\frac{F_e}{mg} = \tan\theta = \frac{x}{2l}$$

$$\boxed{\therefore\ x = 2l\left(\frac{F_e}{mg}\right) \quad \text{or} \quad x = \left(\frac{2q^2 l}{4\pi \in_0 mg}\right)^{\frac{1}{3}}}$$

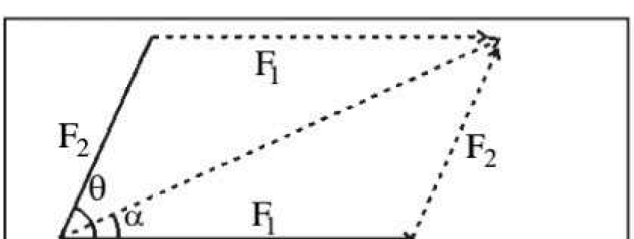
  - If both the spheres are immersed in liquid of density ρ_0 and if the distance between them remains same then the density of the spheres is

$$\rho = \frac{K\rho_0}{K-1}$$

  - If the dielectric constant of liquid is K then,

$$K = \frac{\rho}{\rho - \rho_0}$$

- According to law of parallelogram, the resultant force on a charge due to two electric charges is,



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

where θ = angle between $\vec{F_1}$ and $\vec{F_2}$.

Also $\tan\alpha = \dfrac{F_2 \sin\theta}{F_1 + F_2\cos\theta}$.

- If $F_1 = F_2 = F'$ then for different angle of θ, magnitude of force is :

Angle θ	**Force F**
0°	$2F'$
30°	$\left(2+\sqrt{3}\right)^{\frac{1}{2}} F'$
45°	$\left(2+\sqrt{2}\right)^{\frac{1}{2}} F'$
60°	$\sqrt{3}\,F'$
90°	$\sqrt{2}\,F'$
120°	F'
150°	$\left(2-\sqrt{3}\right)^{\frac{1}{2}} F'$
180°	0

Principle of Superposition

The electric force on electric charge due to system of n charges is,

$$\vec{F}_i = kq_i \sum_{\substack{j=1 \\ j\neq i}}^{n} \frac{q_j}{|\vec{r}_i - \vec{r}_j|^3} \cdot \left(\vec{r}_i - \vec{r}_j\right)$$

Specific charge :

The ratio of electric charge and mass $\left(\frac{e}{m}\right)$ is known as specific charge.

- Its SI unit is $\mathrm{C\,kg^{-1}}$ and dimensional formula is : $M^{-1}T^{1}A^{1}$ or $M^{-1}Q^{1}$

(i) As the velocity of a particle increases, its charge remains same, but mass of the particle increases. $m = \dfrac{m_0}{\sqrt{\dfrac{1-v^2}{C^2}}}$.

So, as velocity increases, the specific charge of the particle decreases.

(ii) Specific charge of electron $\rightarrow -1.76 \times 10^{11}\ \mathrm{C\,kg^{-1}}$

Specific charge of proton $\rightarrow 9.580 \times 10^{7}\ \mathrm{C\,kg^{-1}}$

Charge densities :

Charge distributed per unit dimension (length, area or volume) is called charge density.

- There are three types of charge densities.

(i) **Linear charge density :** Charge distribution per unit length is known as linear charge density.

$$\lambda_1 = \frac{Q}{l}$$

SI unit $\rightarrow Cm^{-1}$; Dimensional formula $\rightarrow L^{-1}T^1A^1$

(ii) **Surface charge density :** Charge Distribusion per unit area is known as surface charge density.

$$\sigma_s = \frac{Q}{A}$$

SI unit $\rightarrow Cm^{-2}$; dimentional formula $\rightarrow L^{-2}T^1A^1$

(iii) **Volume charge density :** Charge distribution per unit volume is known as Volume charge density.

$$\rho_v = \frac{Q}{V}$$

SI unit $\rightarrow Cm^{-3}$; Dimensional formula $\rightarrow L^{-3}T^1A^1$

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(8) The distance between two ions of same positive charge is $5\mathring{A}$ and electric force acting on them is 3.7×10^{-9} N, then electron loss by each ion is ______.

(A) 2 (B) 3 (C) 1 (D) 4

(9) The earth and moon has same type of and equal magnitude of charges. To balance the gravitational force between earth and moon, the required magnitude of charge is ______.

$[M_e = 6 \times 10^{24}$ kg, $M_m = 7.36 \times 10^{22}$ kg $]$

(A) $1/5.7 \times 10^{-13}$ C (B) 5.7×10^{13} AbC

(C) 5.7×10^{13} C (D) 5.7×10^{13} StatC

(10) $+q$ and $-q$ charges are put on diametric end points of circle of diameter d, then the force on third charge $+q$ which is on the center of circle is ______.

(A) $\frac{8Kq^2}{d^2}$ (B) $\frac{2Kq^2}{d^2}$ (C) $\frac{4Kq^2}{d}$ (D) 0

(11) If two unlike charge of same magnitude are placed at certain distance the force between them is F. If 25 % electric charge is moved from one charge to another charge then the force between them is ______.

(A) F (B) $\frac{4}{5}$F (C) $\frac{15F}{16}$ (D) $\frac{9}{16}$F

(12) Two point charges placed at distance of 20 cm in air attracts each other with certain force. When a dielectric slab of thickness 8 cm and dielectric constant K is introduced between these two charges force of interaction becomes half of its previous value. Then the magnitude of K is ______________.

(A) 1 (B) 4 (C) $\sqrt{2}$ (D) 2

(13) Two particles of mass 5 g and charge 10^{-7} C are placed on horizontal table at distance 10 cm. When both the particle are in equilibrium position, the co-efficient of static friction μ_s = ______________.

(A) 0.15 (B) 0.19 (C) 0.18 (D) 0.2

(14) Two point charges q and $2q$ are placed in air at distance d. If third electric charge Q is kept on the line joining two charges such that the resultant force on q and $2q$ becomes zero, then the distance of charge Q from charge q is ______________.

(A) $\dfrac{d}{\sqrt{2}-1}$ (B) $\left(\sqrt{2}-1\right) d$ (C) $\dfrac{d}{\sqrt{3}+1}$ (D) $\left(\sqrt{3}+1\right) d$

(15) Two point charges q_1 and q_2 are kept at distance 3 m. If sum of these charges is $20\ \mu$C and repulsive force between them is 0.075 N, the magnitude of each charge is ______________.

(A) 12 μC, 8 μC (B) 14 μC, 6 μC (C) 16 μC, 4 μC (D) 15 μC, 5 μC

(16) Positive charge on two conducting spheres is q_1 and q_2. These two spheres are brought close to each other such that after touching each other, they return back to their original positious. How much will be the force between then in new situation ?

(A) Force remains same as before the spheres were in contact.

(B) Force becomes more than before the spheres were in contact.

(C) Force becomes less than before the spheres were in contact.

(D) Becomes zero.

(17) The similar spheres of mass 10^{-3} kg are suspended by silk strings of length 0.5 m. When both the spheres are equally charged, they repel each other at 0.2 m distance, then the electric charge on the each sphere is ______________.

(A) 1.53×10^{-3} C (B) 2.15×10^{-6} C (C) 9.43×10^{-8} C (D) 2.36×10^{-6} C

(18) Two balls of same mass and radius are suspended by string of length 1 m. The mass and electric charge on each ball is 15 g and 126 μC respectively. When both the spheres are in equilibrium, the distance between them is 8 cm. Now if the charge on any one ball is reduced up to half then the new distance between them is ______________ cm.

(A) 5.3 (B) 6.4 (C) 4.2 (D) 2.5

(19) Two spheres having same charge of $10\ \mu C$ are suspended from a rigid support by a string of length 1 m. In equilibrium, the angle between them is 60^{o} then the tension produced in string is ______ N.

(A) 18 (B) 0.18 (C) zero (D) 1.8

(20) Charge Q is placed at each of the opposite vertices of a square. Charge q is placed at each of the other two vertices. It the net electric force on Q is zero, then $\frac{Q}{q} =$ ______.

(A) -1 (B) 1 (C) $-2\sqrt{2}$ (D) $-\frac{1}{\sqrt{2}}$

(21) The distance between two equal charge Q is r. A third charge q is placed on line joining these two charges such that all three charges remains in equilibrium. Then what is the position and magnitude of q ?

(A) $2r, Q$ (B) $\frac{r}{2}, -\frac{Q}{4}$ (C) $\frac{r}{2}, -\frac{Q}{2}$ (D) $2r, 2Q$

(22) In right angled triangle PQR, $\angle PQR = \frac{\pi}{2}$. Also $PQ = 5$ cm and $QR = 10$ cm. 10 nC and 20 nC charges are placed respectively on point P and Q. If, due to this charges, the force acting on $1\ \mu C$ charge placed at point Q is $18\sqrt{x}\ mN$, then $x =$ ______.

(A) 3 (B) 2 (C) 11 (D) 5

(23) The position vector of two $1\ nC$ charges are $(1, 1, -1)$m and $(2, 3, 1)$m respectively. Then the magnitude of coulombian force between this two charges is ______.

(A) 10^{-6} N (B) 10^{-3} N (C) 10^{-12} N (D) 10^{-9} N

(24) The specific charge of a steady electron is $1.76 \times 10^{11}\ \text{Ckg}^{-1}$. If it move with velocity $v = \frac{c}{2}$ (where $c =$ velocity of light) then its specific charge is ______ C kg^{-1}.

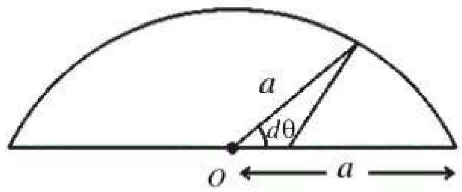
(A) 2.0×10^{11} (B) 1.53×10^{11} (C) Zero (D) 2.6×10^{-15}

(25) The linear charge density on the circumference of a circle of radius a varies as $\lambda = \lambda_0 \cos^2\theta$.

The total charge on it is ______. $\left[\text{Hint :- } \int_0^{2\pi} \cos^2\theta\ d\theta = \pi\right]$

(A) Infinite (B) Zero (C) $2\pi a$ (D) $\pi a \lambda_0$

(26) As shown in figure the linear charge density on the rim of the semi-circular wire is $\lambda = \alpha\theta$ where α = constant. Then the total charge on a semi-circular wire is ____________.



(A) $\frac{a\alpha\pi}{2}$ (B) $\frac{a\alpha\pi^2}{2}$

(C) $a\alpha\pi$ (D) $\frac{2a\alpha}{\pi^2}$

(27) The charge density on a sphere of radius R is given by equation $\rho(r) = \beta r^2$, then the total charge on the sphere is ____________.

(A) $\frac{2\pi R^3\beta}{3}$ (B) $\frac{4\pi R^3\beta}{3}$ (C) $\frac{4\pi R^5\beta}{5}$ (D) Zero

(28) A square having length a has electric charge distribution of surface charge density $\sigma = \sigma_0 xy$, then total electric charge on the square with respect to the Cartesian Co-ordinate system placed at the centre of the square is ____________.

(A) $\frac{\sigma_0 a^4}{4}$ (B) $4\pi\sigma_0 a^2$ (C) $2\sigma_0 a^2$ (D) Zero

Ans. : 8 (A), 9 (C), 10 (A), 11 (D), 12 (B), 13 (C), 14 (B), 15 (D), 16 (B), 17 (C), 18 (B), 19 (D), 20 (C), 21 (B), 22 (D), 23 (D), 24 (A), 25 (D), 26 (B), 27 (C), 28 (D)

Electric field :

The region of space around a system of electric charge, in which its effect can be experienced, is known as Electric field.

- There are four types of electric field :
  - (i) Uniform electric field : The electric field, at every point of which a unit positive test charge experiences the same electric force, is known as Uniform electric field. In uniform electric field, the lines of force are parallel and equidistant. e.g. Electric field between the plates of a parallel plate condenser.
  - (ii) Non - uniform electric field : The electric field, at different points of which a unit positive test charge experiences different forces, is known as Non-uniform electric field.
  - (iii) Variable electric field : The electric field which changes with respect to time is known as Variable electric field. $E = f(t)$
  - (iv) Constant electric field : The electric field which does not depend on time is known as a Constant electric field. $E \neq f(t)$
- The line integral of electric field along any closed path is zero. i.e. the electric field is a conservative force field. $\oint \vec{E} \cdot \vec{dl} = 0$.

Electric field intensity $(\vec{E})$:

The force acting on a unit positive charge at a given point in an electric field of a point charge of a system at charges is called Electric field or intensity of electric field $(\vec{E})$ at that point.

$$\vec{E} = \lim_{q_0 \to 0} \frac{\vec{F}}{q_0}$$

- Force experienced by a charge q in an electric field of intensity $\vec{F} = q\vec{E}$.
- According to Newton's second law $F = ma$.

  $\therefore\ ma = qE$

  $\therefore\ a = \dfrac{qE}{m}$

- If charge is in motion in electric field then,
  - Velocity after 't' seconds is $v = v_0 + \left(\dfrac{qE}{m}\right)t$.
  - Distance travelled in 't' seconds $d = v_0 t + \dfrac{1}{2}\left(\dfrac{qE}{m}\right)t^2$
  - Time taken to fall through a height 'h' is $t = \sqrt{\dfrac{2hm}{qE}}$

Electric field due to a point charge :

By Coulomb's law, $F = \dfrac{kQq}{r^2}$

$$\therefore\ \frac{F}{q} = \frac{kQ}{r^2}$$

$\therefore$ The electric field due to point charge $\boxed{E = \dfrac{kQ}{r^2}}$

In vector form, $\boxed{\vec{E} = \dfrac{kQ}{r^3}\vec{r}}$

- The value of E depends on the magnitude of source charges and distance from that charge.
- The number of electric lines of force passing through unit area imagined around any point in an electric field is defined as Intensity of electric field at that point.

- The electric fiux passing perpendicularly through unit normal area is known as Intensity of electric field. $\vec{E} = \frac{\phi}{\vec{A}}$
- The direction of force acting on unit positive charge at a given point is the direction of electric field at that point.
- SI unit of electric field : (i) NC^{-1} (ii) Vm^{-1}
- Dimensional formula of electric field : $[\vec{E}] = M^1L^1T^{-3}A^{-1}$ or $M^1L^1T^{-2}Q^{-1}$
- A positive charge like alpha-particle, proton and deuteron, experience a force in the direction of electric field and a negative charge like electron experiences a force in a direction opposite to the electric field.
- A charge q_0 is kept in an electric field of strength E and experiences a force F then,

(i) $E < \frac{F}{q_0}$ if field is diverging

(ii) $E = \frac{F}{q_0}$ if field is uniform

(iii) $E > \frac{F}{q_0}$ if field is converging

Electric lines of force :

Scientist Michael Faraday introduced the concept of electric field lines.

- An electric field line is a curve drawn in an electric field in such a way that the tangent to the curve at any point is in the direction of net electric field at that point.

Characteristic of electric field lines :

(1) Electric field lines start from positive charge and end at negative charge.

(2) The tangent drawn at any point on the electric field lines shows the direction of electric field at that point.

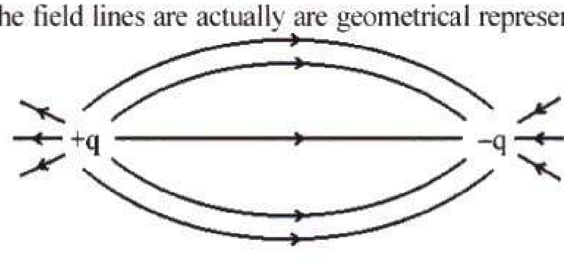
(3) Two field lines never cross each other. If two lines intersect at a point, two tangents can be drawn at that point indicating two directions of electric field at that point which is not possible.

(4) Electric field lines of stationary electric charge distribution do not form closed loops.

(5) The separation of neighbouring field lines in a region at electric field lines indicates the strength of electric field in that region.

(6) Field lines of uniform electric field are mutually parallel and equidistant.

- The electric field lines are geometrical representation of electric field and are not real. But electric field is a reality. The field lines are actually are geometrical representation of electric field.



(29) A coin of mass 1.6 g is placed in an electric field of intensity $10^9\ NC^{-1}$ in vertical direction. For equilibrium of coin, the number of electrons to be removed from the coin is ______________.

(A) 9.8×10^7 (B) 6.25×10^9 (C) 1.6×10^{-19} (D) 4.25×10^{10}

(30) Mass of a bob of simple pendulum is 80 mg and the charge on it is $20\ nC$. It is suspended by a string in a horizontal electric field of intensity $2 \times 10^4\ NC^{-1}$. In equilibrium, the angle made with vertical direction and tension force arising in string is ______________.

(A) $30^\circ,\ 2.4 \times 10^{-2}$ N (B) $45^\circ,\ 1.57 \times 10^{-3}$ N

(C) $27^\circ,\ 8.8 \times 10^{-4}$ N (D) $35^\circ,\ 4.5 \times 10^{-4}$ N

(31) If a particle of mass 1 g and charge $5\ \mu C$ is moved with velocity 20 ms^{-1} in direction opposite of electric field of internsity $2 \times 10^5\ NC^{-1}$ then how much distance is travelled by the particle before coming to rest ?

(A) 1 m (B) 0.4 m (C) 10 cm (D) 0.2 m

(32) Two parallel conducting plates lie at a distance 20 mm. Potential of upper plate is +2400 V wrt lower plate. If an electron is released at lower plate then how much time does it take to reach upper plate ?

$\frac{e}{m} = 1.8 \times 10^{11}\ Ckg^{-1}$

(A) 2 μs (B) 1.4 ns (C) 1.7 ms (D) 2.7 μs

(33) In Millikan experiment, a drop of charge Q remains stationary between the two plates having 2400 V potential difference. If the radius of drop becomes half and potential difference 600 V then for equilibrium, the charge on drop is ______________.

(A) $\frac{Q}{4}$ (B) $\frac{Q}{2}$ (C) Q (D) $\frac{3Q}{2}$

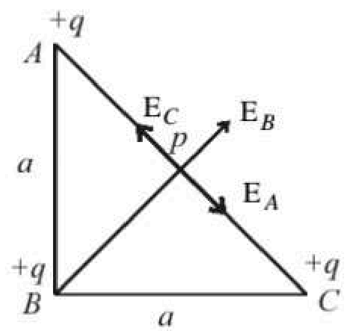
(34) 10^{-8} C and -10^{-8} C charges are placed on any two vertices of equilateral triangle, then the intensity of electric field at third vertix is ______________ NC^{-1}. (length of sides of equilateral triangle is 0.1 m).

(A) 3.6×10^4 (B) 7.2×10^4 (C) 9×10^3 (D) 3×10^9

(35) The length of each side of square PQRS is 5 m. If +50 C, −50 C and +50 C charges are placed at vertices P, R and S respectively then the magnitude and direction of resultant electric field at point Q is ______________. (k = Coulombs, constant)

(A) 3 k, 30^o (B) 2 k, 45^o (C) 3 k, 25.5^o (D) 2 k, 38.5^o

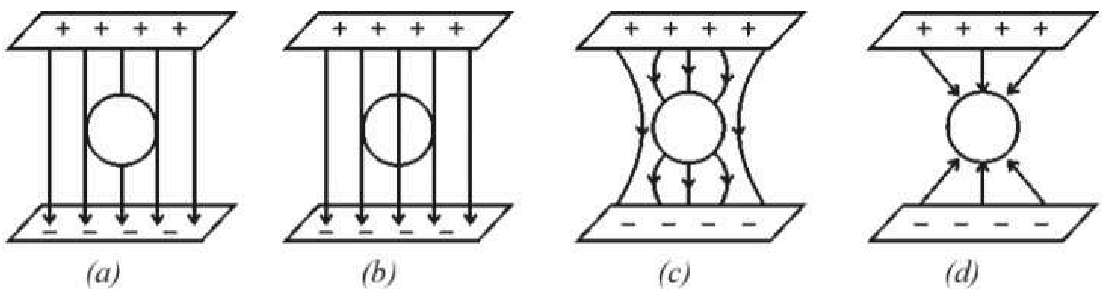
(36) The magnitude of electric field at point P shown in figure is ____________.



(A) $\frac{2kq}{a^2}$ (B) $\frac{kq}{a^2}$

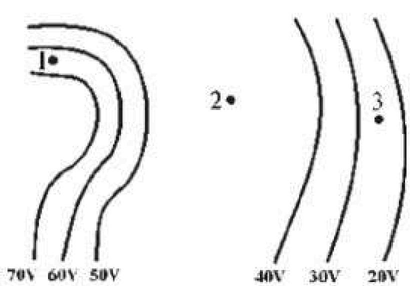
(C) $\frac{3kq}{a^2}$ (D) Zero

(37) An uncharged sphere of metal is placed in between two charged plates as shown in figure. The lines of force look like.



(A) a (B) b (C) c (D) d

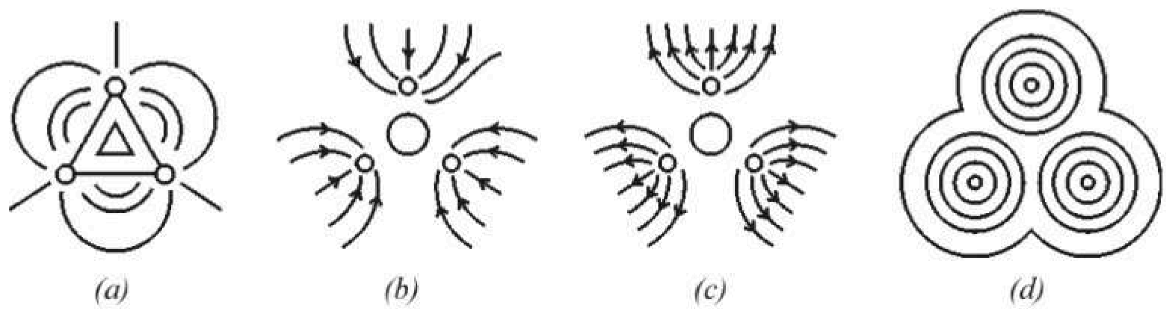
(38) Some equipotential lines are as shown in figure. E_1, E_2 and E_3 are the electric field at point 1, 2 and 3. Then ____________.



(A) $E_1 = E_2 = E_3$ (B) $E_1 > E_2 > E_3$

(C) $E_1 > E_2$, $E_2 < E_3$ (D) $E_1 < E_2 < E_3$

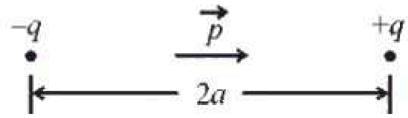
(39) Three positive charges of equal value q are placed at the vertices of an equilateral triangle. Which of the following will be resultant electric field lines ?



Ans. : 29 (A), 30 (C), 31 (D), 32 (B), 33 (B), 34 (C), 35 (C), 36 (A), 37 (C), 38 (C), 39 (C)

Electric Dipole :

A system of two equal and opposite charges, separated by a finite distance is called Electric dipole.



- Electric dipole moment $(\vec{p})$ of the system can be defined as follows :

$$\vec{p} = q\, 2\vec{a}$$

- SI unit of electric dipole moment = Cm (coulomb-meter)

- Dimensional formula of dipole moment $[\vec{p}] = L^1T^1A^1$ or L^1Q^1.

- Electric dipole moment is a vector quantity and its direction is from the negative charge to positive charge.

- The net electric charge on an electric dipole is zero $(-q+q=0)$ but its electric field is not zero, since the position of the two charges is different.

- If lim $q \to \infty$ and 2a → 0 in $\vec{p} = q\,2\vec{a}$, then the electric dipole is called a point dipole.

Electric field of a dipole :

To find out the electric field due to an electric dipole, placed at the co-ordinate system such that its Z-axis coincides with the dipole and origin of the system coincides with the centre of the dipole.

- Electric field at the point on the axis of a dipole is,

$$\vec{E}(z) = \frac{2kpz}{\left(z^2-a^2\right)^2}\,\hat{p}$$

If $z >> a$ then a^2 is not considered in denominator,

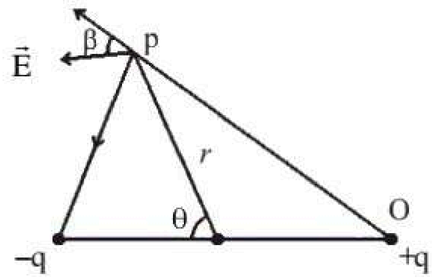
$$\boxed{\vec{E}(z) = \frac{2kp}{z^3}\,\hat{p}}$$

- Electric field at a point on the equator of a dipole is,

$$\vec{E}(y) = \frac{-kp}{\left(y^2+a^2\right)^{\frac{3}{2}}}\,\hat{p}$$

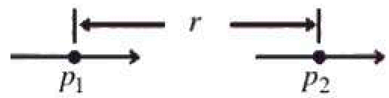
If $y >> a$ then, $\boxed{\vec{E}(y) = \frac{-kp}{y^3}\,\hat{p}}$

- If the point P lies on a line making an angle θ with the axis of the dipole, then the intensity at a point P lying at a distance r from the centre of the dipole is $E = \frac{kp}{r^3}\sqrt{3\cos^2\theta + 1}$.

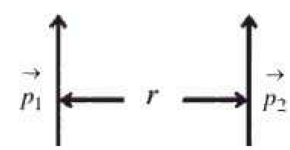


If the direction of $\vec{E}$ is such a way that its makes angle β with OP then $\tan\beta = \frac{1}{2}\tan\theta$.

- For short (small) dipole $\frac{E_{axis}}{E_{equater}} = 2$.



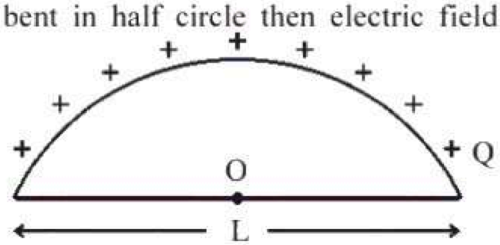
- As shown in figure, if $\vec{p_1}$ and $\vec{p_2}$ are placed at distance r then the force between two dipole is $F = \frac{6kp_1p_2}{r^4}$.



If $\vec{p_1}$ and $\vec{p_2}$ are parallel to each other then electric force $F = \frac{3kp_1p_2}{r^4}$.

If $\vec{p_1}$ and $\vec{p_2}$ are perpendicular to each other then electric force $F = \pm\frac{2kp_1p_2}{r^4}$.

- If a rod of length L and charge Q is bent in half circle then electric field at centre is $E = \frac{Q}{2\epsilon_0 L^2}$.



Torque acting on an electric dipole in a uniform electric field :

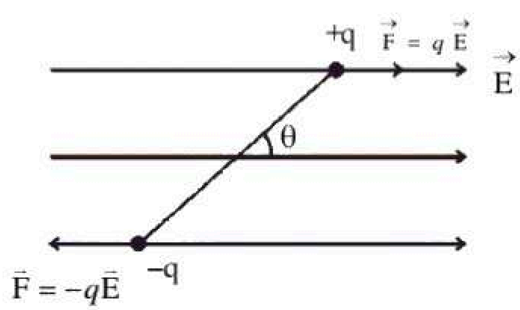
$$\vec{\tau} = \vec{p} \times \vec{E}$$

$$|\vec{\tau}| = pE\sin\theta$$

When $\theta = 0^\circ$ or 180° then $\tau = 0$

$\theta = 90^\circ$ then $\tau_{max} = +pE$

$\theta = 270^\circ$ then $\tau_{min} = -pE$



(A) $\frac{\pi}{3}$ (B) $\frac{3\pi}{2}$

(C) $\tan^{-1}\frac{\sqrt{3}}{2}$ (D) $\frac{\pi}{3}+\tan^{-1}\frac{\sqrt{3}}{2}$

(45) An electric dipole having dipole moment $\vec{p}=10^{-7}\left(5\hat{i}+\hat{j}-2\hat{k}\right)$ Cm placed in a uniform electric field $\vec{E}=10^{7}\left(\hat{i}+\hat{j}+\hat{k}\right)$ Vm^{-1} then magnitude of torque is ____________ Nm.

(A) 8.6 (B) 5 (C) 7.6 (D) Zero

(46) An electric dipole placed in a uniform electric field of intensity 4×10^{5} NC^{-1} at angle 60° with the electric field, experiences torque $8\sqrt{3}$ Nm. If length of dipole is 4 cm then magnitude of charge will be ____________.

(A) 3μC (B) 1 mC (C) 2μC (D) 2 mC

(47) Dipole moment of an electric dipole is 2×10^{-8} Cm. The electric field intensity at a point of distance 1 m and make an angle 60° with the centre of dipole is ____________ NC^{-1}.

(A) 300 (B) 238.1 (C) 429.5 (D) 255.2

(48) An electric dipole consists of two opposite charges 1 μC, each separated by a distance 2 cm is placed in an electric field of 10^{5} Vm^{-1}. The work done for rotation of this dipole from equilibrium to 180° is ____________ J.

(A) 4×10^{-3} (B) 2×10^{-3} (C) 10^{-3} (D) 5×10^{-3}

(49) Three point charges $+q$, $-2q$ and $+q$ are situated at points $(0, a, 0)$, $(0, 0, 0)$, $(a, 0, 0)$ respectively. The magnitude and direction of the dipole moment consisting this charges is ____________

(A) $\sqrt{2}\,qa$, in $+y$ direction

(B) $\sqrt{2}\,qa$, In direction of line joining points $(0, 0, 0)$ and $(a, a, 0)$

(C) qa, In the direction of line joining points $(0, 0, 0)$ and $(a, 0, a)$

(D) $\sqrt{2}\,qa$, in $+x$ direction

(50) An electric dipole consists of charges ±10 μC, each separated by a distance 5 mm. The electric field intensity at the points 15 cm distance on axis and 15 cm distance on equator is ____________ NC^{-1}.

(A) 2.66×10^{5}, 1.33×10^{5} (B) 4.4×10^{5}, 2.2×10^{5}

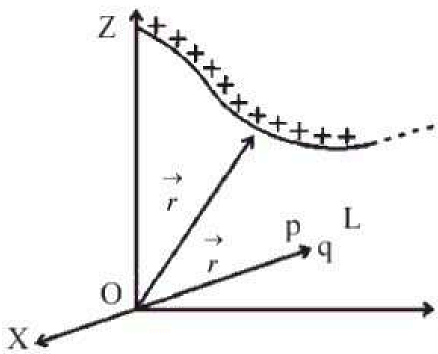
(C) 2.44×10^{5}, 1.22×10^{5} (D) 4.6×10^{5}, 2.3×10^{5}

Ans. : **40 (A), 41 (B), 42 (C), 43 (C), 44 (D), 45 (A), 46 (B), 47 (B), 48 (A), 49 (B), 50 (A)**

Continuous distribution of charges :

- The continuous distribution of electric charge can be of three types :

(1) **Linear charge distribution :**

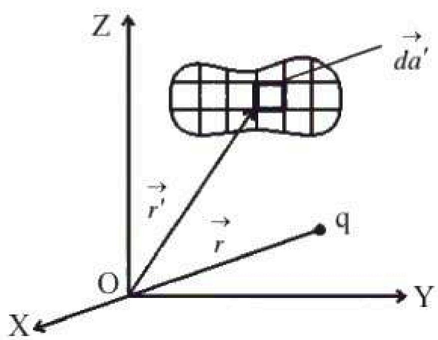


The force acting on a charge due to linear charge distribution is,

$$\vec{F} = kq \int_l \frac{\lambda(\vec{r'})\,|\vec{dl'}|}{|\vec{r} - \vec{r'}|^3}\left(\vec{r} - \vec{r'}\right)$$

$$\therefore \text{ Electric field } \vec{E} = k \int_l \frac{\lambda(\vec{r'})\,|\vec{dl'}|}{|\vec{r} - \vec{r'}|^3}\left(\vec{r} - \vec{r'}\right)$$

(2) **Surface charge distribution :**

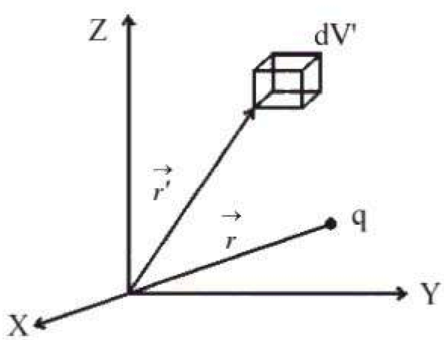


The force acting on a charge due to surface charge distribution is,

$$\vec{F} = kq \int_s \frac{\sigma(\vec{r'})\,|\vec{da'}|}{|\vec{r} - \vec{r'}|^3}\left(\vec{r} - \vec{r'}\right)$$

$$\therefore \text{ Electric field } \vec{E} = k \int_s \frac{\sigma(\vec{r'})\,|\vec{da'}|}{|\vec{r} - \vec{r'}|^3}\left(\vec{r} - \vec{r'}\right)$$

(3) Volume charge distribution :



The force acting on a charge due to volume charge distribution is,

$$\vec{F} = kq \int_v \frac{\rho(\vec{r'})\,dv'}{|\vec{r} - \vec{r'}|^3}\left(\vec{r} - \vec{r'}\right)$$

$$\therefore \text{ Electric field } \vec{E} = k \int_v \frac{\rho(\vec{r'})\,dv'}{|\vec{r} - \vec{r'}|^3}\left(\vec{r} - \vec{r'}\right)$$

- A conducting wire of length L carries total charge q which is uniformly distributed on it, then the electric field at a point located on the axis of the wire at a distance a from the nearer end is

$$E = \frac{1}{4\pi \epsilon_0}\left[\frac{q}{a(L+a)}\right]$$

- An arc of radius r subtends an angle θ at the centre. A charge is distributed over the arc such that the linear charge density is λ. The electric field at the centre is,

- In uniform electric field, the resultant force is zero. Only torque is experienced.
- In non-uniform electric field, it experience force and torque. When dipole is parallel to electric field, torque is zero. Only force is experienced.

Work required for displacement of dipole in uniform electric field :

- The work done for displacement $d\theta$ of a dipole in uniform electric field is

$dW = \tau d\theta = pE\sin\theta\, d\theta$

$\therefore$ Total work $W = \int_{\theta_1}^{\theta_2} pE\sin\theta\, d\theta$

$$\therefore\ W = pE\left[-\cos\theta\right]_{\theta_1}^{\theta_2}$$

$$\therefore\ W = -pE\left[\cos\theta_2 - \cos\theta_1\right]$$

$$\therefore\ \boxed{W = pE\left(\cos\theta_1 - \cos\theta_2\right)}$$

---

(40) Electric field intensity at the centre of electric dipole is ____________.

(A) $\frac{-K\vec{p}}{a^3}$ (B) Infinite (C) Zero (D) $\frac{-2K\vec{p}}{a^3}$

(41) Two electric dipole of same dipole moment 6.2×10^{-3} Ccm are placed on a line in such a way that their axes are is same direction. If the distance between the centre of both dipole is 10^{-8} m, then electric force between them is ____________ N.

(A) 21×10^{39} (B) 2.1×10^{34} (C) 21×10^{-37} (D) 2.1×10^{-17}

(42) A unit positive charge is placed on an axis of electric dipole and its distance from the centre is 0.1 m. It experiences 0.025 N force, when it is placed at 0.2 m distance, the force experienced by it is 0.002 N then the length of dipole is ____________.

(A) 0.05 m (B) 0.2 m (C) 0.1 m (D) 0.4 m

(43) The charge q, q and $-2q$ are placed on a vertices of equilateral triangle ABC. If the length of each side is l then resultant dipole moment of this system is ____________.

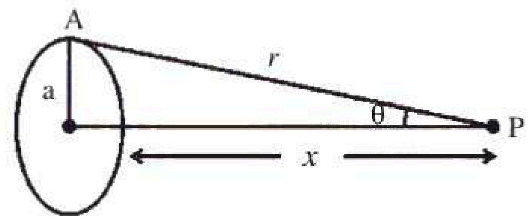
(A) $2l$ (B) $2ql$ (C) $\sqrt{3}\,ql$ (D) $4ql$

(44) An electric dipole coincides with X-axis and its midpoint is placed at the origin O. A point P is 20 cm away from the origin and OP makes an angle $\frac{\pi}{3}$ with the x-axis. If the electric field near the point P makes an angle θ with axis, then the magnitude of θ is ____________.

$$\vec{E} = \frac{k\lambda}{r}\left[-\sin\theta\,\hat{i} + (\cos\theta - 1)\,\hat{j}\right]$$

- A charge Q is uniformly distributed on the circumference of a circular ring of radius a. The electric field at a distance x from the centre is,

$$E = \frac{kQx}{\left(a^2 + x^2\right)^{\frac{3}{2}}}$$



- If point p is at very large distance $(x >> a)$ then electric field, $E = \frac{kQx}{\left(0 + x^2\right)^{\frac{3}{2}}} = \frac{kQ}{x^2}$

  Which is a equation of point charge. It shows that at very large distance, the charge on the ring behaves like a point charge.

---

(51) Surface charge density on the surface of charged sphere is 0.7 Cm^{-2}. When the charge increases by 0.44 C the surface charge density is increased by 0.14 Cm^{-2}. The initial charge and radius of the sphere is ______________.

(A) 2 C, 1 m (B) 2.2 C, 0.5 m (C) 1.5 C, 1 m (D) 2.5 C, 0.5 m

(52) 64 small drops of radius 0.02 m and charge $5\,\mu C$ are combined to form one big drop. If the charge is not leak then the ratio of initial and final charge density on the drop is ______________.

(A) 2 : 4 (B) 1 : 2 (C) 1 : 4 (D) 1 : 1

(53) A charged wire is bent in half circle arc of radius a. If the linear charge density is λ, then the electric field at the center of arc is ______________.

(A) $\frac{\lambda}{2\pi\epsilon_0 a}$ (B) $\frac{\lambda}{2\pi\epsilon_0 a^2}$ (C) $\frac{\lambda}{4\pi^2\epsilon_0 a}$ (D) Zero

(54) Let there be a spherically symmetric charge distribution with charge density varying as $\rho(r) = \rho_0\left(\frac{5}{4} - \frac{r}{R}\right)$ up to $r = R$ and $\rho(r) = 0$ For $r > R$, where r is the distance from the origin. The electric field at a distance $r\ (r < R)$ from the origin is given by ______________

(A) $\frac{4\rho_0 r}{3\epsilon_0}\left[\frac{5}{4} - \frac{r}{R}\right]$ (B) $\frac{\rho_0 r}{3\epsilon_0}\left[\frac{5}{4} - \frac{r}{R}\right]$ (C) $\frac{4\pi\rho_0 r}{3\epsilon_0}\left[\frac{5}{3} - \frac{r}{R}\right]$ (D) $\frac{\rho_0 r}{4\epsilon_0}\left[\frac{5}{3} - \frac{r}{R}\right]$

(55) The linear charge density on a thin circular ring of radius r is $q = q_0\cos\theta$. Here q_0 is constant and θ is angle made in anti clock wise direction by maximum electric charge density from diameter. The electric field at the centre of ring is ______________.

(A) $\frac{q_0}{\epsilon_0 r}$ (B) $\frac{q_0}{4\epsilon_0 r}$ (C) $\frac{q_0}{2\epsilon_0 r}$ (D) $\frac{q_0}{3\epsilon_0 r}$

(56) The radius of thin semi-circular ring is $20\ \text{cm}$. It is uniformly charged with charge $0.7\ \text{nC}$. Then the electric field at the centre of ring is ______________ NC^{-1}.

(A) 10 (B) 75 (C) 50 (D) 125

(57) Charge Q is uniformly distributed on a circumference of ring having radius a. If an electron placed on a centre of ring is displaced very small then it executes simple harmonic motion with frequency f = ______________.

(A) $\frac{1}{2\pi}\sqrt{\frac{Q}{4\pi \in_0 ema^2}}$ (B) $\frac{1}{2\pi}\sqrt{\frac{eQ}{4\pi \in_0 ma^3}}$

(C) $\sqrt{\frac{eQ}{4\pi \in_0 ma}}$ (D) $\sqrt{\frac{Q}{4\pi \in_0 ema^3}}$

(58) A charged wire is bent in the form of a semi circular arc of length 'l'. If the charge on wire is Q then electric field intensity at the centre is ______________ .

(A) $\frac{Q}{2 \in_0 l^2}$ (B) $\frac{\pi Q}{4 \in_0 l^2}$ (C) $\frac{Q}{4\pi \in_0 l^2}$ (D) $\frac{Q}{4\pi \in_0 l}$

Ans. :	**51 (B), 52 (C), 53 (A), 54 (D), 55 (B), 56 (A), 57 (B), 58 (A)**

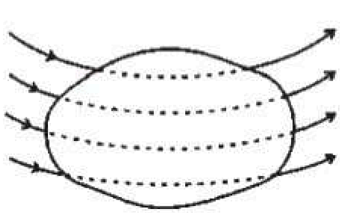
- **Electric flux :**

The concepts of electric flux relates the electric field with its source.

"The flux linked with any surface is the surface integration of the electric field over the given surface."

$$\phi = \int_{\text{Surface}} \vec{E} \cdot d\vec{a}$$

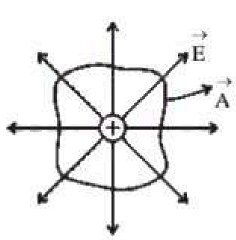
SI unit : (1) Nm^2C^{-1} (2) Vm



$\phi = 0$

Electric field lines (flux) enters in to closed surface is negative and electric field lines (flux) come outer is positive.

$\therefore$ resultant flux $\phi = 0$

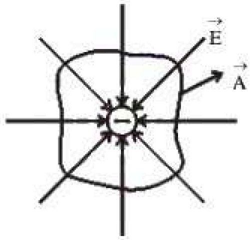


The flux of positive charge

$\phi = EA\cos 0^\circ$

$\phi = EA$

$\phi > 0$ positive flux.

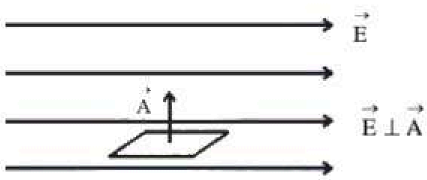


The flux of negative charge

$$\phi = EA\cos 180^\circ$$

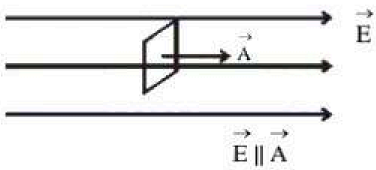
$$\phi = -EA$$

$\phi < 0$ negative flux.



Flux $\phi = EA\cos 90^\circ$

$$\phi = 0$$

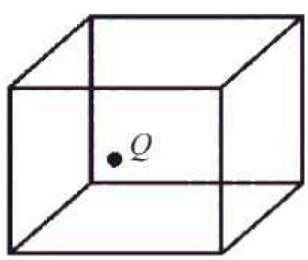


Flux $\phi = EA\cos 0$

$$\phi = EA$$

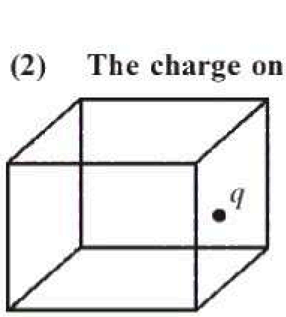
Calculation of flux in different cases :

(1) The charge ***Q*** on center of a cube :



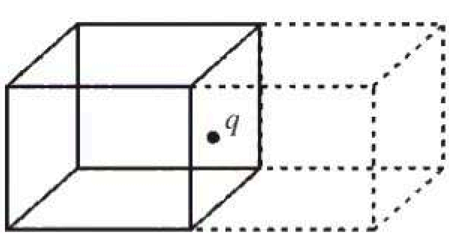
- Total flux $\phi = \dfrac{Q}{\epsilon_0}$
- The flux passing from any one surface $\phi = \dfrac{Q}{6\epsilon_0}$
- The flux passing from any one point of vertices. $\phi = \dfrac{Q}{8\epsilon_0}$
- The flux passing from any one edge $\phi = \dfrac{Q}{12\epsilon_0}$

(2) The charge on centre of any one side of cube :



- The flux passing through the system of two cube

  $\phi = \dfrac{q}{\epsilon_0}$

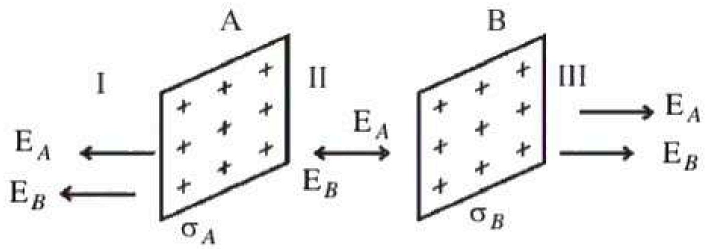


- The flux passing throgh any one cube $\phi = \dfrac{q}{2\epsilon_0}$
- The flux passing through any one side of cube $\phi = \dfrac{q}{10\epsilon_0}$

(2) Electric field due to a uniformly charged infinite plane sheet :

- Electric field due to a uniformly charged infinite plane sheet is $E = \frac{\sigma}{2\epsilon_0}$.
- This electric field is independent of the distance of the point from the plane. It depends only on σ.

(3) Electric fied due to two parallel plane sheet :



For region - I $\quad E = -E_A - E_B = -\frac{1}{2\epsilon_0}(\sigma_A + \sigma_B)$

For region - II $\quad E = \frac{1}{2\epsilon_0}(\sigma_A - \sigma_B)$

For region - III $\quad E = \frac{1}{2\epsilon_0}(\sigma_A + \sigma_B)$

If $\sigma_A = \sigma$ and $\sigma_B = -\sigma$ then,

For region - I $\quad E = 0$

For region - II $\quad E = \frac{\sigma}{\epsilon_0}$

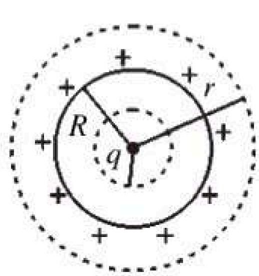
For region - III $\quad E = 0$

Note : I case of conducting metal plate of definite thickness the total charge enclosed $\sum q = 2\sigma A$.

$\therefore$ Electric field $E \cdot 2A = \frac{2\sigma A}{\epsilon_0}$

$$\therefore \boxed{E = \frac{\sigma}{\epsilon_0}}$$

(4) Electric Field Due to a unifrom charged Thin Spherical Shell :



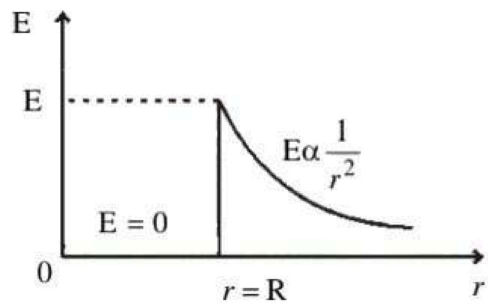
(i) For a point lying Inside a shell

$$\oint \vec{E} \cdot d\vec{a} = \frac{\sum q}{\epsilon_0} = 0$$

$$\therefore \vec{E} = 0$$

Thus, electric field inside the charged spherical shell is zero.

(ii) For a point Lying outside the shell :



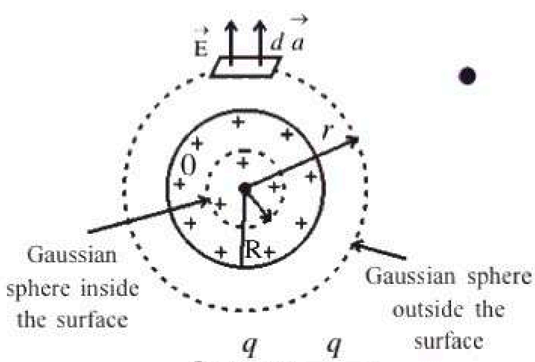
$$E = \frac{1}{4\pi \in_0} \frac{q}{R^2}$$

Put, $q = \sigma A = \sigma 4\pi R^2$

$$E = \frac{1}{4\pi \in_0} \frac{\left(4\pi R^2 . \sigma\right)}{r^2}$$

$$E = \frac{\sigma}{\in_0} \frac{R^2}{r^2}$$

(5) Electric field intensity due to uniformly charged sphere :



$$\rho = \frac{q}{v} = \frac{q}{\frac{4}{3}\pi R^3}$$

- **For point lying inside the sphere :**

Imagine spherical Gaussian surface of radius r' $(r' < R)$ to determine the electric field at a point p' at a distance r'.

$$q' = \frac{4}{3}\pi r'^3 \cdot \rho$$

$$q' = \frac{4}{3}\pi r'^3 \cdot \frac{q}{\frac{4}{3}\pi R^3}$$

$$q' = q \cdot \frac{r'^3}{R^3}$$

The flux linked with the Gaussian surface

$$\int \vec{E} \cdot d\vec{a} = \frac{q'}{\in_0}$$

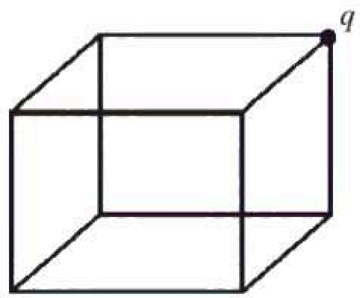
$$\therefore \; E \cdot 4\pi r'^2 = \frac{r'^3}{R^3 \in_0} q$$

$$\therefore \; \boxed{E = \frac{q}{4\pi \in_0} \cdot \frac{r'}{R^3}}$$

Putting the value of q,

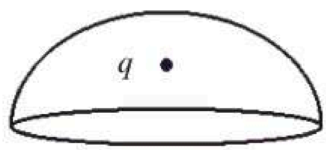
$$\boxed{E = \frac{\rho r'}{3 \in_0}}$$ Thus, $E \propto r'$.

(3) The charge placed on any vertices of cube :



- To consider the charge q on center of cube another seven cube is required.
- Thus the flux passing through the system of eigth cube $\phi = \frac{q}{\epsilon_0}$

$\therefore$ The flux passing through given cube $\phi = \frac{q}{8\epsilon_0}$



- The flux passing through any one side of cube $\phi = \frac{q}{24\epsilon_0}$

(4) The flux related with the surface of semi-sphere $\phi = \pi r^2 E$

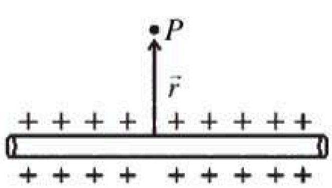
Gauss's Law :

- Gauss's law is one of the fundamental laws of nature.

  "The total electric flux associated with any closed surface is equal to the ratio of the net electric charge enclosed by the surface to ϵ_0"
- Flux associated with any closed surface $\phi = \int \vec{E} \cdot d\vec{a} = \frac{\Sigma q}{\epsilon_0}$.
- Gauss's law implies that the total electric flux through a closed surface is zero if no charge is enclosed by the surface.
- Gauss's law is true for any closed surface, no matter what its shape or size.
- The surface that we choose for the application of Gauss's Law is called Gaussian surface.
- Gauss's law is useful towarde a much easier calculation of electric field when system has some symmetry.

Application of Gauss's Law :

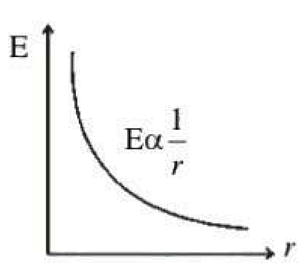
(1) Electric field due to linear charge distribution :



- Electric field at distance r due to an infinitely long straight uniformly charged wire,

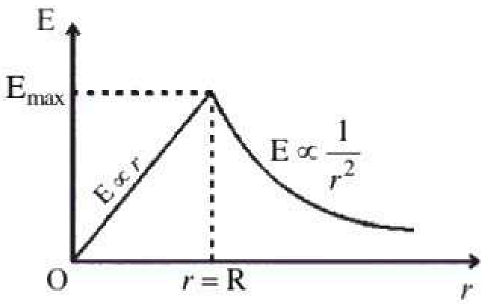
$$\vec{E} = \frac{\lambda}{2\pi\epsilon_0 r}\hat{r} \quad \text{or} \quad \vec{E} = \frac{2k\lambda}{r}\hat{r}$$

Where λ = linear charge distribution



- **For point lying outside the sphere :**

  Consider a Gaussian surface of radius r $(r > R)$,



$$\int \vec{E} \cdot d\vec{a} = \frac{q}{\epsilon_0}$$

$$\therefore \ E \cdot 4\pi r^2 = \frac{q}{\epsilon_0}$$

$$\therefore \ E = \frac{1}{4\pi \epsilon_0} \frac{q}{r^2} \Rightarrow E \propto \frac{1}{r^2}$$

---

(59) A hollow cylinder of radius 1 cm is placed in a uniform electric field of magnitude $\vec{E} = 2 \times 10^4$ NC^{-1} in such a way that its axis is parallel to electric field, then flux linked with cylinder is ____________.

(A) $2 \times 10^4 \pi$ Vm (B) $2 \times 10^2 \pi$ Vm (C) 0.02×10^3 NC^{-1} (D) zero

(60) The electric field in a region is given by the following equation :

$$\vec{E} = \left[\frac{3}{5}\hat{i} + \frac{4}{5}\hat{j}\right] \times 2 \times 10^3 \ NC^{-1}$$

The flux passing through a rectangular of 0.2 m^2 area placed in yz plane inside the electric field is ____________ Nm^{2}C^{-1}.

(A) 240 (B) 120 (C) 2.4×10^2 (D) 3×10^3

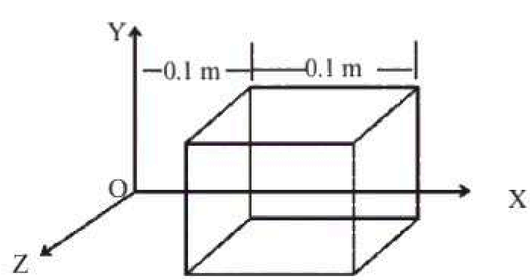
(61) A copper wire having linear charge density λ is passed through a cube of length a, then the maximum flux linked with the cube is ____________.

(A) $\frac{\lambda a}{\epsilon_0}$ (B) $\frac{\sqrt{2}\lambda a}{\epsilon_0}$ (C) $\frac{6\lambda a^2}{\epsilon_0}$ (D) $\frac{\sqrt{3}\lambda a}{\epsilon_0}$

(62) The inward and outward electric flux for a elosed surface are respectively 5×10^5 and 4×10^5 MKS unit. Then how much charge is inside the surface ?

(A) -8.85×10^{-7} C (B) 8.85×10^7 C (C) 8.85×10^{-7} C (D) 6.85×10^{-7} C

(63) As shown in figure the component of electric field produced due to a charge inside a cube is $E_x = 600\, x^{\frac{1}{2}}$, $E_y = 0$ and $E_z = 0$ then the charge inside the cube a ____________.



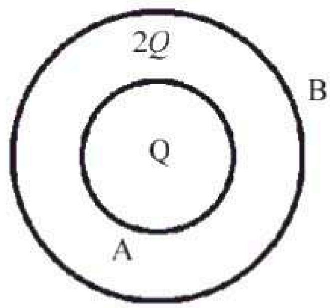
(A) 600 μC (B) 60 μC

(C) 7 μμC (D) 6 μμC

(64) The charge Q and $2Q$ are enclosed by two concentric spheres A and B respectively.

(i) The ratio of electric flux linked with both sphere is ______________.

(ii) If sphere A is fill with substance of dielectric constant $K = 2$, how much flux linked with it ?



(A) (i) 1:3, (ii) $\frac{Q}{5 \epsilon_0}$ (B) (i) 1:4, (ii) $\frac{Q}{4 \epsilon_0}$

(C) (i) 1:3, (ii) $\frac{Q}{2 \epsilon_0}$ (D) (i) 2:1, (ii) $\frac{Q}{\epsilon_0}$

(65) A disk of radius $\frac{a}{4}$ having a uniformly distributed charge of 6 C is placed in the x-y plane with its centre at $\left(\frac{-a}{2}, 0, 0\right)$. A rod of length a carrying a uniformly distributed charge 8 C is placed on the x-axis from $x = \frac{a}{4}$ to $x = \frac{5a}{4}x$. Two point charges -7 C and 3 C are placed at $\left(\frac{a}{4}, \frac{-a}{4}, 0\right)$ and $\left(\frac{-3a}{4}, \frac{3a}{4}, 0\right)$, respectively. Consider a cubical surface formed by six surfaces $x = \pm\frac{a}{2},\ y = \pm\frac{a}{2},\ z = \pm\frac{a}{2}$. The electric flux through this cubical surface is ______________.

(A) $\frac{-2\text{C}}{\epsilon_0}$ (B) $\frac{2\text{C}}{\epsilon_0}$ (C) $\frac{10\text{C}}{\epsilon_0}$ (D) $\frac{12\text{C}}{\epsilon_0}$

(66) $8q$ charge is placed on any one vertex of a cube. The flux linked with this cube is ______________.

(A) $\frac{q}{8 \epsilon_0}$ (B) $\frac{q}{4\pi \epsilon_0}$ (C) $\frac{q}{6 \epsilon_0}$ (D) $\frac{q}{\epsilon_0}$

(67) An infinitely long wire of linear charge distribution λ is passing through any side of cube of length "a", then the total flux passing through cube is ______________.

(A) $\frac{\lambda a}{\epsilon_0}$ (B) $\frac{\lambda a}{2 \epsilon_0}$ (C) $\frac{\lambda a}{4 \epsilon_0}$ (D) $\frac{\lambda a}{6 \epsilon_0}$

(68) The electric charge density on two parallel very long straight wire is $2 \times 10^{-4}\ Cm^{-1}$ respectively. If the distance between these two wire is 0.2 m, then due to charge of first wire the force on unit length of second wire is ____________ N.

(A) 72×10^2 (B) 8.4×10^9 (C) 9×10^9 (D) Zero

(69) The linear charge density on infinitely long straight wire is $\lambda\ Cm^{-1}$. If an electron moving round in perpendicular plane to the wire and its centre is on the wire then the kinetic energy of electron is ____________.

(A) $\frac{\lambda}{2\pi \epsilon_0}$ (B) $\frac{e\lambda}{2\pi \epsilon_0}$ (C) $\frac{e\lambda}{\epsilon_0}$ (D) $\frac{e\lambda}{8\pi \epsilon_0}$

(70) Two wires of linear charge density λ passing through a sphere of radius R and a cube of sides R so that the flux linked with them is maximum. Then the ratio of flux of sphere to the cube is ____________.

(A) $\sqrt{2}$ (B) $\frac{1}{\sqrt{2}}$ (C) $\frac{2}{\sqrt{3}}$ (D) $\frac{\sqrt{3}}{2}$

(71) Electric charge is uniformly distributed on a long straight wire of radius 1 *m*m. The charge per 1 cm length of wire is Q C. Another cylindrical surface of radius 50 cm and length 1 m symmetrically encloses the wire. The total electric flux passing through the cylindrical surface is ____________.

(A) $\frac{Q}{\epsilon_0}$ (B) $\frac{100Q}{\epsilon_0}$ (C) $\frac{10\,Q}{\pi \epsilon_0}$ (D) $\frac{100\,Q}{\pi \epsilon_0}$

(72) The linear charge density on a infinitely long wire is $\frac{1}{3}\ cm^{-1}$. Then the electric field intensity at a point 18 cm perpendicular to the wire is ____________ $N C^{-1}$.

(A) 0.66×10^{11} (B) 3×10^{11} (C) 0.33×10^{11} (D) 1.32×10^{11}

(73) Separation between two long conducting parallel plates is 2 cm . electron starts from rest and moves from one plate to another plate in $2\ \mu s$ then electric charge density on the plate is ____________ Cm^{-2}.

(A) 2×10^{-13} (B) 2.52×10^{-13} (C) 1.52×10^{-13} (D) 3.2×10^{-13}

(74) An electric dipole is prepared by taking two electric charges of $\pm 5nC$ separated by distance 2 *mm*. This dipole is kept near a line charge distribution having density $4.5 \times 10^{-4}\ Cm^{-1}$ in such a way that the negative electric charge of the dipole is at a distance 2.5 cm perpendicular to the wire. The force acting on the dipole ____________ N.

(A) 0.12 (B) 0.5 (C) 1.5 (D) 0.25

(75) The radius of gold nucleus ($Z = 79$) is 7×10^{-15} m. If the volume charge density on nucleus is ρ and electric field on the surface of nucleus is E then electric field at the centre of nucleus radius is ______________.

(A) E (B) 2 E (C) $\frac{E}{3}$ (D) $\frac{E}{2}$

(76) A ball of mass 1 *mg* and charge 20 *n*C is suspended by a string. When a uniformly charged large plate is brought near the ball, string makes angle 30° with plane of plate. Then surface charge density on plate is ______________ .

(A) 2.5×10^{-9} (B) 1.22×10^{-9} (C) 1.5×10^{-8} (D) 3.5×10^{-12}

(77) A large sheet carries uniform surface charge density σ. A rod of length $2\,l$ has a linear charge density λ on one half and $-\lambda$ on the other half. The rod is hanged at midpoint O and makes angle θ with the normal to the sheet. The torque experienced by the rod is ______________.

(A) $\frac{\sigma\lambda l}{\epsilon_0}\cos^2\theta$ (B) $\frac{\sigma\lambda l^2}{2\epsilon_0}\cos\theta$ (C) $\frac{\sigma\lambda l^2}{2\epsilon_0}\sin\theta$ (D) $\frac{\sigma\lambda l}{\epsilon_0}\sin^2\theta$

(78) An electron placed at distance *d* from a uniformly charged long plate is projected parallel to plate with initial velocity *u*. If electron collide with plate after travelling distance *l* in horinzontal direction then the surface charge density on the plate is ______________.

(A) $\frac{d\,\epsilon_0\,mu}{el}$ (B) $\frac{2d\,\epsilon_0\,mu}{el}$ (C) $\frac{d\,\epsilon_0\,mu^2}{el}$ (D) $\frac{4d\,\epsilon_0\,mu^2}{el^2}$

(79) A rectangular frame of sides $25\text{ cm} \times 15\text{ cm}$ is placed perpendicular to uniform electric field of $2 \times 10^4\ NC^{-1}$. If this frame is bent into circular frame then flux linked with it is ______________ Nm^2C^{-1}.

(A) 750 (B) 1019.1 (C) 800 (D) 2015.5

(80) A particle of mass 9×10^{-5} g is held at some distance from very large uniformly charged plane.The surface charge density on the plane is $5 \times 10^{-5}\ Cm^{-2}$. What should be the charge on the particle so that the particle remains stationary even after releasing it ?

(A) 1.6×10^{-19}C (B) 1.56×10^{-13}C (C) 6.25×10^{18}C (D) 2.52×10^{-12}C

Ans. : 59 (D), 60 (A), 61 (D), 62 (A), 63 (C), 64 (A), 65 (A), 66 (D), 67 (C), 68 (A), 69 (B), 70 (C), 71 (B), 72 (C), 73 (B), 74 (A), 75 (D), 76 (A), 77 (C), 78 (D), 79 (B), 80 (B)

Assertion - Reason type Question :

Instruction : Read assertion and reason carefully, select proper option from given below.

(a) Both assertion and reason are true and reason explains the assertion.

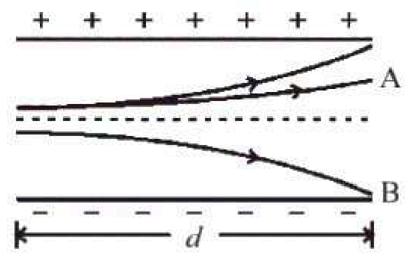
(b) Both assertion and reason are true but reason does not explain the assertion.

(c) Assertion is true but reason is false.

(d) Assertion is false and reason is true.

(81) **Assertion :** Two charged particle A and B move in uniform electric field as shown in figure. The ratio of charge and mass of particle B is greater than that of particle A. Neglect the gravitational effect.

Reason : The vertical acceleration of particle A is greater than that of particle B.



(A) (a) (B) (b)

(C) (c) (D) (d)

(82) **Assertion :** If dielectric substance having dielectric constant K is put between two electric charge then electric field is reduced.

Reason : According to equation $E_m = \frac{Ea}{K}$ electric field becomes $\frac{1}{K}$.

(A) (a) (B) (b) (C) (c) (D) (d)

(83) **Assertion :** Electric field lines cross each other.

Reason : In uniform electric field, electric field lines are parallel to each other.

(A) (a) (B) (b) (C) (c) (D) (d)

(84) **Assertion :** If proton and electron are placed in uniform electric field, their accelerations are different.

Reason : The electric force on unit positive charge is independent of mass.

(A) (a) (B) (b) (C) (c) (D) (d)

(85) **Assertion :** Electric flux coming out and going inside from closed surface are 3 KVm and 8 KVm respectively. Electric charge enclosed by close surface is $0.53\ \mu C$.

Reason : From Gauss's theorem $\phi = \frac{Q}{\epsilon_0}$, equation $Q = \phi\, \epsilon_0$ can be used to verify this statement.

(A) (a) (B) (b) (C) (c) (D) (d)

(86) **Assertion :** Two spherical shells have radii r_1 amd r_2 respectively. Their surface charge densities are equal. Thus, electric field intensities near their surface is also same.

Reason : Surface charge density $= \frac{\text{Electric charge}}{\text{Surface area}}$

(A) (a) (B) (b) (C) (c) (D) (d)

(87) **Assertion :** When a high energy X-Ray beam is made incident on a small metal ball suspended in uniform electric field, the ball experiences some deflection.

Reason : X-Ray produces photo electron, so metal ball becomes negatively charged.

(A) (a) (B) (b) (C) (c) (D) (d)

(88) **Assertion :** A charge is put at midpoint of line joining two identical charges. For equilibrium of this system, the magnitude of this charge must be $\left(\frac{Q}{4}\right)$.

Reason : For equilibrium of any charge, the forces applied on it must be equal in magnitude and opposite in direction.

(A) (a) (B) (b) (C) (c) (D) (d)

(89) **Assertion :** When a substance is negatively charged, its mass is slightly decreased.

Reason : Due to displacement of electron, the mass of substance is changed.

(A) (a) (B) (b) (C) (c) (D) (d)

(90) **Assertion :** When two substance attract each other, then maybe they are not charged.

Reason : Due to induction, charged substance attract neutral substance.

(A) (a) (B) (b) (C) (c) (D) (d)

Ans. : 81 (A), 82 (A), 83 (D), 84 (B), 85 (A), 86 (B), 87 (C), 88 (B), 89 (D), 90 (A)

Comprehension Type Questions :

Passage (I) :

The distance between two horizontal parallel plates is 1.5 cm and electric field between them is $10^5\ Vm^{-1}$ in downward direction. A oil drop of mass 4.9×10^{-15} kg and radius 5×10^{-5} m is placed stationery between these two plate. Density of air is negligible compare to oil. Co-efficient of viscosity is $1.8 \times 10^{-5}\ Nsm^{-2}$.

(91) Number of excess electron on the oil drop ______.

(A) 2 (B) 3 (C) 4 (D) 5

(92) If the direction of electric field is inverted then initial acceleration of oil drop is ______.

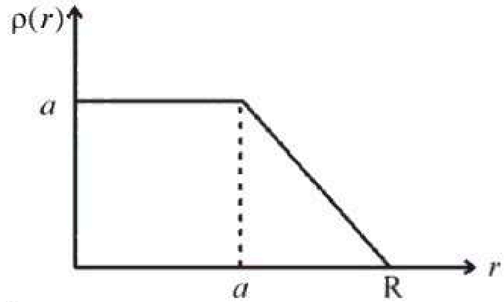
(A) $4.9\ ms^{-2}$ (B) $9.8\ ms^{-2}$ (C) $19.6\ ms^{-2}$ (D) Zero

(93) Terminal velocity of drop is nearly ______ ms^{-1}.

(A) 2.7×10^{-5} (B) 3.7×10^{-5} (C) 4.7×10^{-5} (D) 5.7×10^{-5}

Passage (II) :

The nuclear charge 'Ze' is non uniformly distributed within a nucles of a radius R. The charge density $\rho(r)$ (charge per unit volum) depend only on the radial distance r from the center of the nucleus as shown in figure. The electric field is along radial direction.



(94) At $r = R$ electric field is ______________.

(A) independent of a (B) directly proportional to a

(C) directly proportional to a^2 (D) inverselay proportional to a

(95) For $a = 0$, the magnitude of d (the maximum magnitude of ρ) ______________.

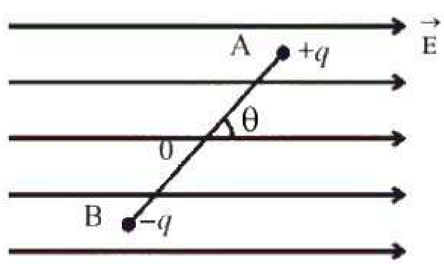
(A) $\frac{3Ze^2}{4\pi R^2}$ (B) $\frac{3Ze}{\pi R^3}$ (C) $\frac{4Ze}{3\pi R^2}$ (D) $\frac{Ze}{3\pi R^2}$

(96) Inside the nucleus, normally electric field depends linearly on r. For this, ______________.

(A) $a = 0$ (B) $a = \frac{R}{2}$ (C) $a = R$ (D) $a = \frac{2R}{3}$

Passage - III

Two point particle of mass m are connected at the end of light rod of length l. These two particles have charge $+q$ and $-q$ respectively. This arrangement is put into uniform electric field at small angle θ.



(97) Magnitude of torque applied on rod is ______________.

(A) $qEl\cos\theta$ (B) $qEl\sin\theta$ (C) qEl (D) Zero

(98) When rod becomes free, it rotates with ______________ angular frequency.

(A) $\left(\frac{qE}{ml}\right)^{\frac{1}{2}}$ (B) $\left(\frac{2qE}{ml}\right)^{\frac{1}{2}}$ (C) $\left(\frac{qE}{2ml}\right)^{\frac{1}{2}}$ (D) $\frac{1}{2}\left(\frac{qE}{2ml}\right)^{\frac{1}{2}}$

(99) When rod becomes free, the minimum time required for becoming parallel to electric field is ______________.

(A) $\frac{\pi}{2}\left(\frac{ml}{2qE}\right)^{\frac{1}{2}}$ (B) $2\pi\left(\frac{ml}{qE}\right)^{\frac{1}{2}}$ (C) $2\pi\left(\frac{2ml}{qE}\right)^{\frac{1}{2}}$ (D) $2\pi\left(\frac{ml}{2qE}\right)^{\frac{1}{2}}$

Ans. : 91 (B), 92 (C), 93 (D), 94 (A), 95 (B), 96 (C), 97 (B), 98 (B), 99 (A)

Match the columns :

Match appropriately the column-1 with column-2 :

(100)

	Column-1		Column-2
(a)	Electric field of a point charge is proportional to _ at any point.	(p)	$\frac{1}{r}$
(b)	Electric field of a short electric dipole is proportional to _ at any point.	(q)	$\frac{1}{r^2}$
(c)	Electric field of linear charge distribution is proportional to _ at any point.	(r)	$\frac{1}{r^3}$

(A) a – q, b – r, c – p (B) a – r, b – q, c – p

(C) a – p, b – q, c – r (D) a – r, b – p, c – q

(101)

	Column-1		Column-2
(a)	If $Q_1 = 0$ and $Q_2 \neq 0$ then	(p)	$E \neq 0$ and $\phi \neq 0$
(b)	If $Q_1 \neq 0$ and $Q_2 = 0$ then	(q)	E will change but ϕ will not
(c)	If Q_1 changes	(r)	$E \neq 0$ but $\phi \neq 0$
(d)	If Q_2 changes	(s)	Both E and ϕ will change

(A) a – s, b – p, c – q, d – r (B) a – r, b – p, c – q, d – s

(C) a – q, b – s, c – p, d – r (D) a – r, b – q, c – s, d – p

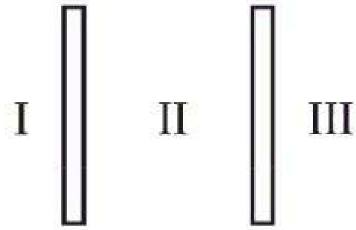
(102)

	Column-1		Column-2
(a)	Electric field due to a uniformly charged infinite plane sheet of thickness *d*	(p)	Zero
(b)	Electric field of a point lying inside the sphere	(q)	$\frac{\sigma}{\epsilon_0}$
(c)	Electric field of a point lying inside a shell	(r)	$\frac{\rho r}{3 \epsilon_0}$

(A) a – r, b – p, c – q (B) a – p, b – r, c – q

(C) a – q, b – r, c – p (D) a – p, b – q, c – r

(103) Two plates of surface charge density σ_1 and σ_2 are placed parallel to each other.



Column-1		Column-2	
(a)	$\sigma_1 = \sigma_2 = -\sigma$	(p)	In area I and II, $E = 0$
(b)	$\sigma_1 = \sigma_2 = +\sigma$	(q)	In area II, $E = 0$
(c)	$\sigma_1 = -\sigma$ and $\sigma_2 = +\sigma$	(r)	In area I, II and III, $E = 0$

(A) a – p, b – q, c – r

(B) a – p, b – p, c – r

(C) a – q, b – q, c – p

(D) a – q, b – q, c – r

Ans. : 100 (A), 101 (B), 102 (C), 103 (C)

Matrix matching questions

Note : The question below have some statement/option. shown in Column-I and Column - II. Match this statement/option correctly. Show the answer by filling the circle of matrix as given.

(104) By introducing a di-electric substance of constant K between two charges, its......

Column-1		Column-2	
(a)	Electric Charge	(p)	Becomes $\frac{1}{K}$ times
(b)	Electric Field	(q)	Becomes $\frac{1}{K^2}$ times

	p	q	r
a	○	○	○
b	○	○	○
c	○	○	○

Ans. :

	p	q	r
a	○	○	●
b	●	○	○
c	●	○	○