

JEE RANK COMPANION

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PHYSICS

For JEE Main & Advanced
Aligned with Latest JEE Pattern

ELECTROSTATICS

1

Electrostatics

1. ELECTRIC CHARGE AND ITS PROPERTIES

Charge of a material body or particle is the property (acquired or natural) due to which it produces and experience electrical and magnetic effects. Some of naturally charged particles are electron, proton, α -particle etc.

Types of Charge :

(i) **Positive Charge:** It is due to the deficiency of electrons compared to protons.

(ii) **Negative Charge:** It is due to the excess of electrons compared to protons.

Unit of charge

Charge is a derived physical quantity. Charge is measured in coulomb in S.I. unit. Dimensional formula of charge = $[M^0L^0T^1A^1]$.

2. PROPERTIES OF CHARGE

(i) **Charge is a scalar quantity:** It adds algebraically and for material bodies, it usually represents an excess, or deficiency of electrons.

(ii) **Charge is transferable :** Charging a body implies transfer of charge (electrons) from one body to another. Positively charged body means loss of electrons, i.e., deficiency of electrons. Negatively charged body means excess of electrons. This also shows that mass of a negatively charged body $>$ mass of a positively charged identical body.

(iii) **Charge is conserved :** In an electrically isolated system, total charge (sum of positive and negative) remains constant whatever change takes place in that system.

(iv) **Charge is quantized:** Charge on anybody always exists in integral multiples of a fundamental unit of electric charge. This unit is equal to the magnitude of charge on electron ($1e = 1.6 \times 10^{-19}$ coulomb). So charge on anybody $Q = \pm ne$, where n is an integer and e is the charge of the electron.

Example - 1

Three metallic spheres say X, Y and Z have charges 10C, -10C, 10C respectively. X, Y, Z are brought in contact such that charge on each of X and Y becomes 3C what is charge on Z?

(A) 1 C

(B) 2 C

(C) 3 C

(D) 4 C

Solution: (D)

Net charge initially on X, Y and Z

$$= (+10 - 10 + 10) = 10C$$

$$\text{Final net charge on X, Y and Z} = q_X + q_Y + q_Z$$

$$= 3 + 3 + q_Z = 10C$$

$$\therefore q_Z = 4C.$$

- **Method of Charging, in Conductor and Insulator** **Conductor:** Materials which have large number of free electrons, for example metals.

- **Insulator or Dielectric or Nonconductor:** Materials which do not have free electrons, for example plastic.

Charging of a Body

A body can be charged by means of

(A) Friction

(B) Conduction

(C) Induction, etc.

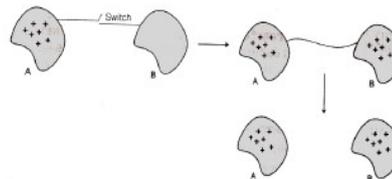
(A) **Charging by Friction:** When a neutral body is rubbed with another neutral body then some electrons are transferred from one body to other. The body which gains electrons becomes negatively charged and other becomes positively charged. The bodies can be of any type of material.



Neutral

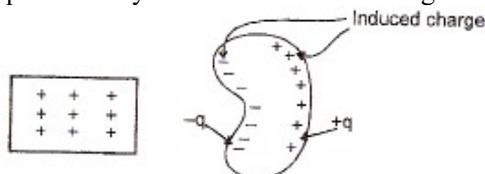
For example: comb gets charged when passed through hair.

(B) **Conduction: (flow) :** When a charged conductor is connected with a neutral conductor then charge flows from one body to other body. In case of two charged conductors charge flows from higher potential to lower potential. The charge stops flowing when the electric potential of the two bodies become same.



(C) **Induction:** When a charged particle or a body is taken near to neutral metallic object then the electrons move to one side and there is excess of electrons on that side making it negatively

charged and deficiency on the other side making that side positively charged. Hence charges appear on two sides of the body (although total charge of the body is still zero). This phenomenon is called induction and the Charge produced by it is called induced charge.



3. COULOMB'S LAW

On the basis of experiments Coulomb established the following law known as Coulomb's law. The magnitude of electrostatic force between two point charges is directly proportional to the product of charges and inversely proportional to the square of the distance between them.

$$\text{i.e., } F \propto q_1 q_2 \text{ and } F \propto \frac{1}{r^2}$$

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

• **Important points regarding Coulomb's law:**

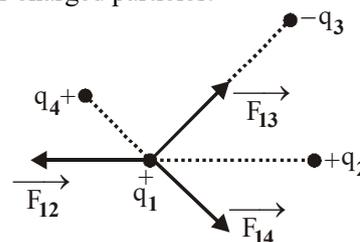
- (i) It is applicable only for point charges.
- (ii) The constant of proportionality K in SI units in vacuum is expressed as $\frac{1}{4\pi\epsilon_0}$ and in any other medium expressed as $\frac{1}{4\pi\epsilon}$. Here ϵ_0 and ϵ are called permittivity of vacuum and absolute permittivity of the medium respectively. The ratio $\epsilon/\epsilon_0 = \epsilon_r$ is called relative permittivity of the medium, which is a dimensionless quantity.
- (iii) The value of relative permittivity ϵ_r is constant for medium and lies between 1 and ∞ . For vacuum, by definition it is equal to 1. For air it is nearly equal to 1 and may be taken to be equal to 1 for calculations.
- (iv) The value of $\frac{1}{4\pi\epsilon_0} = 9 \times 10^9 \text{ Nm}^2 / \text{C}^2$
 $\Rightarrow \epsilon_0 = 8.855 \times 10^{-12} \text{ C}^2 / \text{Nm}^2$.
 Dimensional formula of ϵ is $M^{-1}L^{-3}T^4A^2$.
- (v) The force acting on one point charge due to the other point charge is always along the line joining these two charges. It is equal in magnitude and opposite in direction on two charges, irrespective of the medium, in which they lie.
- (vi) The force is conservative in nature i.e., work done by electrostatic force in moving a point charge along a closed loop of any shape is zero.
- (vii) In vector form formula can be given as below:

$$\vec{F} = \frac{1}{4\pi\epsilon_0\epsilon_r} \frac{q_1 q_2}{|\vec{r}|^3} \vec{r} = \frac{1}{4\pi\epsilon_0\epsilon_r} \frac{q_1 q_2}{|\vec{r}|^2} \hat{r}$$

here \vec{r} is position vector of the test charge (on which force is to be calculated, which is a unit positive charge) with respect to the source charge (due to which force is to be calculated).

4. SUPERPOSITION OF ELECTROSTATIC FORCES:

Electrostatics forces obey the principle of superposition, which means that the force between two particles is not affected by the presence of other charges. This principle is used to find the net force exerted on a given particle by the other charged particles.

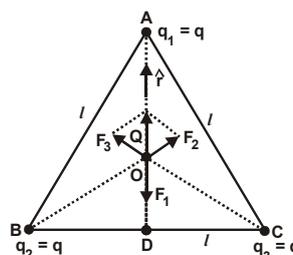


The net force \vec{F}_1 on q_1 is simply the vector sum $\vec{F}_1 = \vec{F}_{12} + \vec{F}_{13} + \vec{F}_{14}$

Note that the notation \vec{F}_{12} represents the force on q_1 due to q_2 .

Example - 2

Consider three identical charges each equal to q at the vertices of an equilateral triangle of side l . What is the force on a charge Q (with the same sign as q) placed at the centroid of the triangle, as shown in figure?



- (A) $\frac{3}{4\pi\epsilon_0} \frac{Qq}{l^2}$ (B) $\frac{1}{4\pi\epsilon_0} \frac{Qq}{l^2}$
 (C) $\frac{\sqrt{2}}{4\pi\epsilon_0} \frac{Qq}{l^2}$ (D) zero

Solution: (D)

In the given equilateral triangle ABC of sides of length l . If we draw a perpendicular AD to the side BC.

$AC = AC \cos 30^\circ = \left(\frac{\sqrt{3}}{2}\right) l$ and the distance AO of the centroid O from A is $(2/3) AD = \left(1/\sqrt{3}\right) l$.

By symmetry $AO = BO = CO$.

Thus,

Force F_1 on Q due to charge q at A

$$= \frac{3}{4\pi\epsilon_0} \frac{Qq}{l^2} \text{ Along AO}$$

Force F_2 on Q due to charge q at B

$$= \frac{3}{4\pi\epsilon_0} \frac{Qq}{l^2} \text{ Along BO}$$

Force F_3 on Q due to charge q at C

$$= \frac{3}{4\pi\epsilon_0} \frac{Qq}{l^2} \text{ Along CO}$$

The resultant of forces F_2 and F_3 is

$$\frac{3}{4\pi\epsilon_0} \frac{Qq}{l^2} \text{ along OA, by the parallelograms law.}$$

Therefore, the total force on Q = $\frac{3}{4\pi\epsilon_0} \frac{Qq}{l^2} (\hat{r} - \hat{r}) = 0$,

Where \hat{r} is the unit vector along OA.

It is clear also by symmetry that the three forces will sum to zero.

Example - 3

What is the force between two small charged spheres having charges of 2×10^{-7} C and 3×10^{-7} C placed 30 cm apart in air ?

- (A) 6×10^{-3} newton
- (B) 4×10^{-3} newton
- (C) 3×10^{-3} newton
- (D) 2×10^{-3} newton

Solution: (A)

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

$$F = \frac{(9 \times 10^9)(2 \times 10^{-7})(3 \times 10^{-7})}{(0.30)^2}$$

$$F = 6 \times 10^{-3} \text{ newton}$$

Example - 4

The electrostatic force on a small sphere of charge $0.4\mu\text{C}$ due to another small sphere of charge $-0.8\mu\text{C}$ in air is 0.2 N. What is the distance between the two spheres?

- (A) 0.10 meter
- (B) 0.12 meter
- (C) 0.14 meter
- (D) 0.16 meter

Solution: (B)

$$F = \frac{1}{4\pi\epsilon_0} \frac{q_1q_2}{r^2};$$

$$(0.2) = 9 \times 10^9 \frac{(0.4 \times 10^{-6})(0.8 \times 10^{-6})}{r^2};$$

$$r = 0.12 \text{ meter}$$

5. ELECTRIC FIELD DUE TO POINT CHARGE & DISTRIBUTED CHARGE:

- **Electric Field :**
- Electric field is the region around charged particle or charged body in which if another charge is placed, it experiences electrostatic force.
- Electric field intensity at a point is equal to the electrostatic force experienced by a unit positive point charge both in magnitude and direction.

- If a test charge q_0 is placed at a point in an electric field and experiences a force \vec{F} due to some charges (called source charges), the electric field intensity at that point due to source charges is given by $\vec{E} = \frac{\vec{F}}{q_0}$.
- Magnitude of electric field at a distance 'r' due to a point charge 'q' is given by $|\vec{E}| = \frac{1}{4\pi\epsilon_0} \frac{q}{r^2}$.

Properties of electric field intensity \vec{E} :

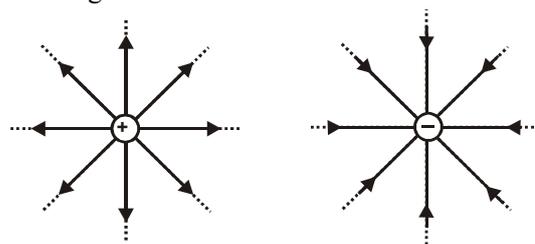
- (i) It is a vector quantity. Its direction is the same as the force experienced by positive charge.
- (ii) Electric field due to positive charge is always away from it, while due to negative charge always towards it.
- (iii) Its S.I. unit is newton / coulomb.
- (iv) Its dimensional formula is $[MLT^{-3}A^{-1}]$.
- (v) Electric force on a charge q placed in a region of electric field at a point where the electric field intensity \vec{E} is given by $\vec{F} = q\vec{E}$. Electric force on point charge is in the same direction of electric field on positive charge and in opposite direction on a negative charge.
- (vi) It obeys the superposition principle, that is, the field intensity at a point due to a system of charges is vector sum of the field intensities due to individual point charges.
 $\vec{E} = \vec{E}_1 + \vec{E}_2 + \vec{E}_3 + \dots$

• **Electric Lines of Force (ELOF)**

The line of force in an electric field is an imaginary line, the tangent to which at any point on it represents the direction of electric field at the given point.

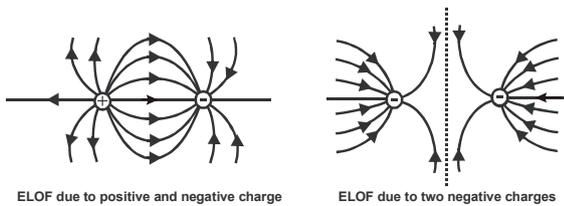
• **Properties :**

- (i) Line of force originates out from a positive charge and terminates on a negative charge. If there is only one positive charge then lines start from positive charge and terminate at ∞ . If there is only one negative charge then lines start from ∞ and terminates at negative charge.



ELOF of isolated positive charge

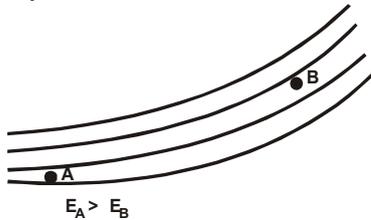
ELOF of isolated negative charge



ELOF due to positive and negative charge

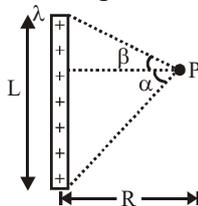
ELOF due to two negative charges

(ii) The electric intensity at a point is the number of lines of force passing through per unit area normal to the direction of the intensity at that point. The intensity will be more where the density of lines is more.



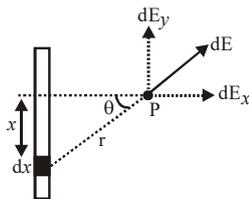
$$E_A > E_B$$

Field intensity at a distance R from a finite line of charge of length L and linear charge density λ , as shown in the figure.



Consider a small element of length dx at a distance x , as shown in figure. The magnitude of the contribution to the field at point P from this element is $dE = \frac{k\lambda dx}{r^2}$

To carry out the integration, we express the variables in terms of the angle θ , From the figure,



$$r = R \sec \theta \text{ and } x = R \tan \theta \text{ on differentiating, } dx = R \sec^2 \theta d\theta$$

Using these expressions (i) may be modified as

$$dE = \frac{k\lambda(R \sec^2 \theta d\theta)}{(R \sec \theta)^2} = \frac{k\lambda d\theta}{R}$$

The components of dE are $dE_x = dE \cos \theta, dE_y = dE \sin \theta$

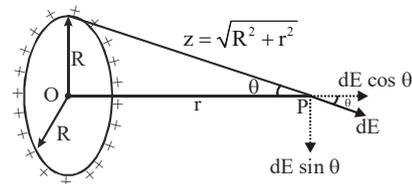
On integrating

$$E_x = \frac{k\lambda}{R} \int_{-\beta}^{+\alpha} \cos \theta d\theta = \frac{k\lambda}{R} [\sin \alpha + \sin \beta]$$

$$\text{and } E_y = \frac{k\lambda}{R} \int_{-\beta}^{+\alpha} \sin \theta d\theta = \frac{k\lambda}{R} [\cos \beta - \cos \alpha]$$

Note: For an infinite line of charge, $\alpha = \pi/2$ and $\beta = \pi/2$. Therefore, $E_x = \frac{2k\lambda}{R}$ and $E_y = 0$

Electric field intensity at an axial point at a distance r from the centre of the ring having charge Q which is uniformly distributed over the circumference of a ring.



The electric field at P due to the charge element dq of the ring is given by

$$dE = \frac{1}{4\pi\epsilon_0} \frac{dq}{z^2} = \frac{1}{4\pi\epsilon_0} \frac{dq}{(R^2 + r^2)}$$

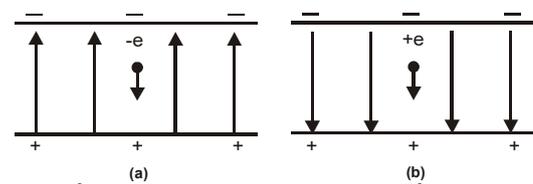
Hence, the electric field at P due to the uniformly charged ring is given by

$$E = \int dE \cos \theta = \frac{1}{4\pi\epsilon_0} \frac{Qr}{(R^2 + r^2)^{3/2}}$$

$$\left\{ \cos \theta = \frac{r}{z} \right\}$$

Example - 5

An electron falls through a distance of 1.5 cm in a uniform electric field of magnitude $2.0 \times 10^4 \text{ N C}^{-1}$ as shown in the figure. Compute the time of fall.



- (A) $1.9 \times 10^{-9} \text{ sec}$
- (B) $2.9 \times 10^{-9} \text{ sec}$
- (C) $3.0 \times 10^{-8} \text{ sec}$
- (D) $2.0 \times 10^{-8} \text{ sec}$

Solution: (B)

In figure the field is upward, so the negatively charged electron experiences downward force of magnitude eE and where E is the magnitude of the electric field. The acceleration of the electron is $a_e = eE / m_e$

Where m_e is the mass of the electron. Starting from rest, the time required by the electron to fall through a distance h is given by

$$t_e = \sqrt{\frac{2h}{a_e}} = \sqrt{\frac{2hm_e}{eE}}$$

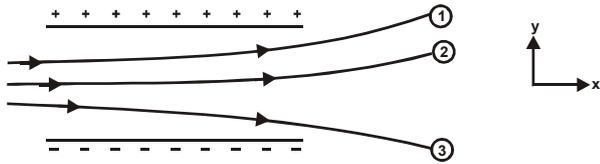
For $e = 1.6 \times 10^{-19} \text{ C}, m_e = 9.11 \times 10^{-31} \text{ kg}$

$$E = 2.0 \times 10^4 \text{ NC}^{-1}, h = 1.5 \times 10^{-2} \text{ m}$$

$$t_e = 2.9 \times 10^{-9} \text{ s}$$

Example - 6

Figure shows track of three charged particles in a uniform electrostatic field. Give the signs of the three charges.



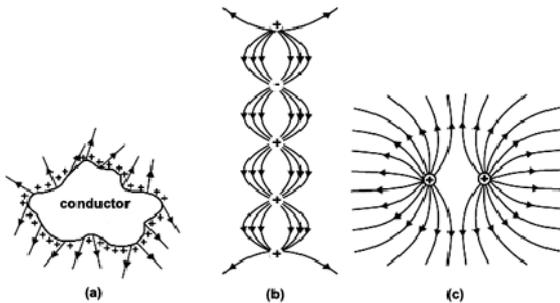
- (A) Charge (a) and (b) are negative, charge (c) is positive
- (B) Charge (a) and (c) are negative, charge (b) is positive
- (C) Charge (b) and (c) are negative, charge (a) is positive
- (D) All charges are positive

Solution: (A)

Charge (1) and (2) are negative, charge (3) is positive.

Example - 7

Which among the curves shown in figure cannot possibly represent electrostatic field lines ?



- (A) Figure (a) and Figure (b)
- (B) Figure (b) and Figure (c)
- (C) Figure (a) and Figure (c)
- (D) Only Figure (C)

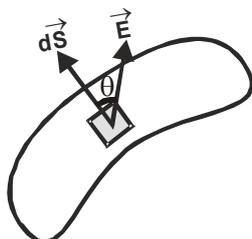
Solution: (A)

Only Figure (c) is right; the rest cannot represent electrostatic field lines, Figure (a) is wrong because field lines must be normal to a conductor. Figure (b) is wrong because field lines cannot start from a negative charge.

6. ELECTRIC FLUX

Consider some surface in an electric field \vec{E} .

Let us select a small area element $d\vec{S}$ on this surface. The electric flux of the field over the area element is given by $\phi_E = \vec{E} \cdot d\vec{S}$



Direction of $d\vec{S}$ is normal to the surface. It is along \hat{n}

or $d\phi_E = Ed\cos\theta$

or $d\phi_E = (E\cos\theta)dS$

or $d\phi_E = E_n dS$

where E_n is the component of electric field in the direction of $d\vec{S}$.

The electric flux over the whole area is given by

$$\phi_E = \int_S \vec{E} \cdot d\vec{S} = \int_S E_n dS$$

If the electric field is uniform over that area then

$$\phi_E = \vec{E} \cdot \vec{S}$$

Physical Meaning

The electric flux through a surface inside an electric field represents the total number of electric field lines crossing the surface in a direction normal to the surface. It is a property of electric field.

Unit :

- (i) The SI unit of electric flux is $Nm^2 C^{-1}$ (gauss) or $J m C^{-1}$.
- (ii) Electric flux is a scalar quantity. (It can be positive, negative or zero).

Example - 8

What is the net flux of the uniform electric field \vec{E} which is in positive x direction through a cube of side 20 cm oriented so that its faces are parallel to the co-ordinate planes?

- (A) 20E
- (B) 10E
- (C) 400E
- (D) Zero

Solution: (D)

Zero. The number of lines entering the cube is the same as the number of lines leaving the cube.

7. GAUSS'S LAW & ITS APPLICATIONS

This law was stated by a mathematician Kari F Gauss. This law gives the relation between the electric field at a point on a closed surface and the net charge enclosed by that surface. This surface is called Gaussian surface. It is a closed hypothetical surface. Its validity is shown by experiments. It is used to determine the electric field due to some symmetric charge distributions.

Statement and Details

Gauss's law is stated as given below.

“The surface integral of the electric field intensity over any closed hypothetical surface

(Gaussian surface) is $\frac{1}{\epsilon_0}$ times that of net

charge enclosed by that surface.” Here, ϵ_0 is the permittivity of free space. If S is the

Gaussian surface and $\sum_{i=1}^n q_i$ is the total charge

enclosed by the Gaussian surface, then according to Gauss's law,

$$\phi_E = \oint \vec{E} \cdot d\vec{S} = \frac{1}{\epsilon_0} \sum_{i=1}^n q_i$$

The circle on the sign of integration indicates that the integration is to be carried out over the closed surface.

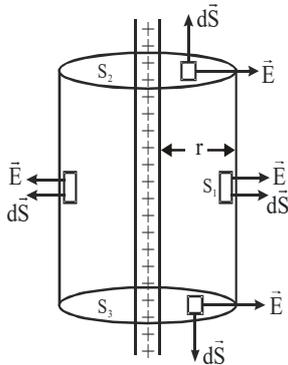
Note:

- (i) Flux through gaussian surface is independent of its shape.
- (ii) Flux through gaussian surface depends only on total charge present inside gaussian surface.
- (iii) Flux through gaussian surface is independent of position of charges inside gaussian surface.
- (iv) Electric field intensity at the gaussian surface is due to all the charges present inside as well as outside the gaussian surface.
- (v) For a closed surface incoming flux is taken negative while outgoing flux is taken positive, because \hat{n} is taken positive in outward direction.
- (vi) For a gaussian surface $\phi = 0$ does not imply $E = 0$ at every point of the surface but $E = 0$ at every point implies $\phi = 0$.

- **Application of Gauss's Law :**

- **Field Due To An Infinite Line Charge:**

Assume cylindrical gaussian surface of length L and radius r.



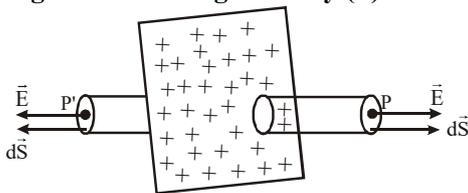
The charge enclosed by the cylinder is $Q = \lambda L$.

Applying Gauss's law to the curved surface, we have

$$E \oint dS = E(2\pi rL) = \frac{\lambda L}{\epsilon_0}$$

$$\text{or } E = \frac{\lambda}{2\pi\epsilon_0 r}$$

- **Field Due to an Infinite Charged Plane Sheet Having Surface Charge Density (σ):**



Assume cylindrical gaussian surface of cross sectional area A.

The flux through the two plane ends of cylindrical Gaussian surface

$$\phi_E = \int \vec{E} \cdot d\vec{S} + \int \vec{E} \cdot d\vec{S} = \int E dS + \int E dS$$

$$= EA + EA = 2EA$$

The charge enclosed by the Gaussian surface

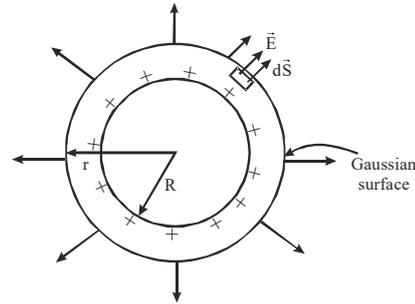
$$q = \sigma A$$

Applying Gauss's law, we have

$$2EA = \frac{\sigma A}{\epsilon_0} \Rightarrow E = \frac{\sigma}{2\epsilon_0}$$

Electric Field Due To an Uniformly Charged Spherical Shell:

(A) At an external point ($r > R$)



According to Gauss's law

$$E \oint dS = E(4\pi r^2) = \frac{Q}{\epsilon_0}$$

$$\text{Therefore, } E = \frac{1}{4\pi\epsilon_0} \frac{Q}{r^2}$$

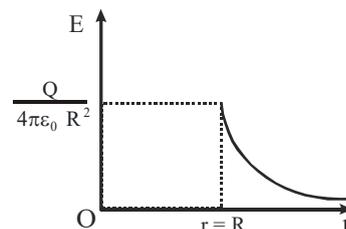
For points outside the charged conducting sphere or the charged spherical shell, the field is same as that of a point charge at the centre.

(B) At an Internal Point ($r < R$):

The field still has the same symmetry and so we again pick a spherical Gaussian surface, but now with radius r less than R. Since the charge enclosed is zero, from Gauss's law we have

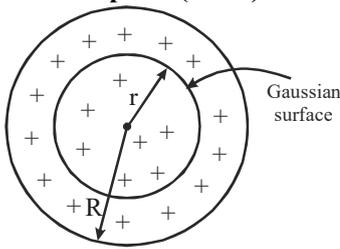
$$E(4\pi r^2) = 0 \therefore E = 0$$

Thus, we conclude that $E = 0$ at all points inside a uniformly charged conducting sphere or the charged spherical shell. Variation of E with the distance from the centre (r)



Electric Field Due To An Uniformly Charged Non-Conducting Sphere Having Charge 'Q' :

(A) **At an internal point (r < R) :**



Applying Gauss's law

$$\oint \vec{E} \cdot d\vec{S} = E(4\pi r^2) = \frac{Q'}{\epsilon_0}$$

$$\text{Here, } Q' = \left(\frac{4}{3}\pi r^3\right)\rho = \left(\frac{4}{3}\pi r^3\right) \times \frac{Q}{\frac{4}{3}\pi R^3} = \frac{Qr^3}{R^3}$$

Where ρ is volume charge density Therefore

$$E(4\pi r^2) = \frac{Qr^3}{R^3\epsilon_0} \text{ or } E = \frac{1}{4\pi\epsilon_0} \frac{Q}{R^3} r$$

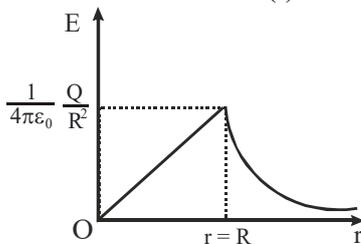
The field increases linearly with distance from the centre

(B) **At an external point (r > R) :**

To find the electric field outside the charged sphere, we use a spherical Gaussian surface of radius (r > R). This surface encloses the entire charged sphere. So from Gauss's law, we have

$$E(4\pi r^2) = \frac{Q}{\epsilon_0} \text{ or, } E = \frac{1}{4\pi\epsilon_0} \frac{Q}{r^2}$$

The field at points outside the sphere is same as that of a point charge at the centre. Variation of E with the distance from the centre (r)



Example - 9

A uniformly charged conducting sphere of 2.4 m diameter has a surface charge density of $80.0\mu\text{C}/\text{m}^2$. What is the total electric flux leaving the surface of the sphere ?

- (A) $1.6 \times 10^8 \text{ Nm}^2/\text{C}$ (B) $3.2 \times 10^8 \text{ Nm}^2/\text{C}$
 (C) $4.8 \times 10^8 \text{ Nm}^2/\text{C}$ (D) $6.4 \times 10^8 \text{ Nm}^2/\text{C}$

Solution: (A)

Charge on the sphere = Surface Density \times Area

$$= 80 \times 10^{-6} \times 4\pi(1.2)^2$$

$$= 1.45 \times 10^{-3} \text{ Coulomb}$$

$$\phi = \frac{q}{\epsilon_0} = \frac{1.45 \times 10^{-3}}{8.86 \times 10^{-12}}$$

$$= 1.6 \times 10^8 \text{ Nm}^2/\text{C}$$

Example - 10

An infinite line charge produces a field of $9 \times 10^4 \text{ N/C}$ at a distance of 2 m. Calculate the linear charge density.

- (A) $5 \times 10^{-6} \text{ C/m}$ (B) $10 \times 10^{-6} \text{ C/m}$
 (C) $15 \times 10^{-6} \text{ C/m}$ (D) $20 \times 10^{-6} \text{ C/m}$

Solution: (B)

For an infinite line charge $E = \frac{\lambda}{2\pi\epsilon_0 r}$

$$9 \times 10^4 = \frac{\lambda}{2\pi(8.86 \times 10^{-12})(2)}$$

$$\lambda = 10 \times 10^{-6} \text{ C/m}$$

8. ELECTROSTATIC POTENTIAL ENERGY

The potential energy possessed by a system of two - point charges q_1 and q_2 separated by a distance r is the work required to bring them slowly to this arrangement from infinity. This electrostatic potential energy is given by $U = \frac{q_1 q_2}{4\pi\epsilon_0 r}$

$$U = \frac{q_1 q_2}{4\pi\epsilon_0 r}$$

Note: While calculating potential energy, charges must be multiplied with their signs.

Electric Potential Energy of a System of Point Charges:

The electric potential energy of such a system is the work done in assembling this system starting from infinite separation between any two-point charges. For a system of point charges q_1, q_2, \dots, q_n , the potential energy is

$$U = \frac{1}{2} \sum_{i=1}^n \sum_{j=1}^n \frac{q_i q_j}{4\pi\epsilon_0 r_{ij}}$$

It simply means that we have to consider all the pairs that are possible.

Important points regarding Electrostatic potential energy

(i) Work done required by an external agency to move a charge q from A to B in an electric field with constant speed

$$W_{A-B} = q[V_B - V_A]$$

(ii) When a charge q is let free in an electric field, it loses potential energy and gains kinetic energy, if it goes from A to B

$$\text{or } q(V_B - V_A) = \frac{1}{2} mV_B^2 - \frac{1}{2} mV_A^2$$

Example - 11

Two charges $3 \times 10^{-8} \text{ C}$ and $-2 \times 10^{-8} \text{ C}$ are located 15 cm apart. Find the potential energy of the system.

- (A) $1.2 \times 10^{-5} \text{ J}$ (B) $2.4 \times 10^{-5} \text{ J}$
 (C) $3.6 \times 10^{-5} \text{ J}$ (D) $4.8 \times 10^{-5} \text{ J}$

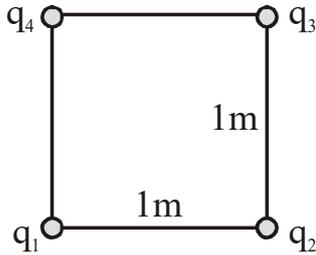
Solution: (C)

$$U = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r}$$

$$= \frac{(9 \times 10^9)(3 \times 10^{-8})(-2 \times 10^{-8})}{0.15} = 3.6 \times 10^{-5} \text{ J}$$

Example - 12

Four charges $q_1 = 1\text{mC}$, $q_2 = 2\text{ mC}$, $q_3 = -3\text{ mC}$ and $q_4 = 4\text{ mC}$ are kept on the vertices of a square of side 1 m. Find the electric potential energy of this system of charges.



- (A) $-1.22 \times 10^{-2}\text{ J}$ (B) $3.69 \times 10^{-3}\text{ J}$
 (C) $-7.62 \times 10^{-2}\text{ J}$ (D) $-1.99 \times 10^{-4}\text{ J}$

Solution: (C)

$$U = \frac{1}{4\pi\epsilon_0 r} [q_1q_2 + q_2q_3 + q_3q_4 + q_4q_1] + \frac{1}{4\pi\epsilon_0 \sqrt{2}r} [q_1q_3 + q_2q_4]$$

$$U = -7.62 \times 10^{-2}\text{ J}$$

q_1, q_2, q_3 and q_4 are taken with their sign.

Example - 13

Two point charges are located on the x-axis, $q_1 = -1\text{ mC}$ at $x = 0$ and $q_2 = +1\text{ mC}$ at $x = 1\text{ m}$. Find the work that must be done by an external force to bring a third point charge $q_3 = +1\text{ mC}$ from infinity to $x = 2\text{ m}$.

- (A) $1.5 \times 10^{-3}\text{ J}$ (B) $3.0 \times 10^{-3}\text{ J}$
 (C) $4.5 \times 10^{-3}\text{ J}$ (D) $6.0 \times 10^{-3}\text{ J}$

Solution: (C)

Potential at $x = 2$ due to the two charges placed at $x = 0$ and $x = 1$

$$V = \frac{1}{4\pi\epsilon_0} \left[-\frac{1 \times 10^{-6}}{2} + \frac{1 \times 10^{-6}}{1} \right]$$

$$V = 4.5 \times 10^3\text{ V}$$

Hence work done in bringing the charge q_3 from infinity will be $W = q_3(\Delta V)$

$$\Rightarrow q_3 \left(\frac{V}{x=2} - V_\infty \right) = 1 \times 10^{-6} (4.5 \times 10^3 - 0) = 4.5 \times 10^{-3}\text{ J}$$

• **Electrostatic Potential due to a Point Charge & Distributed Charges:**

The electric potential at a point in an electric field is the external work needed to bring slowly a unit positive charge from infinity (point of zero potential) to the given point. Thus,

$$V = \frac{W_{\text{ext}}}{q_0}$$

Where W_{ext} is work done by external agent in moving slowly a charge q_0 from infinity to given point.

Important points regarding electric potential:

(i) As electric field is conservative, $W_{\text{ext}} = U$ (where U is potential energy) So, $V = \frac{U}{q_0}$ or, $U = q_0V$

Thus, the electric potential at a point is numerically equal to the potential energy per unit charge at that point.

(ii) It is a scalar having SI unit (J/C) called volt(V).

(iii) If V_A and V_B are the electric potentials of two points A and B, the potential difference between A and B is equal to $V_B - V_A$.

Thus the potential difference between two points. A and B, is defined as $V_A - V_B = \frac{W_{AB}}{q_0}$

where W_{A-B} is the work done by an external agent in moving slowly a positive test charge q_0 from A to B.

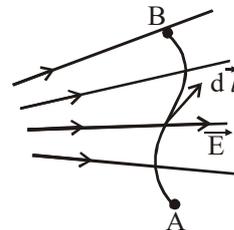
(iv) We know that $\Delta V = \frac{W_{\text{ext}}}{q_0}$

$$\text{Now, } W_{\text{ext}} = \int \vec{F}_{\text{ext}} \cdot d\vec{l}$$

Since the external force is equal and opposite to the electrostatic force, we have $\vec{F}_{\text{ext}} = -q\vec{E}$

$$\text{or } W_{\text{ext}} = -\int q \vec{E} \cdot d\vec{l}$$

The figure shows a curved path in a non-uniform field.



The potential difference between the point A and B is given by

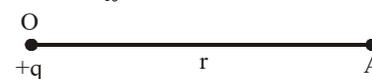
$$V_B - V_A = -\int_A^B \vec{E} \cdot d\vec{l}$$

Since the electrostatic field is conservative, the value of this line integral depends only on the end points A and B but not on the path taken.

Electric Potential at a Point Due to a Point Charge:

$$\text{As } \vec{E} = \frac{1}{4\pi\epsilon_0} \frac{q}{r^3} \vec{r} \text{ and } V = -\int_\infty^r \vec{E} \cdot d\vec{r}$$

$$\therefore V = -\int_\infty^r \frac{1}{4\pi\epsilon_0} \frac{q}{r^3} \vec{r} \cdot d\vec{r} = -\frac{1}{4\pi\epsilon_0} \int_\infty^r \frac{q}{r^2} dr$$



$$\text{or, } V = \frac{1}{4\pi\epsilon_0} \frac{q}{r}$$

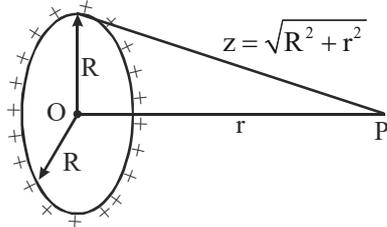
where r is the distance of A from the point charge q . The electric potential at A (V_A) is positive, if the point charge q is positive. V_A will be negative if the point charge q is negative.

Electric Potential due to a Group of Point Charges:

The potential at any point due to a group of point charges is the algebraic sum of the potentials contributed at the same point by all the individual point charges.

$$V = V_1 + V_2 + V_3 + \dots$$

Electric potential at an axial point at a distance r from the centre of the ring if a charge Q is uniformly distributed over the circumference of a ring.



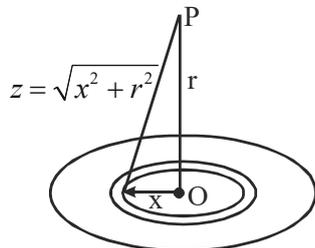
The electric potential at P due to the charge element dq of the ring is given by

$$dV = \frac{1}{4\pi\epsilon_0} \frac{dq}{Z} = \frac{1}{4\pi\epsilon_0} \frac{dq}{(R^2 + r^2)^{1/2}}$$

Hence, the electric potential at P due to the uniformly charged ring is given by

$$V = \int \frac{1}{4\pi\epsilon_0} \frac{dq}{(R^2 + r^2)^{1/2}} = \frac{1}{4\pi\epsilon_0} \frac{dq}{(R^2 + r^2)^{1/2}} \int dq = \frac{1}{4\pi\epsilon_0} \frac{Q}{\sqrt{(R^2 + r^2)}}$$

Potential at a point on the axis at a distance ‘ r ’ of a non-conducting disc of radius ‘ R ’ having a uniform surface charge density σ from its centre.



The symmetry of the disc tells us that the appropriate choice of element is a ring of radius x and thickness dx . All points on this ring are at the same distance $Z = \sqrt{x^2 + r^2}$, from the point P. The charge on the ring is $dq = \sigma dA = \sigma(2\pi x dx)$ and so the potential due to the ring is

$$dV = \frac{1}{4\pi\epsilon_0} \frac{dq}{Z} = \frac{1}{4\pi\epsilon_0} \frac{\sigma(2\pi x dx)}{\sqrt{x^2 + r^2}}$$

Since potential is a scalar quantity the potential due to the whole disc is given by

$$V = \frac{\sigma}{2\epsilon_0} \int_0^R \frac{x dx}{\sqrt{x^2 + r^2}} = \frac{\sigma}{2\epsilon_0} \left[(x^2 + r^2)^{1/2} \right]_0^R = \frac{\sigma}{2\epsilon_0} \left[(R^2 + r^2)^{1/2} - r \right]$$

Let us see this expression at large distance when $r \gg R$.

$$V = \frac{1}{4\pi\epsilon_0} \frac{Q}{r}, \text{ where } Q = \pi r^2 \sigma \text{ is the total charge}$$

on the disc.

Thus, we conclude that at large distance, the potential due to the disc is the same as that of a point charge Q .

Potential at a point of a shell of radius R has a charge Q uniformly distributed over its surface.

(A) **Outside the shell; ($r > R$):** At points outside a uniform spherical distribution, the electric field is

$$\vec{E} = \frac{1}{4\pi\epsilon_0} \frac{Q}{r^2} \hat{r}$$

Since \vec{E} is radial, $\vec{E} \cdot d\vec{r} = E dr$

Since $V(\infty) = 0$, we have

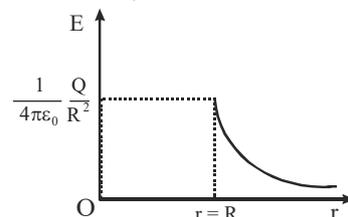
$$V(r) - V(\infty) = \int_{\infty}^r \frac{Q}{4\pi\epsilon_0 r^2} dr = \frac{Q}{4\pi\epsilon_0} \left[-\frac{1}{r} \right]_{\infty}^r \Rightarrow V = \frac{1}{4\pi\epsilon_0} \frac{Q}{r} \quad (r > R)$$

We see that the potential due to a uniformly charged shell is the same as that due to a point charge Q at the centre of the shell.

(B) **Inside the shell ($r < R$): At an internal Point**

At points inside the shell, $E = 0$. So, the work done in bringing a unit positive charge from a point on the surface to any point inside the shell is zero. Thus, the potential has a fixed value at all points within the spherical shell and is equal to the potential at the surface.

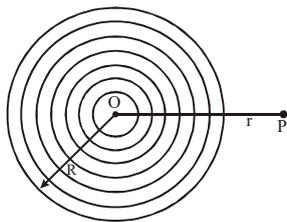
$$V = \frac{1}{4\pi\epsilon_0} \frac{Q}{R}$$



Variation of electric potential with the distance from the centre (r). All the above results hold for a “conducting sphere also whose charge lies entirely on the outer surface.

A charge Q is uniformly distributed throughout a non-conducting spherical volume of radius R . Hence potential at:

- (A) **External point ($r > R$):** At an external point Let O be the centre of a non-conducting sphere of radius R, having a charge Q distributed uniformly over its entire volume.



Let us divide the sphere into a large number of thin concentric shells carrying charges q_1, q_2, q_3, \dots etc. The potential at the point P due to the shell of charge q_1 is $\frac{1}{4\pi\epsilon_0} \frac{q_1}{r}$. Now, potential is a

scalar quantity. Therefore the potentials V due to the whole sphere is equal to the sum of the potentials due to all the shells.

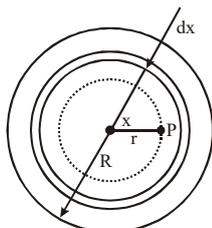
$$\begin{aligned} \therefore V &= \frac{1}{4\pi\epsilon_0} \frac{q_1}{r} + \frac{1}{4\pi\epsilon_0} \frac{q_2}{r} + \dots \\ &= \frac{1}{4\pi\epsilon_0 r} [q_1 + q_2 + q_3 + \dots] \end{aligned}$$

But $q_1 + q_2 + q_3 + \dots = Q$, the charge on the sphere

$$\therefore V = \frac{1}{4\pi\epsilon_0} \frac{Q}{r}$$

- (B) **Internal point ($r < R$)** where r is the distance of the point from the centre of the sphere

Suppose the point P lies inside the sphere at a distance r from the centre O, if we draw a concentric sphere through the point P, the point P will be external for the solid sphere of radius r, and internal for the outer spherical shell of internal radius r and external radius R.



The charge on the inner solid spheres $\frac{4}{3}\pi r^3 \rho$. Therefore the potential V_1 at P due to this sphere is given by

$$V_1 = \frac{1}{4\pi\epsilon_0} \frac{4/3\pi r^3 \rho}{r} = \frac{r^2 \rho}{3\epsilon_0}$$

Let us now find the potential at P due to the outer spherical shell. Let us divide this shell into a number of thin concentric shells and consider one such shell of radius x and infinitesimally small thickness dx. The volume of this shell = surface area \times thickness = $4\pi x^2 dx$. The charge on this shell, $dq = 4\pi x^2 dx \rho$. The potential at P due to this shell

$$dV_2 = \frac{1}{4\pi\epsilon_0} \frac{dq}{x} = \frac{1}{4\pi\epsilon_0} \frac{4\pi x^2 (dx) \rho}{x} = \frac{\rho x dx}{\epsilon_0}$$

The potential V_2 at P due to the whole shell of internal radius r and external radius R is given by

$$V_2 = \int_r^R \frac{\rho}{\epsilon_0} x dx = \frac{\rho}{\epsilon_0} \left[\frac{x^2}{2} \right]_r^R = \frac{\rho(R^2 - r^2)}{2\epsilon_0}$$

Since the potential is a scalar quantity, the total potential V at P is given by

$$\begin{aligned} V &= V_1 + V_2 \\ &= \frac{r^2 \rho}{3\epsilon_0} + \frac{\rho(R^2 - r^2)}{2\epsilon_0} = \frac{\rho(3R^2 - r^2)}{6\epsilon_0} \end{aligned}$$

But

$$\rho = \frac{Q}{\frac{4}{3}\pi R^3} \therefore V = \frac{1}{4\pi\epsilon_0} \frac{Q}{2R^3} [3R^2 - r^2]$$

Example - 14

Two tiny spheres carrying charges $1.5 \mu\text{C}$ and $2.5 \mu\text{C}$ are located 30 cm apart. Find the potential at the mid-point of the line joining the two charges.

- (A) $1.2 \times 10^5 \text{ Volt}$ (B) $2.4 \times 10^5 \text{ Volt}$
(C) $3.6 \times 10^5 \text{ Volt}$ (D) $4.8 \times 10^5 \text{ Volt}$

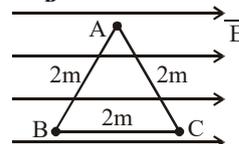
Solution: (B)

$$V = \frac{1}{4\pi\epsilon_0} \left[\frac{1.5 \times 10^{-6}}{(0.15)} + \frac{2.5 \times 10^{-6}}{(0.15)} \right]$$

$$V = 2.4 \times 10^5 \text{ Volt}$$

Example - 15

In uniform electric field $\vec{E} = 10 \text{ N/C}$ as shown in figure, find $V_A - V_B$



- (A) + 5 volt (B) - 5 volt
(C) + 10 volt (D) - 10 volt

Solution: (D)

$$\begin{aligned} \Delta V &= -E \cdot \Delta r \\ &= -10 \text{ volt } V_A - V_B = -10 \times 2 \cos 60^\circ \end{aligned}$$

Equipotential Surface

Locus of all such points where the potential is same is called equipotential surface.

- **Important Points Regarding Equipotential surface :**

- The lines of force are always normal to equipotential surfaces
- The net work done in taking a charge from A to B is zero if A and B are on same equipotential surface.

Example:

- In the field of a point charge, the equipotential surfaces are spheres centered on the point charge.

- (ii) In a uniform electric field, the equipotential surfaces are planes which are perpendicular to the fields lines.
- (iii) In the fields of an infinite line charge, the equipotential surfaces are co-axial cylinders having their axes at the line charge.
- (iv) The surface of a conductor is an equipotential surface and the inside of conductor is equipotential space. Hence there is no electric field (and charge) inside the conductor's surface. The lines of forces are always normal to the surface of a conductor.

Example -16

Two charges $2 \mu\text{C}$ and $-2 \mu\text{C}$ are placed at points A and B 6 cm apart. Consider A is at origin & B is at $x = 6 \text{ cm}$. Identify the coordinate of equipotential surface of the system.

- (A) at (2, 0, 3) (B) at (5, 2, 4)
- (C) at (4, 9, 4) (D) at (3, 2, 4)

Solution: (D)

Equipotential surface of the system will be a plane passing through the mid-point and perpendicular to the line joining the two charges because of the following reasons.

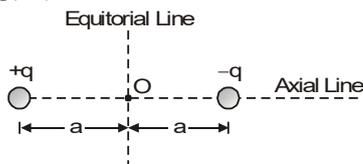
- (A) At any position on this plane distance of charges is same.
- (B) Magnitude of charge is same but of opposite nature.

9. DIPOLE

• **Electric Dipole And Dipole Moment:**

Two equal and opposite charges separated by a distance together constitute a dipole.

Dipole moment (\vec{p}) is defined as the simple product of magnitude of either charge and the distance of separation between the two charges.
 $\vec{p} = q(2\vec{a})$



Dipole moment \vec{p} always points from $-q$ to $+q$. Its SI unit is coulomb metre (Cm).

Electric Field Due To A Dipole At A Point Lying On Axial Line

Consider an electric dipole consisting of two point charges $-q$ and $+q$ separated by some distance $2a$. Let P be an observation point on axial line such that its distance from centre of the dipole is r . If E_A is the electric field intensity at P due to charge $+q$ then

$$E_A = \frac{1}{4\pi\epsilon_0} \frac{q}{(r+a)^2}$$

Again, if E_B is electric field intensity at P due to charge $-q$ then

$$E_B = \frac{1}{4\pi\epsilon_0} \frac{q}{(r-a)^2}$$

So, $E_{axial} = E_B - E_A \quad \{ \because E_B > E_A \}$

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

$$E_{axial} = \frac{1}{4\pi\epsilon_0} \frac{4rqa}{(r^2 - a^2)^2}$$

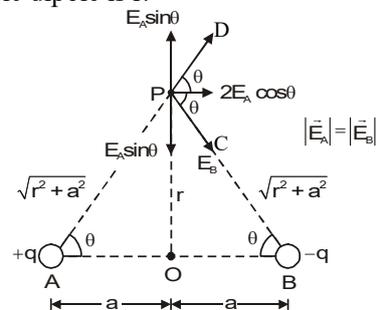
Since $p = q(2a)$

$$E_{axial} = \frac{1}{4\pi\epsilon_0} \frac{2pr}{(r^2 - a^2)^2};$$

For $r \gg a \quad E_{axial} = \frac{1}{4\pi\epsilon_0} \frac{2p}{r^3}$

• **Electric field due to dipole at a point lying on the equatorial line**

Consider an electric dipole consisting of two point charges $+q$ and $-q$ separated by distance $2a$. Let P be an observation point on equatorial line such that its distance from mid-point O of the electric dipole is r .



If E_A is electric field intensity at P due to $+q$

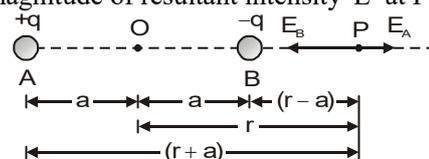
$$E_A = \frac{1}{4\pi\epsilon_0} \frac{q}{AP^2} = \frac{1}{4\pi\epsilon_0} \frac{q}{(r^2 + a^2)}$$

\vec{E}_A is represented both in magnitude and direction by \vec{PD} .

If E_B is electric field intensity at P due to $-q$

$$E_B = \frac{1}{4\pi\epsilon_0} \frac{q}{(r^2 + a^2)}$$

is represented both in magnitude and direction by \vec{PC} clearly, $E_A = E_B$. Let us resolve E_A and E_B into two components in two mutually perpendicular directions components of \vec{E}_A and \vec{E}_B along the equatorial line cancel each other but the components perpendicular to equatorial line get added up because they act in same direction. So magnitude of resultant intensity \vec{E} at P



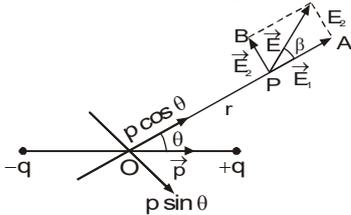
$$E = 2E_A \cos\theta = 2 \frac{q}{4\pi\epsilon_0 (r^2 + a^2)} \frac{a}{\sqrt{r^2 + a^2}}$$

$$E_{equatorial} = \frac{1}{4\pi\epsilon_0} \frac{p}{(r^2 + a^2)^{3/2}}$$

$$\text{For } r \gg a \quad E_{\text{equatorial}} = \frac{1}{4\pi\epsilon_0} \frac{p}{r^3}$$

Electric field intensity at a general point due to short electric dipole

Let P be the general point. Consider a short electric dipole of dipole moment \vec{p} placed in vacuum. Let O be the mid-point of the dipole. Let the line OP make an angle θ with \vec{p} . Resolving \vec{p} along OP and perpendicular to OP, we get $p \cos\theta$ and $p \sin\theta$ respectively. Point P is on the axial line of dipole of dipole moment $p \cos\theta$. Let \vec{E}_1 be the electric field intensity at P due to $p \cos\theta$.



Then $E_1 = \frac{1}{4\pi\epsilon_0} \frac{2p \cos\theta}{r^3}$ along PA

Let \vec{E}_2 be the electric field intensity at P due to $p \sin\theta$

Then $\vec{E}_2 = \frac{1}{4\pi\epsilon_0} \frac{p \sin\theta}{r^3}$ along PB

If E is the magnitude of the resultant electric intensity \vec{E} , then

$$E^2 = E_1^2 + E_2^2 = \left[\frac{1}{4\pi\epsilon_0} \frac{p}{r^3} \right]^2 (4\cos^2\theta + \sin^2\theta) \text{ or}$$

$$E = \frac{1}{4\pi\epsilon_0} \frac{p}{r^3} \sqrt{3\cos^2\theta + \cos^2\theta + \sin^2\theta}$$

or $E = \frac{1}{4\pi\epsilon_0} \frac{p}{r^3} \sqrt{3\cos^2\theta + 1}$

If β is the angle which \vec{E} makes with \vec{E}_1 , then

$$\tan\beta = \frac{E_2}{E_1} = \frac{1}{4\pi\epsilon_0} \frac{p \sin\theta}{r^3} \times \frac{4\pi\epsilon_0 r^3}{2p \cos\theta} = \frac{\tan\theta}{2}$$

or $\beta = \tan^{-1}\left(\frac{1}{2} \tan\theta\right)$

Case I: When P lies on the axial line of the dipole

$$E = \frac{1}{4\pi\epsilon_0} \frac{p}{r^3} \sqrt{3\cos^2 0^\circ + 1} \text{ or } E = \frac{1}{4\pi\epsilon_0} \frac{2p}{r^3}$$

So, the electric field intensity is along the axial line.

Case II: When P lies on the equatorial line of the dipole

$$\theta = 90^\circ, \cos\theta = \cos 90^\circ = 0$$

$$E = \frac{1}{4\pi\epsilon_0} \frac{p}{r^3} \sqrt{3\cos^2 90^\circ + 1}$$

or $E = \frac{1}{4\pi\epsilon_0} \frac{p}{r^3}$

$$\tan\beta = \frac{\tan 90^\circ}{2} = \infty \text{ or } \beta = 90^\circ$$

So, the electric field intensity is perpendicular to equatorial line and hence parallel to axial line.

Torque On A Dipole Placed In A Uniform Electric Field

Suppose an electric dipole is placed in a uniform external electric field \vec{E} where the dipole moment makes an angle θ with the field. The forces on the two charges are equal and opposite each having a magnitude $F = qE$

Thus, we see that the net force on the dipole is zero. However, the two forces produce a net torque on the dipole, and the dipole tends to rotate such that its axis gets aligned with the field. The torque due to the force on the positive charge about an axis through O is given by $F a \sin\theta$ where, $a \sin\theta$ is the moment arm of F about O. This force tends to produce a clockwise rotation. Likewise, the torque on the negative charge about O is also $F a \sin\theta$, and so the net torque τ about O is given by $\tau = 2F a \sin\theta$

Since $F = qE$ and $p = 2aq$

$$\Rightarrow \tau = 2aqE \sin\theta$$

$$\Rightarrow \tau = pE \sin\theta$$

It is convenient to express the torque in vector form as the cross product of the vectors \vec{p} and \vec{E} ,

so vectorially, $\vec{\tau} = \vec{p} \times \vec{E}$

Potential Energy Of A Dipole Placed In A Uniform Electric Field

Work must be done by an external agent to rotate the dipole through a given angle in the field. This work done is then stored as potential energy in the system, that is, the dipole and the external field. The work dW required to rotate the dipole through an angle $d\theta$ is given by

$$dW = \tau d\theta$$

Since, $\tau = pE \sin\theta$

This work is transformed into potential energy

U. We find this for a rotation from θ_0 to θ . So,

$$U = \int_{\theta_0}^{\theta} \tau d\theta = \int_{\theta_0}^{\theta} pE \sin\theta d\theta = pE \int_{\theta_0}^{\theta} \sin\theta d\theta$$

$$\Rightarrow U = pE (-\cos\theta) \Big|_{\theta_0}^{\theta} = pE (\cos\theta_0 - \cos\theta)$$

The term involving $\cos\theta_0$ is a constant that depends on the initial orientation of the dipole.

It is convenient to choose $\theta_0 = 90^\circ$, so that $\cos\theta_0 = \cos 90^\circ = 0$. In this case, we can express

U as $U = -pE \cos\theta$

This is equivalent to the dot product of the vectors \vec{p} and \vec{E} . So,

$$U = -\vec{p} \cdot \vec{E} = -(p_x E_x + p_y E_y + p_z E_z)$$

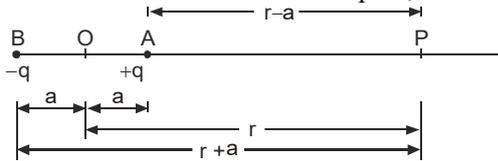
I. Electric potential due to an electric dipole at a point on the axial line of the electric dipole

Let P be the observation point on the axial line of the electric dipole AB. Let r be the distance of the observation point P from the mid point O of the electric dipole. Potential, due to charge +q,

$$\text{at } P = \frac{1}{4\pi\epsilon_0} \frac{q}{r-a}$$

Potential, due to charge -q at P = $-\frac{1}{4\pi\epsilon_0} \frac{q}{r+a}$

Potential at P due to electric dipole,



Potential at a point on axial line

$$\begin{aligned} V &= \frac{1}{4\pi\epsilon_0} \frac{q}{r-a} - \frac{1}{4\pi\epsilon_0} \frac{q}{r+a} \\ &= \frac{1}{4\pi\epsilon_0} q \left[\frac{1}{r-a} - \frac{1}{r+a} \right] \\ &= \frac{1}{4\pi\epsilon_0} q \left[\frac{r+a-r+a}{r^2-a^2} \right] \\ &= \frac{1}{4\pi\epsilon_0} \frac{q \times 2a}{r^2-a^2} = \frac{1}{4\pi\epsilon_0} \frac{p}{r^2-a^2} \end{aligned}$$

If $r \gg a$, then $V = \frac{1}{4\pi\epsilon_0} \frac{p}{r^2}$

II. Electric Potential Due To An Electric Dipole At A Point On The Equatorial Line

Potential at P due to charge +q, $V = \frac{1}{4\pi\epsilon_0} \frac{q}{AP}$

Potential at P due to charge -q, $V = -\frac{1}{4\pi\epsilon_0} \frac{q}{BP}$

Potential at P due to electric dipole,

$$V = \frac{1}{4\pi\epsilon_0} \frac{q}{AP} - \frac{1}{4\pi\epsilon_0} \frac{q}{BP} = \frac{1}{4\pi\epsilon_0} q \left[\frac{1}{AP} - \frac{1}{BP} \right]$$

But $AP = BP$ {From considerations of symmetry}

$\Rightarrow V = 0$

So, the potential due to an electric dipole at a point on the equatorial line of the dipole is zero.

Example - 17

A system has two charges $q_A = 2.5 \times 10^{-7} \text{ C}$ and $q_B = -2.5 \times 10^{-7} \text{ C}$ located at points A : (0, 0, -15 cm) and B : (0, 0, + 15 cm), respectively. What is the electric dipole moment of the system?

- (A) $2.5 \times 10^{-8} \text{ c-m}$
- (B) $5.0 \times 10^{-8} \text{ c-m}$
- (C) $7.5 \times 10^{-8} \text{ c-m}$
- (D) $1.0 \times 10^{-8} \text{ c-m}$

Solution: (C)

Dipole moment = $q \times l$

Dipole moment = $(2.5 \times 10^{-7}) (0.30) = 7.5 \times 10^{-8} \text{ c-m}$

Example - 18

An electric dipole with dipole moment $4 \times 10^{-9} \text{ C m}$ is aligned at 30° with the direction of a uniform electric field of magnitude $5 \times 10^4 \text{ NC}^{-1}$. Calculate the magnitude of the torque acting on the dipole.

- (A) $5 \times 10^{-5} \text{ N-m}$
- (B) $10 \times 10^{-5} \text{ N-m}$
- (C) $15 \times 10^{-5} \text{ N-m}$
- (D) $20 \times 10^{-5} \text{ N-m}$

Solution: (B)

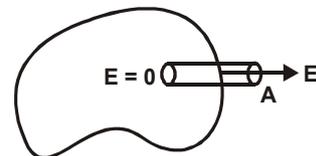
Torque $\vec{\tau} = \vec{p} \times \vec{E}$

$$\begin{aligned} |\vec{\tau}| &= PE \sin\theta = 4 \times 10^{-9} \times 5 \times 10^4 \sin 30 \\ &= 10 \times 10^{-5} \text{ N-m} \end{aligned}$$

10. ELECTROSTATICS OF CONDUCTOR

Conductors contain free electrons which are free to move throughout the body of the material. There are some characteristic properties of conductors in electrostatics which are given below,

- (A) Electric field remains zero inside a stationary conductor.
- (B) In electrostatic condition potential of conductor is same at its every point
- (C) Excess charges reside on the surface of the conductor.
- (D) Field on the surface of a conductor is normal to the surface.
- (E) If there is some cavity in the conductor and within that cavity there is some charge, then the field in the cavity will not be zero.
- (F) Field near the surface of the conductor:



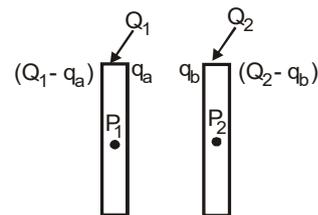
Applying Gauss's Law we have

$$EA = \frac{\sigma A}{\epsilon_0} \Rightarrow E = \frac{\sigma}{\epsilon_0}$$

(as there is no field inside the conductor).

(A) Charge Distribution on Conducting Plates:

Two identical plates of a parallel plate capacitor are given the charges Q_1 and Q_2 . Let the charge appearing on the inner surface of plate be q_a and q_b . Then, the charges appearing on other surfaces are as shown in the figure. If we take a point P inside the plate 1, then electric field at P should be zero. Suppose surface area of each plate is A.



$$\vec{E}_P = \vec{E}_1 + \vec{E}_2 + \vec{E}_3 + \vec{E}_4$$

E_1, E_2, E_3 and E_4 are the electric fields due to four surfaces.

$$\vec{E}_{P_1} = \frac{Q_1 - q_a}{2A\epsilon_0} \hat{i} + \frac{q_a}{2A\epsilon_0} \hat{i} - \frac{q_b}{2A\epsilon_0} \hat{i} - \frac{Q_2 - q_b}{2A\epsilon_0} \hat{i}$$

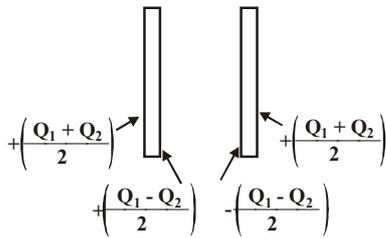
and $\vec{E}_{P_1} = 0 \Rightarrow q_a = \frac{Q_1 - Q_2}{2}$

Similarly

$$\vec{E}_{P_2} = \frac{Q_1 - q_a}{2A\epsilon_0} \hat{i} + \frac{q_a}{2A\epsilon_0} \hat{i} + \frac{q_b}{2A\epsilon_0} \hat{i} - \frac{Q_2 - q_b}{2A\epsilon_0} \hat{i}$$

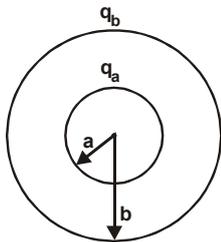
$$\vec{E}_{P_2} = 0 \Rightarrow q_b = -\left(\frac{Q_1 - Q_2}{2}\right) = -q_a$$

Hence charge distribution will be as follows

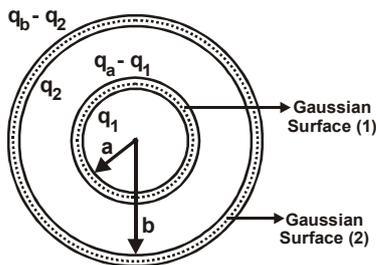


(B) Charge Distribution on Spherical conductor :

If there are two concentric shells of radii a and b having charge q_a and q_b .



We can consider shells where charge is distributed as follows:



For Gaussian Surface (A) :

$$\oint \vec{E} \cdot d\vec{S} = \frac{q_i}{\epsilon_0} \quad 0 = \frac{q_1}{\epsilon_0} \Rightarrow q_1 = 0$$

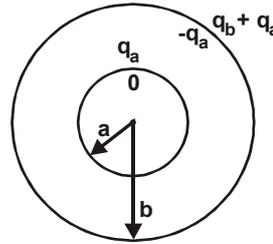
(E remains zero inside conductor)

For Gaussian Surface (B) :

$$\oint \vec{E} \cdot d\vec{S} = \frac{q_i}{\epsilon_0}$$

$$0 = \frac{(q_2) + (q_a - q_1) + (q_1)}{\epsilon_0} \Rightarrow q_2 = -q_a$$

Hence charge will distribute as follows

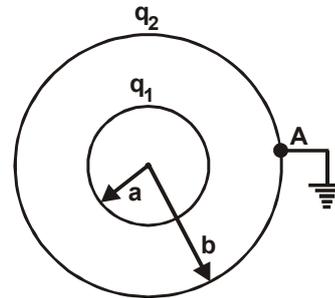


(C) Earthing of Conductors:

The earth is a good conductor of electricity. If we assume that the earth is uncharged, its potential will be zero. Also, if a small quantity of charge is given to the earth or is taken away from it the potential doesn't change by any appreciable extent. This is because of the large size of the earth. If conductor is connected to the earth, the potential of the conductor becomes equal to that of the earth, i.e. zero. If the conductor is at some other potential, charges will flow from it to the earth or from the earth to it to bring its potential to zero.

Example - 19

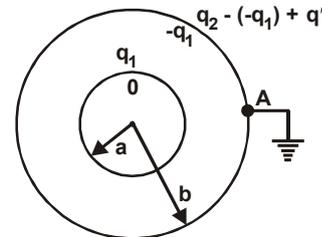
Let there be two concentric shells of charge q_1 and q_2 having radii a and b and outer shell is earthed at point A. Find net charge on inner surface of outer layer after earthing.



- (A) $+q_1$
- (B) $-q_1$
- (C) $q_1 + q_2$
- (D) zero

Solution: (B)

Let us consider q' charge has come from the earth on outer shell then by distribution of charge.

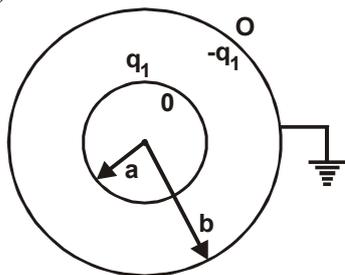


Now potential of point A will be zero

$$V_A = \frac{1}{4\pi\epsilon_0} \left(\frac{q_1}{b} + \frac{-q_1}{b} + \frac{q_2 + q_1 + q'}{b} \right) = 0$$

$$\Rightarrow q' = -(q_1 + q_2)$$

Hence final charge on each layer will be as shown in the figure,



Example - 20

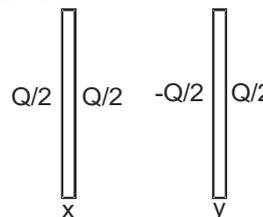
Two conducting plates X and Y, each having large surface area A (on one side), are placed parallel to each other as shown in figure. The plate X is given a charge Q whereas the other is neutral. Find the electric field at a point to the left of the plates.



- (A) $\frac{Q}{2A\epsilon_0}$ towards left (B) $\frac{Q}{2A\epsilon_0}$ towards right
 (C) $\frac{Q}{A\epsilon_0}$ towards left (D) $\frac{Q}{A\epsilon_0}$ towards right

Solution: (A)

By charge distribution



Surface charge density at inner surface of the plate x

will be $\sigma = \frac{Q/2}{A} = \frac{Q}{2A}$

Electric field at a point to the left of the plates.

$$E = \frac{\sigma}{2\epsilon_0} + \frac{\sigma}{2\epsilon_0} - \frac{\sigma}{2\epsilon_0} + \frac{\sigma}{2\epsilon_0}$$

$$= \frac{\sigma}{\epsilon_0} = \frac{(Q/2)/A}{\epsilon_0} = \frac{Q}{2A\epsilon_0} \text{ towards left}$$

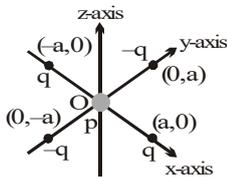
EXERCISE # 1

Based On Field & Force Calculation

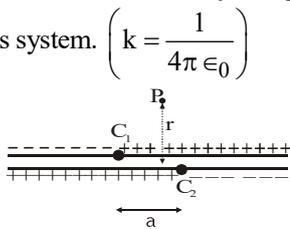
1. The figure shows, two point charges $q_1 = 2Q$ (>0) and $q_2 = -Q$. The charges divide the line joining them in three parts I, II and III



- (A) Region III has a local maxima of electric field
 (B) Region I has a local minima of electric field
 (C) Equilibrium position for a test charge lies in region II
 (D) None of these
2. In the figure shown, the equilibrium of proton p is neutral with respect to its displacement along



- (A) x-axis
 (B) y-axis
 (C) z-axis
 (D) At 45° with x-axis in x-y plane
3. Two long thin rods having charge density λ_0x and $-\lambda_0x$ (where x is the distance from their respective centres C_1 and C_2) are placed close and parallel to each other in such a way that distance between their centres is a . Find out the electric field intensity at a point P distant r from this system.



- (A) data insufficient (B) $\frac{k\lambda_0a}{r}$
 (C) $\frac{k\lambda_0a}{2r}$ (D) $\frac{2k\lambda_0a}{r}$
4. Two charged particles (M, $+Q$) and (m, $-q$) are placed in uniform electric field E. After the particles are released, they stay at a constant distance from each other. This distance will be

- (A) $\sqrt{\frac{(M+m)KQq}{E(qM+Qm)}}$ (B) $\sqrt{\frac{(M-m)KQq}{E(qM+Qm)}}$
 (C) $\sqrt{\frac{(M+m)KQq^2}{E(qM-Qm)}}$ (D) $\sqrt{\frac{(M-m)KQ^2q}{E^2(qM-Qm)}}$

5. A point charge $-3q$ is positioned at the origin of a Cartesian coordinate system. A test point charge $2q$ is placed at point $(1m, 1m, 1m)$. Which of the following is the unit vector in the direction of the force acting on the test charge?

- (A) $\hat{i} + \hat{j} + \hat{k}$ (B) $-(\hat{i} + \hat{j} + \hat{k})$
 (C) $(\hat{i} + \hat{j} + \hat{k})/\sqrt{3}$ (D) $-(\hat{i} + \hat{j} + \hat{k})/\sqrt{3}$

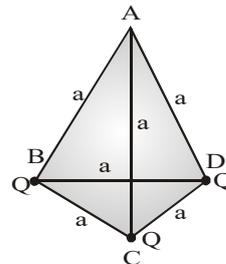
6. A thin conducting ring of radius r has an electric charge $+Q$. If a point charge q is placed at the center of the ring, the increment in tension in the ring will be

- (A) $\frac{Qq}{8\pi\epsilon_0r^2}$ (B) $\frac{Qq}{4\pi\epsilon_0r^2}$ (C) $\frac{Qq}{8\pi^2\epsilon_0r^2}$ (D) $\frac{Qq}{4\pi^2\epsilon_0r^2}$

7. An infinitely large nonconducting plane of uniform surface charge density σ has circular aperture of certain radius R carved out from it. The electric field at a point which is at a distance 'a' from the centre of the aperture and perpendicular to the plane is $\frac{\sigma}{2\sqrt{2}\epsilon_0}$. The radius of aperture R is

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

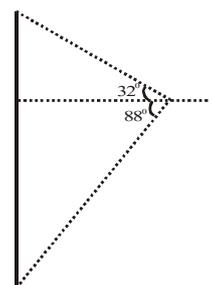
8. A,B,C,D are the corners of a regular tetrahedron of side a . Three identical charges each Q are fixed at three corners B, C and D. The magnitude of electric field intensity at the corner A is



- (A) $\frac{\sqrt{6}Q}{4\pi\epsilon_0 a^2}$ (B) $\frac{2\sqrt{3}Q}{2\pi\epsilon_0 a^2}$
 (C) $\frac{\sqrt{6}Q}{2\pi\epsilon_0 a^2}$ (D) $\frac{2\sqrt{3}Q}{4\pi\epsilon_0 a^2}$

9. Consider a finite charged rod. Electric field at Point P (shown) makes an angle θ with horizontal dotted line then angle θ is :

- (A) 60°
 (B) 28°
 (C) 44°
 (D) information insufficient



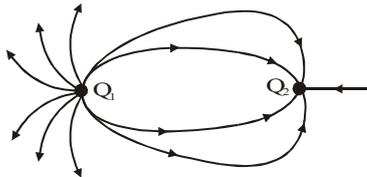
10. A point charge $+q$ is placed at a distance $5f$ from optical centre of a converging lens of focal length f and another point charge $-q$ is placed at image position, magnitude of electric field at the optical centre due to these charges is

- (A) $\frac{16kq}{25f^2}$ (B) zero
 (C) $\frac{41kq}{25f^2}$ (D) $\frac{kq}{235f^2}$

11. A point charge $25 \mu\text{C}$ is located in the XY plane at the point of position vector $\vec{r}_0 = (\hat{i} + \hat{j})\text{m}$. What is the magnitude of electric field at the point of position vector $\vec{r}_1 = (4\hat{i} + 5\hat{j})\text{m}$?

- (A) $900 \frac{\text{V}}{\text{m}}$ (B) $9 \frac{\text{kV}}{\text{m}}$
 (C) $90 \frac{\text{V}}{\text{m}}$ (D) can't be determined

12. From the field pattern shown in figure, identify the correct statement related to the charges Q_1 and Q_2 :

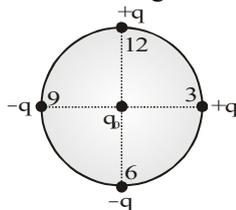


- (A) $\frac{Q_1}{Q_2} = +2.5$ (B) $\frac{Q_1}{Q_2} = +2$
 (C) $\frac{Q_1}{Q_2} = -2$
 (D) There is no relation exist between Q_1 & Q_2

13. A ring of radius R has a linear charge density $\lambda = \lambda_0 \cos^2 \theta$ along its circumference. Total charge on the ring is :

- (A) $3\lambda_0\pi R$ (B) $2\lambda_0\pi R$
 (C) $\lambda_0\pi R$ (D) can't be determined

14. Four charges are placed at the circumference of dial clock as shown in figure.



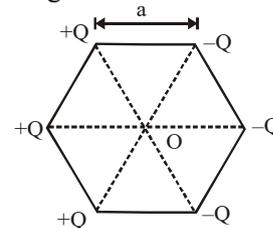
If the clock has only hour hand, then the resultant force on a charge q_0 placed at the centre, points in the direction which show the time as :

- (A) 1:30 (B) 7:30 (C) 4:30 (D) 10:30

15. Three point charges q_1, q_2 and q_3 are taken such that when q_1 and q_2 are placed close together to form a single point charge, the force on q_3 at distance L from this combination is a repulsion of 2 units in magnitude. When q_2 and q_3 are so combined the force on q_1 at distance L is an attractive force of magnitude 4 units. Also q_3 and q_1 when combined exert an attractive force on q_2 of magnitude 18 unit at same distance L . The algebraic ratio of charges q_1, q_2 and q_3 is

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

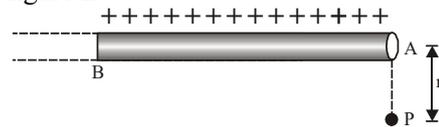
16. Six charges are placed at the vertices of a regular hexagon as shown in the figure.



Component of the electric field along the line passing through point O and perpendicular to the plane of the figure at a distance of x ($\gg a$) from O is

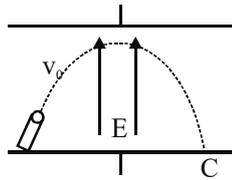
- (A) $\frac{Qa}{\pi\epsilon_0 x^3}$ (B) $\frac{2Qa}{\pi\epsilon_0 x^3}$
 (C) $\frac{\sqrt{3}Qa}{\pi\epsilon_0 x^3}$ (D) zero

17. A semi-infinite insulating rod has linear charge density λ . The electric field at the point P shown in figure is



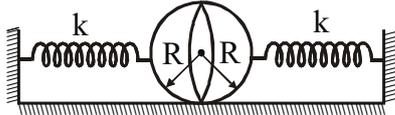
- (A) $\frac{2\lambda^2}{(4\pi\epsilon_0 r)^2}$ at 45° with AB
 (B) $\frac{\sqrt{2}\lambda}{4\pi\epsilon_0 r^2}$ at 45° with AB
 (C) $\frac{\sqrt{2}\lambda}{4\pi\epsilon_0 r}$ at 45° with AB
 (D) $\frac{\sqrt{2}\lambda}{4\pi\epsilon_0 r}$ at perpendicular to AB

18. Two negatively charged particles having charges e_1 & e_2 and masses m_1 & m_2 respectively are projected one after another into a region with equal initial velocities. The electric field E is along the y -axis, while the direction of projection makes an angle α with the y -axis. If the ranges of the two particles along the x -axis are equal then, one can conclude that



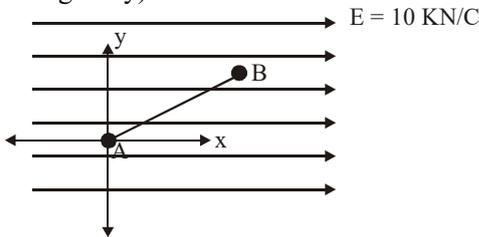
- (A) $e_1 > e_2$ & $m_1 < m_2$ (B) $e_1 = e_2$ only
 (C) $m_1 = m_2$ only (D) $e_1 m_2 = m_1 e_2$

19. Two non-conducting hemispherical surfaces, which are having uniform charge density σ are placed on smooth horizontal surface as shown in figure. Assuming springs are ideal, calculate compression in each spring if both the hemispherical surface are just touching each other.



- (A) $\frac{\sigma^2 R^2}{2\epsilon_0 k}$ (B) R
 (C) $\frac{\sigma^2 \pi R^2}{2\epsilon_0 k}$ (D) None of these

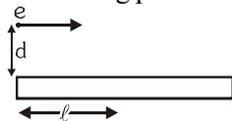
20. Two charged particles A & B having charge $-2mc$ & $4mc$, and mass $2kg$ & $1kg$ respectively. Both charges are released in uniform electric field of strengths 10 kN/C . Initially A is at origin and B is at point $(100, 100)$. At $t = 3\text{ sec}$ if B is at a point $(50, 70)$ then find the location of the point where A would be at this time (Assuming there is no gravity)



- (A) $(160, 30)$ (B) $(90, 30)$
 (C) $(160, 15)$ (D) $(70, 15)$

Based On GAUSS LAW

21. An electron of mass m is projected from a distance 'd' with initial velocity u parallel to a uniformly charged flat conducting plate as shown.

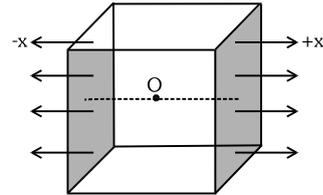


It strikes the plate after travelling a distance l along the direction of projection, the surface charge density of conducting plate is equal to

- (A) $\frac{2d\epsilon_0 mu^2}{e l^2}$ (B) $\frac{2d\epsilon_0 mu^2}{e l}$
 (C) $\frac{d\epsilon_0 mu^2}{e l}$ (D) $\frac{d\epsilon_0 mu}{e l}$

22. In a certain region \vec{E} increases radially as $\vec{E} = 90r(-\hat{r})$. The electric charge contained within a sphere of radius $2m$ centered at the origin is
 (A) $80\ \mu\text{C}$ (B) $-80\ \text{nC}$
 (C) $100\ \mu\text{C}$ (D) $-160\ \text{nC}$

23. A cube of side 20 cm has its center at the origin and its one side is along the x -axis, so that one end is at $x = +10\text{ cm}$ and the other is at $x = -10\text{ cm}$. The magnitude of electric field is 100 N/C and for $x > 0$ it is pointing in the $+ve\ x$ -direction and for $x < 0$ it is pointing in the $-ve\ x$ -direction as shown.

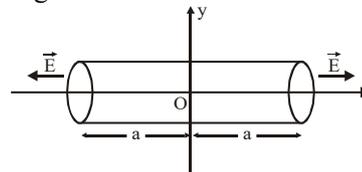


The sign and value of charges inside the box, are:-

(Given that $\epsilon_0 = 8.85 \times 10^{-12}\text{ C}^2/\text{N}\cdot\text{m}^2$)

- (A) Negative, $6 \times 10^{-11}\text{ C}$
 (B) Positive, $7.08 \times 10^{-11}\text{ C}$
 (C) Positive, $6 \times 10^{-11}\text{ C}$
 (D) Negative, $7.08 \times 10^{-11}\text{ C}$

24. A right circular cylinder of length $2a\text{ cm}$ and radius $r\text{ cm}$ has its centre at the origin O and its axis along the x -axis so that one flat face is at $x = +a\text{ cm}$ and the other is at $x = -a\text{ cm}$ as is shown in the figure.



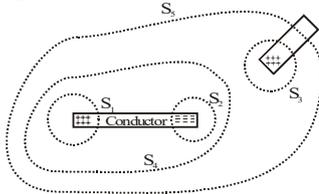
It is placed in a uniform electric field $\vec{E} = E_x \hat{i}\text{ NC}^{-1}$ for $x > 0$ and $\vec{E} = -E_x \hat{i}\text{ NC}^{-1}$ for $x < 0$. Then

- (A) The net outward flux through each flat surface is $E_a \pi r^2 \times 10^{-6}\text{ Nm}^2/\text{C}$
 (B) The net outward flux through curved surface of the cylinder is zero
 (C) The net charge inside the cylinder is $E_a r^2 \times 5 \times 10^{-15}\text{ C}$
 (D) The net charge inside the cylinder is $E_a r^2 \times 25 \times 10^{-15}\text{ C}$

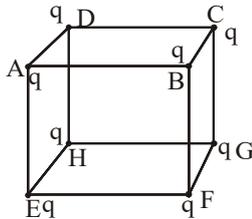
25. For a spherically symmetrical charge distribution, electric field at a distance r from the centre of sphere is $\vec{E} = kr^7 \hat{r}$. Where k is a constant. What will be the volume charge density at a distance r from the centre of sphere ?

- (A) $\rho = 9k\epsilon_0 r^6$ (B) $\rho = 5k\epsilon_0 r^3$
 (C) $\rho = 3k\epsilon_0 r^4$ (D) $\rho = 9k\epsilon_0 r^0$

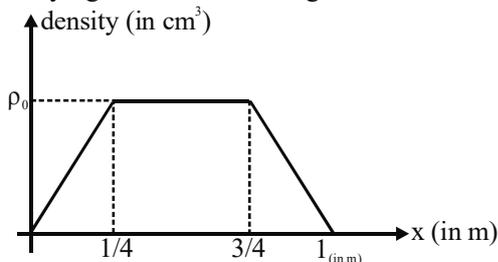
26. A rod containing charge $+Q$ is brought near an initially uncharged isolated conducting rod as shown. Regions with total surface charge $+Q$ and $-Q$ are induced in the conductor as shown in the figure. The only regions where the net charge in this configuration is non-zero are indicated by the "+" and "-" signs. Let us denote the total flux of electric field outward through closed surface S_1 as ϕ_1 , through S_2 as ϕ_2 , etc. Which of the following is necessarily false.



- (A) $\phi_1 > 0$ (B) $\phi_2 = \phi_1$
 (C) $\phi_3 = \phi_1$ (D) $\phi_4 = 0$
27. Eight point charges having magnitude q are fixed at vertices of a cube. The electric flux through square surface ABCD of the cube is

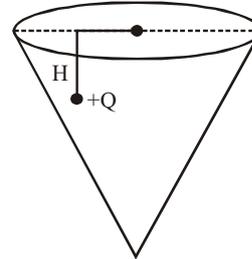


- (A) $\frac{q}{24\epsilon_0}$ (B) $\frac{q}{12\epsilon_0}$ (C) $\frac{q}{6\epsilon_0}$ (D) $\frac{q}{3\epsilon_0}$
28. The electric field in a region is given by $\vec{E} = 200\hat{i}$ N/C for $x > 0$ and $-200\hat{i}$ N/C for $x < 0$. A closed cylinder of length 2m and cross-section area 10^2 m^2 is kept in such a way that the axis of cylinder is along X-axis and its centre coincides with origin. The total charge inside the cylinder is
 [Take : $\epsilon_0 = 8.85 \times 10^{-12} \text{ C}^2 \text{ m}^2 \text{ N}^{-1}$]
- (A) zero (B) $1.86 \times 10^{-5} \text{ C}$
 (C) $1.77 \times 10^{-11} \text{ C}$ (D) $35.4 \times 10^{-8} \text{ C}$
29. The volume charge density as a function of distance X from one face inside a unit cube is varying as shown in the figure.

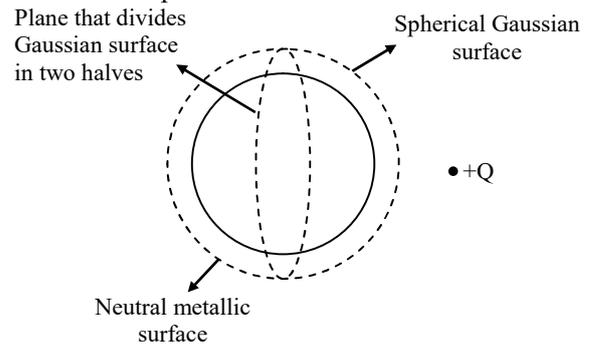


- The total flux (in S.I. units) through the cube if $(\rho_0 = 8.85 \times 10^{-12} \text{ C/m}^3)$ is
 (A) $1/4$ (B) $1/2$ (C) $3/4$ (D) 1

30. A charge $+Q$ is located somewhere inside a vertical cone such that the depth of the charge from the free surface of the cone is H . It is found that the flux associated with the cone with the curved surface is $\frac{3Q}{5\epsilon_0}$. If the charge is raised vertically through a height $2H$, then the flux through the curved surface is



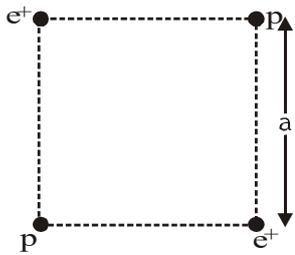
- (A) $\frac{3Q}{5\epsilon_0}$ (B) $\frac{2Q}{5\epsilon_0}$ (C) $\frac{4Q}{5\epsilon_0}$ (D) Zero
31. Figure shows a neutral metallic sphere with a point charge $+Q$ placed near its surface. Electrostatic equilibrium conditions exist on metallic sphere. Mark the correct statements :



- (A) Net flux through Gaussian surface due to charge Q is non zero
 (B) Net flux through Gaussian surface due to charges appearing on the outer surface of metallic sphere cannot be zero
 (C) If point charge Q is displaced towards metallic sphere, magnitude of flux through right hemispherical part of Gaussian surface due to this charge increases.
 (D) If point charge Q is displaced towards metallic sphere, charge distribution on outer surface of sphere will not change

Based On Potential and Potential Energy

32. Two positrons (e^+) and two protons (p) are kept on four corners of a square of side a as shown in figure. The mass of proton is much larger than the mass of positron. Let q denote the charge on the proton as well as the positron then the kinetic energies of one of the positrons and one of the protons respectively after a very long time will be—



- (A) $\frac{q^2}{4\pi\epsilon_0 a} \left(1 + \frac{1}{2\sqrt{2}}\right), \frac{q^2}{4\pi\epsilon_0 a} \left(1 + \frac{1}{2\sqrt{2}}\right)$
- (B) $\frac{q^2}{2\pi\epsilon_0 a}, \frac{q^2}{4\sqrt{2}\pi\epsilon_0 a}$
- (C) $\frac{q^2}{4\pi\epsilon_0 a}, \frac{q^2}{4\pi\epsilon_0 a}$
- (D) $\frac{q^2}{2\pi\epsilon_0 a} \left(1 + \frac{1}{4\sqrt{2}}\right), \frac{q^2}{8\sqrt{2}\pi\epsilon_0 a}$

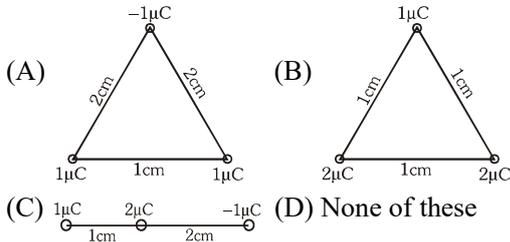
33. A solid conducting sphere of radius a has charge $+q$. The sphere is surrounded concentrically by a conducting shell of inner and outer radii r and R respectively. The electric potential at a point which is at a distance x , ($r < x < R$), from the centre of the sphere is :-

- (A) $\frac{q}{4\pi\epsilon_0 R}$ (B) $\frac{3q}{4\pi\epsilon_0 R}$
- (C) $\frac{8q}{4\pi\epsilon_0 R}$ (D) $\frac{5q}{4\pi\epsilon_0 R}$

34. A conducting sphere is placed in air of dielectric strength 3×10^6 volt/m. The minimum radius of the sphere that can be raised to a potential of 9 million volts is :

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

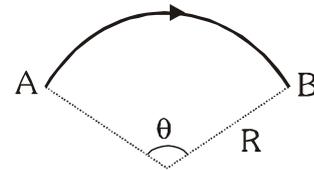
35. Which of the following systems of charges have zero electrostatic potential energy?



36. The potential on the N^{th} shell due to N concentric shells having charges $Q, 2Q, 3Q, \dots, NQ$ and radii $a, 2a, 3a, \dots, Na$ respectively is-

- (A) $\frac{Q(N+1)}{8\pi\epsilon_0 A}$ (B) $\frac{QN(N+1)}{8\pi\epsilon_0 A}$
- (C) $\frac{Q}{2\pi\epsilon_0 A}$ (D) $\frac{Q(N+1)}{2\pi\epsilon_0 A}$

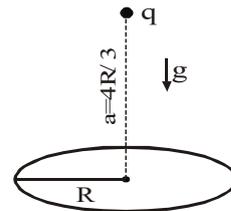
37. Figure shows an electric line of force which curves along a circular arc. The magnitude of electric field intensity is same at all points on this curve and is equal to E . If the potential at A is V then the potential at B is



- (A) $V - ER \sin\left(\frac{\theta}{2}\right)$ (B) $V - ER\theta$
- (C) $V + ER\theta$ (D) $V + ER \sin\left(\frac{\theta}{2}\right)$

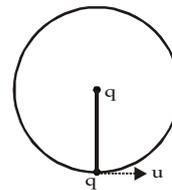
38. A point charge q & mass m is just dropped from a height $a = 4R/3$ above a conducting ring of charge Q & radius R . If q just reaches the centre of the ring. Find the value of q (given

$$\frac{Q^2}{4\pi\epsilon_0 R^2} = mg)$$



- (A) $q = \frac{Q}{3}$ (B) $q = 3Q$
- (C) $q = \frac{10Q}{3}$ (D) $q = \frac{3Q}{10}$

39. A small ball of mass m having a charge of q is suspended by a string of length ℓ .

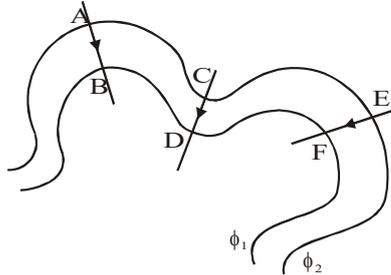


Another identical ball having the same charge is kept at the point of suspension. Determine the minimum horizontal velocity which should be imparted to the lower ball so that it can make a

complete revolution. $\left(\frac{q^2}{4\pi\epsilon_0 \ell^2} = mg\right)$

- (A) $\sqrt{g\ell}$ (B) $2\sqrt{g\ell}$
- (C) $\frac{\sqrt{g\ell}}{2}$ (D) $\frac{\sqrt{g\ell}}{3}$

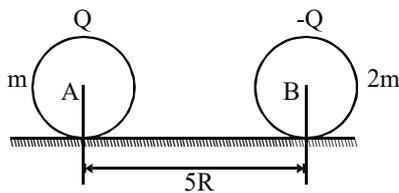
40. In moving from A to B along an electric field line, the electric field does 1.28×10^{-18} J of work on an electron. If ϕ_1, ϕ_2 are equipotential surfaces, then potential difference $V_E - V_D$ is equal to



- (A) -8 volt (B) +8 volt
(C) zero (D) None of these

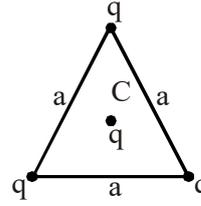
41. If two electric charges q and $-2q$ are placed at distance $6a$ apart, then locus of point in the plane of charges, where electric potential is zero is : (Take charge q at origin and $-2q$ lies on positive x -axis)
- (A) $x^2 + y^2 + 4ax - 6a^2 = 0$
 (B) $x^2 + y^2 + 4ax - 12a^2 = 0$
 (C) $x^2 + y^2 + 2ax - 12a^2 = 0$
 (D) $x^2 + y^2 - 4ax + 12a^2 = 0$

42. Two smooth spherical non conducting shells each of radius R having uniformly distributed charge Q and $-Q$ on their surfaces are released on a smooth non-conducting surface when the distance between their centres is $5R$. The mass of A is m and that of B is $2m$. The speed of A just before A and B collide is [Neglect gravitational interaction] $\left(K = \frac{1}{4\pi\epsilon_0} \right)$



- (A) $\sqrt{\frac{2KQ^2}{5mR}}$ (B) $\sqrt{\frac{4KQ^2}{5mR}}$
 (C) $\sqrt{\frac{8KQ^2}{5mR}}$ (D) $\sqrt{\frac{16KQ^2}{5mR}}$

43. Four equal charges of magnitude q as shown in fig.



Now the charge at center C is taken to infinite slowly, then work done by external force will be-

- (A) $\frac{-3Kq^2}{a}$ (B) $\frac{-3\sqrt{3}Kq^2}{a}$
 (C) $\frac{-3Kq^2}{a}(\sqrt{3}+1)$ (D) $\frac{3Kq^2}{a}(\sqrt{3}+1)$

44. Three identical charges each of $16\mu\text{C}$ are placed at the vertices of the triangle ABC. If $AB + AC = 10$ cm and $AB \cdot AC = 16$ cm² then potential energy of charge A is
- (A) 14.4 J (B) 144 J
 (C) 0.144 J (D) None

45. The intensity of an electric field depends only on the coordinates x, y and z as follows :

$$\vec{E} = a \frac{(x\hat{i} + y\hat{j} + z\hat{k})}{(x^2 + y^2 + z^2)^{3/2}} \text{ unit}$$

The electrostatic energy stored between two imaginary concentric spherical shells of radii R and $2R$ with centre at origin is :-

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

EXERCISE # 2

Question One or More Than One Correct Answer Type Questions

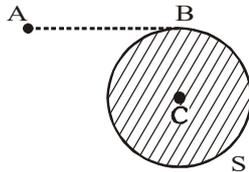
1. A thin insulator rod is placed between two unlike point charges $+q_1$ and $-q_2$.



For this situation tick the correct alternative (s)-

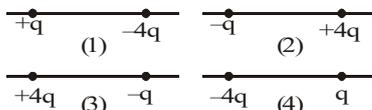
- (A) The total force acting on charge $+q_1$ will increase.
- (B) The total force acting on charge $-q_2$ will increase.
- (C) The total force acting on charge $-q_2$ will decrease.
- (D) The force acting on charge $+q_1$ due to $-q_2$ will remain same.

2. S is a solid neutral conducting sphere. A point charge q of $1 \times 10^{-6}C$ is placed at point A. C is the centre of sphere and AB is a tangent. BC = 3m and AB = 4m.



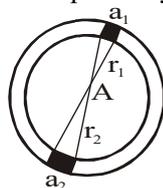
- (A) The electric potential of the conductor is 1.8 kV.
- (B) The electric potential of the conductor is 2.25 kV.
- (C) The electric potential at B due to induced charges on the sphere is -0.45 kV.
- (D) The electric potential at B due to induced charges on the sphere is 0.45 kV.

3. The figure shows four situations in which charges as indicated ($q > 0$) are fixed on an axis. In which situation is there a point to the left of the charges where an electron would be in equilibrium ?



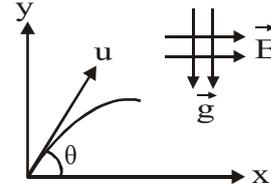
- (A) 1 (B) 2 (C) 3 (D) 4

4. A wire having a uniform linear charge density λ , is bent in the form of a ring of radius R. Point A as shown in the figure, is in the plane of the ring but not at the centre. Two elements of the ring of lengths a_1 and a_2 subtend very small same angle at the point A. They are at distances r_1 and r_2 from the point A respectively.



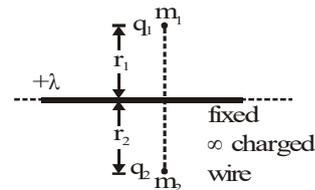
- (A) The ratio of charges of elements a_1 and a_2 is r_1/r_2 .
- (B) The element a_1 produced greater magnitude of electric field at A than element a_2 .
- (C) The elements a_1 and a_2 produce same potential at A.
- (D) The direction of net electric field at A is towards element a_2 .

5. A particle of mass m and charge $-q$ has been projected from ground as shown in the figure below. Mark out the correct statements (s) :-



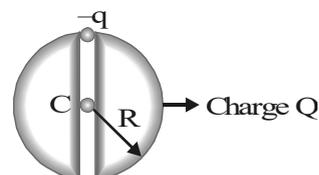
- (A) The path of motion of the particle is parabolic
- (B) The path of motion of the particle is a straight line
- (C) Time of flight of particle is $\frac{2u \sin \theta}{g}$
- (D) Range of motion of the particle will be less than $\frac{u^2 \sin 2\theta}{g}$

6. For the arrangement shown below, the two point charges are in equilibrium. The infinite wire is fixed in the horizontal plane and the two point charges are placed one above and the other below the wire. Considering the gravitational effect of the earth, then nature of q_1 and q_2 can be :



- (A) $q_1 \rightarrow +ve, q_2 \rightarrow +ve$
- (B) $q_1 \rightarrow +ve, q_2 \rightarrow -ve$
- (C) $q_1 \rightarrow -ve, q_2 \rightarrow -ve$
- (D) $q_1 \rightarrow -ve, q_2 \rightarrow +ve$

7. In a uniformly charged dielectric sphere a very thin tunnel has been made along the diameter as shown in the figure below. A charge particle $-q$ having mass m is released from rest at one end of tunnel. For the situation described, mark out the correct statement (s) :- [Neglect gravity]



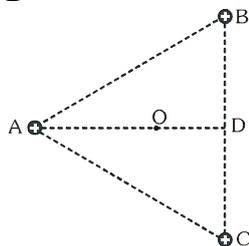
- (A) Charged particle will perform SHM about centre of the sphere as mean position
 (B) Time period of the particle is $2\pi\sqrt{\frac{4\pi\epsilon_0 mR^3}{qQ}}$.
 (C) Particle will perform oscillation but not SHM.
 (D) Speed of the particle while crossing-mean position is $\sqrt{\frac{Qq}{4\pi\epsilon_0 mR}}$

8. A point charge Q is placed at origin. Let \vec{E}_A , \vec{E}_B and \vec{E}_C be the electric field at three points A (1,0,1), B (-1,√6,1) and C (√6,1,-1) due to charge Q. Then
 (A) $\vec{E}_A \perp \vec{E}_B$ (B) $|\vec{E}_B| = |\vec{E}_C|$
 (C) $\vec{E}_B \parallel \vec{E}_C$ (D) $E_A = 4E_B$

9. A particle of mass 2kg and charge 1mC is projected vertically with a velocity 10 m/s. There is a uniform horizontal electric field of 10^4 N/C. Then
 (A) the horizontal range of the particle is 10 m
 (B) the time of flight of the particle is 2s
 (C) the maximum height reached is 5m
 (D) the horizontal range of the particle is 0

10. A point charge q is placed at origin. Let \vec{E}_A , \vec{E}_B and \vec{E}_C be electric field at three points. A (1, 2, 3), B(1, 1,-1) and C (2, 2, 2) due to charge q. Then
 (A) $\vec{E}_A \perp \vec{E}_B$ (B) $\vec{E}_A = \vec{E}_B$
 (C) $|\vec{E}_B| = 4|\vec{E}_C|$ (D) $|\vec{E}_B| = 16|\vec{E}_C|$

11. Three identical point charges are placed on the vertices of an equilateral triangle ABC as shown in the figure. Consider a median AD, where point O is the centroid. As we move from point A to point D

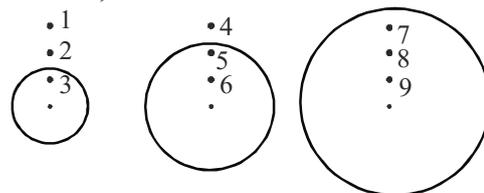


- (A) Electric field vanishes only once at O, between points A and D.
 (B) Electric field vanishes two times, first at O and then somewhere between O & D.
 (C) Electric field vanishes two times, first at a point somewhere between A & O and then at O.
 (D) Electric field vector changes direction more than once.

12. A spherical soap bubble of radius R has uniformly distributed charge over its surface with surface charge density σ then [T = surface tension of the soap solution]
 (A) excess pressure inside the bubble is $\frac{4T}{R} - \frac{\sigma^2}{2\epsilon_0}$
 (B) excess pressure inside the bubble is $\frac{4T}{R} + \frac{\sigma^2}{2\epsilon_0}$
 (C) excess pressure inside the bubble is $\frac{4T}{R}$
 (D) electrostatic pressure is $\frac{\sigma^2}{2\epsilon_0}$

13. A simple pendulum of length ℓ has a bob of mass m, with a charge q on it. A non-conducting thin vertical sheet of charge, with charge σ per unit area, passes through the point of suspension of the pendulum. At equilibrium, the string makes an angle θ with the vertical. Its time period of oscillation is T. In this position
 (A) $\tan \theta = \frac{\sigma q}{2\epsilon_0 mg}$ (B) $\tan \theta = \frac{\sigma q}{\epsilon_0 mg}$
 (C) $T < 2\pi\sqrt{\frac{\ell}{g}}$ (D) $T > 2\pi\sqrt{\frac{\ell}{g}}$

14. Figure shows three spherical shells in separate situations, with each shell having the same uniform positive net charge. Points 1, 4 and 7 are at the same radial distances from the centre of their respective shells; so are points 2, 5 and 8 ; and so are points 3, 6 and 9. With the electric potential taken equals to zero at an infinite distance, choose correct statement.



- (A) Point 3 has highest potential
 (B) point 1, 4 and 7 are at same potential
 (C) Point 9 has lowest potential
 (D) point 5 and 8 are at same potential
15. Two point charges are located on the x-axis. The first is a charge +Q at $x = -a$. The second is an unknown charge located at $x = +3a$. The net electric field these charges produce at the origin has a magnitude of $\frac{2kQ}{a^2}$. What are the possible value (s) of the unknown charge?
 (A) -9Q (B) +9Q
 (C) +27Q (D) +8Q

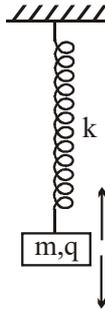
16. Charge Q_1 and Q_2 lie inside and outside respectively of a closed surface S . Let E be the field at any point on S and ϕ be the flux of E over S .
- (A) If Q_1 changes, both E and ϕ will change.
 - (B) If Q_2 changes, E will change but ϕ will not change.
 - (C) If $Q_1 = 0$ and $Q_2 \neq 0$ then $E \neq 0$ but $\phi = 0$.
 - (D) If $Q_1 \neq 0$ and $Q_2 = 0$ then $E = 0$ but $\phi \neq 0$.

17. A large insulating thick sheet of thickness $2d$ carries a uniform charge per unit volume ρ . A particle of mass m , carrying a charge q having a sign opposite to that of the sheet, is released from the surface of the sheet. The sheet does not offer any mechanical resistance to the motion of the particle. Choose the correct option.

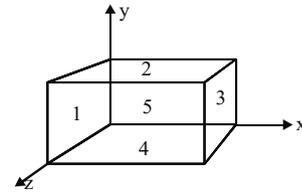
(A) $v = \frac{1}{2\pi} \sqrt{\frac{q\rho}{m\epsilon_0}}$ (B) $v = \frac{1}{2\pi} \sqrt{\frac{2q\rho}{m\epsilon_0}}$
 (C) $\omega = \sqrt{\frac{2q\rho}{\epsilon_0 m}}$ (D) $\omega = \sqrt{\frac{q\rho}{\epsilon_0 m}}$

18. The following figure shows a block of mass m suspended from a fixed point by means of a vertical spring. The block is oscillating simple harmonically and carries a charge q . There also exists a uniform electric field in the region. Consider four different cases. The electric field is zero, in case-1, $\frac{mg}{q}$ downward in case-2, $\frac{mg}{q}$ upward in case-3 and $\frac{2mg}{q}$ downward in case-4.

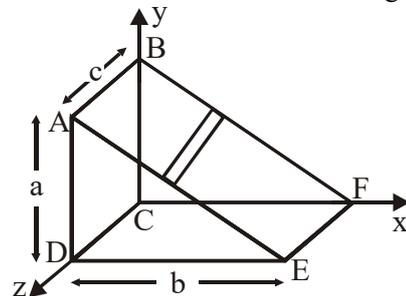
The speed at mean position is same in all cases. Select the correct alternative(s).



- (A) Time periods of oscillation are equal in case-1 and case-3
 - (B) Amplitudes of displacement are same in case-2 and case-3
 - (C) The maximum elongation (increment in length from natural length) is maximum in case-4.
 - (D) Time periods of oscillation are equal in case-2 and case-4
19. In a region of space, the electric field $\vec{E} = E_0x\hat{i} + E_0y\hat{j}$. Consider an imaginary cubical volume of edge 'a' with its edges parallel to the axes of coordinates. Now,



- (A) the total electric flux through the faces 1 and 3 is E_0a^3
 - (B) the charge inside the cubical volume is $2\epsilon_0E_0a^3$
 - (C) the total electric flux through the faces 2 and 4 is $2E_0a^3$
 - (D) the charge inside the cubical volume is $\epsilon_0E_0a^3$
20. A long thin straight wire with linear charge density λ runs along axis of a thin hollow metal cylinder of radius R . The cylinder has a net linear charge density 2λ . Assume λ is positive. Mark correct options:
- (A) $\vec{E}(r > R) = \frac{3\lambda}{2\pi\epsilon_0} \frac{\hat{r}}{r}$
 - (B) $\vec{E}(r < R) = \frac{3\lambda}{2\pi\epsilon_0} \frac{\hat{r}}{r}$
 - (C) Linear charge density on inner surface of cylinder is $-\lambda$
 - (D) Linear charge density on outer surface of cylinder is 3λ
21. A uniform surface charge of density $2\epsilon_0$ in SI unit is distributed over x, y plane. We consider spherical gaussian surface of radius $5m$, and center at (a, b, c) then :
- (A) If $(a, b, c) = (2, 0, 0)$; $\phi = 50 \pi \text{ Nm}^2/\text{C}$
 - (B) If $(a, b, c) = (0, 4, 0)$; $\phi = 30 \pi \text{ Nm}^2/\text{C}$
 - (C) If $(a, b, c) = (0, 2, 6)$; $\phi = 0 \text{ Nm}^2/\text{C}$
 - (D) If $(a, b, c) = (4, 3, 0)$; $\phi = 50 \pi \text{ Nm}^2/\text{C}$
22. In the given hypothetical electric field $\vec{E} = [(d+x)\hat{i} - E_0\hat{j}] \text{ N/C}$, a hypothetical closed surface is taken as shown in figure :



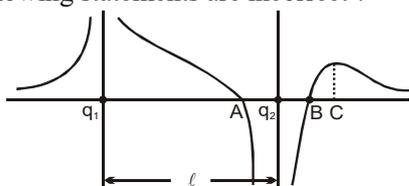
- (A) Net flux through plane ABCD is $-acd$ unit.
- (B) Net flux through plane CDEF is bcE_0 unit.
- (C) Net flux through plane ABEF is $\left[-bcE_0 + acd + \frac{acb}{2}\right]$ unit.
- (D) Net charge enclosed by the closed surface is $abc\epsilon_0$ unit.

23. Two point charges Q and $-\frac{Q}{4}$ are separated by a distance L as shown in figure, then



- (A) Potential is zero at a point on the axis which is $L/3$ on the right side of charge $-\frac{Q}{4}$
- (B) Potential is zero at a point on the axis which is at a distance $L/5$ on the left side of charge $-\frac{Q}{4}$
- (C) Electric field is zero at a point on the axis which is at a distance L on the right side of charge $-\frac{Q}{4}$
- (D) There exist two points on the axis, where electric field is zero

24. The curve represents distribution of potential along a line joining two charges q_1 and q_2 (separated by distance ℓ) then which of the following statements are incorrect ?



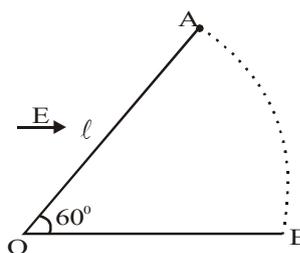
- (A) $|q_1| < |q_2|$
- (B) q_1 is negative in nature
- (C) A and B are equilibrium points
- (D) C is point of unstable equilibrium
25. Two infinite, parallel, nonconducting sheets carry equal positive charge density σ . One is placed in the y - z plane at $x = 0$ and the other at distance $x = a$. Take potential $V = 0$ at $x = 0$. If V_x is the potential at a distance x from y - z plane, then

- (A) For $0 \leq x \leq a$, potential $V_x = 0$
- (B) For $x \geq a$, potential $V_x = \frac{\sigma}{\epsilon_0}(x - a)$
- (C) For $x \geq a$, potential $V_x = -\frac{\sigma}{\epsilon_0}(x - a)$
- (D) For $x \leq 0$, potential $V_x = \frac{\sigma}{\epsilon_0}x$

26. Small identical balls with equal charges are fixed at the vertices of a regular polygon of N sides, each of length d . At a certain instant, one of the balls is released. After a long time interval, the adjacent ball to the previous one is released. The difference in kinetic energies of the two released ball is K at a sufficiently long distance from the polygon.

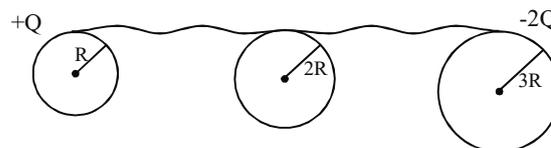
- (A) Final kinetic energy of the first ball is greater than that of the second ball.
- (B) Final kinetic energy of the second ball is greater than that of the first ball.
- (C) Charge on each ball is $\sqrt{2\pi\epsilon_0 dK}$
- (D) Charge on each ball is $\sqrt{4\pi\epsilon_0 dK}$

27. A particle of mass m and charge q is fastened to one end of a string fixed at point O. The whole system lies on a frictionless horizontal plane. Initially, the mass is at rest at A. A uniform electric field in the direction shown is then switched on. Then



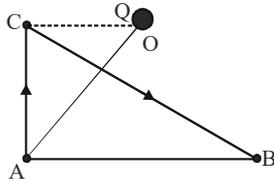
- (A) the speed of the particle when it reaches B is $\sqrt{\frac{2qE\ell}{m}}$
- (B) the speed of the particle when it reaches B is $\sqrt{\frac{qE\ell}{m}}$
- (C) the tension in the string when particles reaches at B is $2qE$
- (D) the tension in the string when the particle reaches at B is qE

28. Two conducting spheres of radii R and $3R$ carry charges Q and $-2Q$. Between these spheres a neutral conducting sphere of radius $2R$ is connected. The separation between the sphere is considerably large then



- (A) The final charge on initially neutral conducting sphere is $-\frac{Q}{3}$
- (B) The decrease in electric potential energy of sphere of radius R is $\frac{35KQ^2}{72R}$
- (C) The decrease in electric potential energy of sphere of radius R is $\frac{37KQ^2}{72R}$
- (D) The final electric potential of sphere of radius $3R$ will be $-\frac{KQ}{6R}$

29. There is a fixed positive charge Q at O and A and B are points equidistant from O . A positive charge $+q$ is taken slowly by an external agent from A to B long the line AC and then along the line CB .



- (A) The total work done on the charge is zero
 (B) The work done by the electrostatic force from A to C is negative
 (C) The work done by the electrostatic force from C to B is positive
 (D) The work done by electrostatic force in taking the charge from A to B is dependent on the actual path followed.

30. Four identical particles each having mass m and charge q are placed at the vertices of a square of side ℓ . All the particles are free to move without any friction and released simultaneously from rest. Then

- (A) At all instants, the particles remains at vertices of square whose edge length is changing
 (B) The configuration is changing (not remaining square) as the time passes
 (C) The speed of the particles when one of the particles get displaced by $\frac{\ell}{\sqrt{2}}$ is

$$\sqrt{\frac{q^2}{8\pi\epsilon_0 m \ell} \left(2 + \frac{1}{\sqrt{2}}\right)}$$

- (D) Speed of the particles can not be found

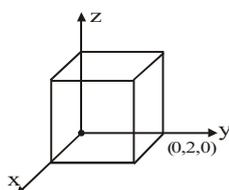
31. Charge 20C moves from A to B . Work done by electric force is 100 J . Choose the correct statement

- (A) $V_B - V_A = -5\text{ Volt}$
 (B) $V_B - V_A = 5\text{ Volt}$
 (C) work done by electric force to move -10 C charge from B to A will be -50 J
 (D) work done by electric force to move -10 C charge from B to A will be 50 J

Question | **Passage Based Type Questions**

Passage # 1 (Q. 32 to Q.34)

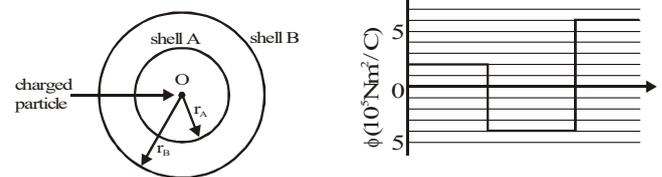
Electric field in a region is given by following equation $\vec{E} = \frac{K(\vec{r} - \vec{r}_0)}{|\vec{r} - \vec{r}_0|^2}$ where $\vec{r} = x\hat{i} + y\hat{j}$ and $\vec{r}_0 = \hat{i} + \hat{j}$ and an imaginary cube is made as shown in the diagram.



32. Find total flux through this cube due to the given electric field.
 (A) $4\pi K$ (B) $6\pi K$ (C) $16K$ (D) $8K$
33. Find total charge enclosed in this imaginary shown cube.
 (A) $4K\pi\epsilon_0$ (B) $8K\pi\epsilon_0$ (C) $6K\pi\epsilon_0$ (D) $2K\pi\epsilon_0$
34. If then find the value of total flux through the walls $\vec{r}_0 = (2\hat{i} + 2\hat{j})$ of the shown cube
 (A) $2K\pi$ (B) $K\pi$ (C) $4K\pi$ (D) $4K$

Passage # 2 (Q. 35 to Q.37)

A charged particle is suspended at the centre of two thin concentric spherical charged shells, made of non conducting material. Figure A shows cross section of the arrangement. Figure B gives the net flux ϕ through a Gaussian sphere centered on the particle, as a function of the radius r of the sphere.



35. What is the charge on the central particle ?
 (A) $0.2\ \mu\text{C}$ (B) $2\ \mu\text{C}$
 (C) $1.77\ \mu\text{C}$ (D) $3.4\ \mu\text{C}$
36. What is the charge on shell A?
 (A) $5.31 \times 10^{-6}\text{C}$ (B) $-5.31 \times 10^{-6}\text{C}$
 (C) $-3.54 \times 10^{-6}\text{C}$ (D) $-1.77 \times 10^{-6}\text{C}$
37. In which range of the values of r is the electric field zero ?
 (A) 0 to r_A
 (B) r_A to r_B
 (C) for $r > r_B$
 (D) for no range of r , electric field is zero.

Passage # 3 (Q. 38 to Q.40)

A sphere of radius R has total charge Q . If a sphere has volumetric charge distribution as a function of radial distance r the electric field is considered to be radial. Consider a charge density that decreases linearly from ρ_0 at the centre to zero at the surface of sphere

$$\rho = \rho_0 \left(1 - \frac{r}{R}\right)$$

38. Electric field inside sphere is given by
 (A) $\frac{Qr}{8\pi\epsilon_0 R^3} \left[\frac{2}{3} - \frac{2r}{3R}\right]$ (B) $\frac{Qr}{2\pi\epsilon_0 R^3} \left(2 - \frac{r}{3R}\right)$
 (C) $\frac{Qr}{4\pi\epsilon_0 R^3} \left(4 - 3\frac{r}{R}\right)$ (D) $\frac{Qr}{8\pi\epsilon_0 R^3} \left(2 - \frac{3r}{2R}\right)$
39. What is E_{max} :
 (A) $\frac{Q}{2\pi\epsilon_0 R^2}$ (B) $\frac{Q}{4\pi\epsilon_0 R^2}$
 (C) $\frac{Q}{3\pi\epsilon_0 R^2}$ (D) $\frac{4}{3} \frac{Q}{4\pi\epsilon_0 R^2}$

40. What is expression for the volume charge density $\rho(r)$ inside the ball as a function of r :-
 (A) $\frac{3Q}{4\pi} \frac{r^3}{Q^6}$ (B) $\frac{4Q}{3\pi} \frac{r^3}{R^6}$ (C) $\frac{2Q}{3\pi} \frac{r^3}{R^6}$ (D) $\frac{3Q}{2\pi} \frac{r^3}{R^6}$

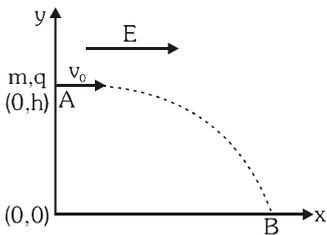
Passage # 4 (Q. 41 to Q.43)

The electric potential varies in space according to the relation $V = (3x+4y +5)$ volts where x and y are in meters. A particle of mass 10 g starts from point (2m, 3.2 m, 0) under the influence of this field. The charge on the particle is $10 \mu\text{C}$.

41. The component of electric field in X-direction is
 (A) 3 Vm^{-1} (B) 4 Vm^{-1}
 (C) 5 Vm^{-1} (D) 7 Vm^{-1}
42. The component of electric field in Y-direction is
 (A) 3 Vm^{-1} (B) 4 Vm^{-1}
 (C) 5 Vm^{-1} (D) 7 Vm^{-1}
43. The time taken to cross x-axis is
 (A) 4 s (B) 40 s
 (C) 400 s (D) 4000 s

Passage # 5 (Q. 44 to Q.46)

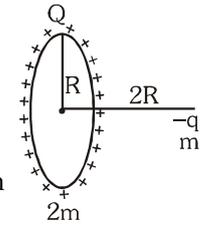
A particle of mass m and positive charge 'q' is projected horizontally from height 'h' with velocity v_0 as shown in figure. A uniform electric field is acting in +ve x-direction. When the particle reaches at points B then find out



44. Time taken by the particle to reaches at point B
 (A) $v_0 \sqrt{\frac{qE}{m}}$ (B) $\sqrt{\frac{2h}{g}}$ (C) $v_0 \sqrt{\frac{m}{qE}}$ (D) $\sqrt{\frac{h}{2g}}$
45. The x-coordinate of point B
 (A) $v_0 \sqrt{\frac{2h}{g}}$ (B) $\frac{qE}{m} \left(\frac{2h}{g} \right)$
 (C) $v_0 \sqrt{\frac{2h}{g}} + \frac{qEh}{2mg}$ (D) $v_0 \sqrt{\frac{2h}{g}} + \left(\frac{qEh}{mg} \right)$
46. Work done by electric field
 (A) $qE \left(v_0 \sqrt{\frac{2h}{g}} + \frac{qEh}{mg} \right)$
 (B) $qE \left(v_0 \sqrt{\frac{h}{g}} + \frac{2qEh}{mg} \right)$
 (C) $qE \left(v_0 \sqrt{\frac{h}{2g}} + \frac{2qEh}{mg} \right)$
 (D) $qE \left(v_0 \sqrt{\frac{h}{g}} + \frac{qEh}{2mg} \right)$

Passage # 6 (Q. 47 to Q.48)

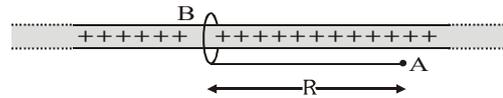
A ring having radius R , charge Q & mass $2m$. Ring is non-conducting and charge is uniformly distributed. A point charge $(-q)$ having mass m is placed at a distance $2R$ as shown in figure.



47. Find maximum velocity of negative charge $(-q)$
 (A) $2 \sqrt{\frac{KQq}{3Rm} \left(1 - \frac{1}{\sqrt{5}} \right)}$ (B) $\sqrt{\frac{KQq}{3Rm} \left(1 + \frac{1}{\sqrt{5}} \right)}$
 (C) $\sqrt{\frac{2KQq}{3Rm} \left(1 - \frac{1}{\sqrt{5}} \right)}$ (D) $\sqrt{\frac{2KQq}{3Rm} \left(1 + \frac{1}{\sqrt{5}} \right)}$
48. After some time distance between ring & point charge becomes R . At that time velocity of ring is v_1 & point charge is v_2 . Find $\frac{v_1}{v_2}$.
 (A) $\frac{2}{1}$ (B) $\frac{1}{2}$
 (C) $\frac{1}{1}$ (D) None of these

Passage # 7 (Q. 49 to Q.51)

Figure shows a very long smooth non conducting rod of radius r , charged with uniform charge density λ , fixed horizontally.



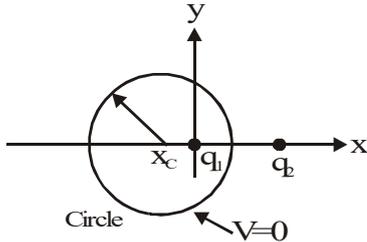
A neutral and smooth ring B of mass M can slide freely on the rod which happens to just fit in it. A is a nonconducting particle having mass m and charge q , attached to the ring by means of a non-conducting and inextensible string of length R . If P is released from the position shown in figure then answer the following questions.

49. The loss in electrostatic potential energy when string becomes vertical, is:-
 (A) $\frac{q\lambda}{4\pi\epsilon_0} \ln \left(1 + \frac{R}{r} \right)$ (B) $\frac{q\lambda}{2\pi\epsilon_0} \ln \left(1 + \frac{R}{r} \right)$
 (C) $\frac{q\lambda}{2\pi\epsilon_0} \ln \left(1 - \frac{r}{R} \right)$ (D) $\frac{q\lambda}{2\pi\epsilon_0} \ln \left(1 + \frac{r}{R} \right)$
50. If $M = 2m$ and $R = 2r$ then the speed of particle when string becomes vertical, is:-
 (A) $\sqrt{\frac{2}{3} \left(2gR + \frac{q\lambda}{\pi\epsilon_0 m} \ln 3 \right)}$
 (B) $\frac{2}{3} \sqrt{\left(2gR + \frac{q\lambda}{\pi\epsilon_0 m} \ln 3 \right)}$
 (C) $\sqrt{\left(2gR + \frac{q\lambda}{2\pi\epsilon_0 m} \ln 3 \right)}$
 (D) None of these

51. If $M = 2m$ and $R = 2r$ then the tension in the string when the string is vertical, is:-
- (A) $3mg + \frac{q\lambda}{6\pi\epsilon_0 r} [2 + 3\ln 3]$
- (B) $mg + \frac{q\lambda}{12\pi\epsilon_0 r} [2 + 3\ln 3]$
- (C) $4mg + \frac{q\lambda}{12\pi\epsilon_0 r} [2 + 9\ln 3]$
- (D) None of these

Passage # 8 (Q. 52 to Q.54)

A point charge $q_1 = +6e$ fixed at the origin of a coordinate system and another point charge $q_2 = -10e$ is fixed at $x = 8\text{nm}$, $y = 0$. The locus of all points in the xy plane for which potential $V = 0$ (other than infinity) is a circle centered on the x -axis, as shown.



52. Radius R of the circle is :
- (A) 3 nm (B) 6 nm
(C) 7.5 nm (D) 9 nm
53. x -coordinate of the centre of the circle is:
- (A) -2 nm (B) -3 nm
(C) -4.5 nm (D) -7.5 nm
54. The potential at the centre of the circle is :-
- (A) 0.32 V (B) 0.77 V
(C) 1.2 V (D) -1.2 V

Passage # 9 (Q. 55 to Q.57)

The potential energy at a point, relative to the reference point is defined as the negative of work done by the conservative force as the object moves from the reference point to the point considered. The value of potential energy at the reference point itself can be set equal to zero because we are always concerned only with differences of potential energy between two points and the associated change of kinetic energy. A particle A is fixed at origin of a fixed coordinate system. Another particle B which is free to move

experiences an force $\vec{F} = \left(-\frac{2\alpha}{r^3} + \frac{\beta}{r^2} \right) \hat{r}$ due to particle

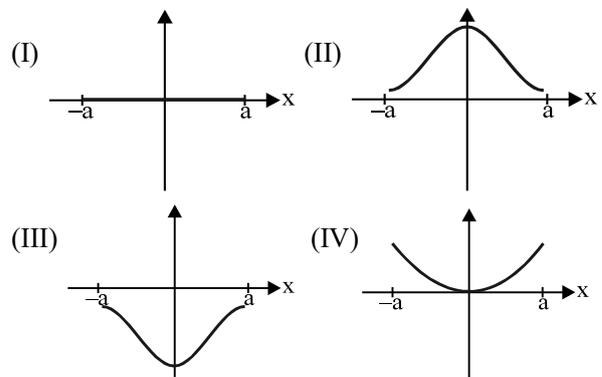
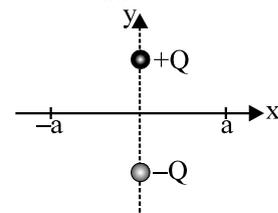
A where \vec{r} is the position vector of particle B relative to A. It is given that the force is conservative in nature and potential energy at infinity is zero. If B has to be removed from the influence of A, energy has to be supplied for such a process. The ionization energy E_0 is work that has to be done by an external agent to move the particle from a distance r_0 to infinity slowly. Here r_0 is the equilibrium position of the particle.

55. What is potential energy function of particle as function of r .
- (A) $\frac{\alpha}{r^2} - \frac{\beta}{r}$ (B) $-\frac{\alpha}{r^2} + \frac{\beta}{r}$ (C) $-\frac{\alpha}{r^2} - \frac{\beta}{r}$ (D) $\frac{\alpha}{r^2} + \frac{\beta}{r}$

56. Find the ionization energy E_0 of the particle B.
- (A) $\frac{\beta^2}{2\alpha}$ (B) $\frac{2\beta^2}{\alpha}$ (C) $\frac{\beta^2}{4\alpha}$ (D) $\frac{\beta^2}{\alpha}$
57. If particle B is transferred slowly from point $P_1(\sqrt{2}r_0, \sqrt{2}r_0)$ to point $P_2\left(\frac{r_0}{\sqrt{2}}, \frac{r_0}{\sqrt{2}}\right)$ in the xy - plane by an external agent, calculate work required to be done by it in the process.
- (A) $\frac{9\beta^2}{64\alpha}$ (B) $\frac{\beta^2}{16\alpha}$
(C) $\frac{\beta^2}{64\alpha}$ (D) None of these

Passage # 10 (Q. 58 to Q.60)

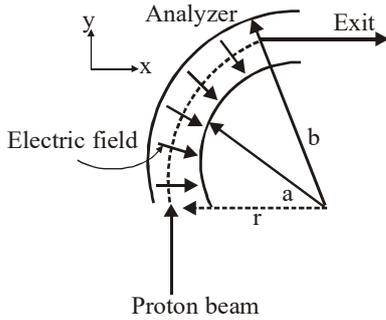
The figure shows a pair of equal but opposite charges. The figure shows a pair of equal but opposite charges. The point charges are fixed in the positions shown on the y axis; the positive charge $+Q$ is located at the point $(0, a)$ and the negative charge $-Q$ is located at the point $(0, -a)$. **Question 58 to 60** relate to the graphs labeled (I) to (IV) that appear below.



58. Which graph best depicts the electric field magnitude along the x axis, from $x = -a$ to $x = a$?
- (A) I (B) II (C) III (D) IV
59. Which graph best illustrates the electric potential along the x axis, from $x = -a$ to $x = a$?
- (A) I (B) II (C) III (D) IV
60. If a negative charge, $-q$, were moved along the x axis from $x = -a$ to $x = a$, which graph best depicts the magnitude of the electric force it would experience during this motion?
- (A) I (B) II (C) III (D) IV

Passage # 11 (Q. 61 to Q.63)

Figure shows a schematic view of an electrostatic analyzer. It can sort out charged particles by speed and charge to mass ratio. Spacecraft uses such analyzers to characterize charged particles in interplanetary space. Two curved metal plates establish an electric field given by $E=E_0(b/r)$ where E_0 and b are positive constants. The field points towards the centre of curvature and r is distance from centre. There is no influence of gravity. Proton (charge $+e$; mass ‘ m ’) enters along y -axis and exits along x -axis while moving along a circular path.



61. Speed with which proton is to be projected is v and centripetal acceleration of electron is a_c is given by respectively. Mark the correct statement

- (A) $v = \sqrt{\frac{eE_0b}{m}}$; $a_c = \frac{2e}{m} E_0 \left(\frac{b}{r}\right)$
- (B) $v = \sqrt{\frac{2eE_0b}{m}}$; $a_c = \frac{e}{2m} E_0 \left(\frac{b}{r}\right)$
- (C) $v = \sqrt{\frac{eE_0b}{2m}}$; $a_c = \frac{2e}{m} E_0 \left(\frac{b}{r}\right)$
- (D) $v = \sqrt{\frac{eE_0b}{m}}$; $a_c = \frac{e}{m} E_0 \left(\frac{b}{r}\right)$

62. Mark the INCORRECT option

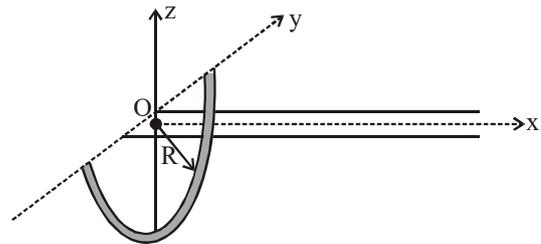
- (A) Work done by electric field on proton is zero.
- (B) If $v = \sqrt{\frac{2eE_0b}{m}}$ proton may strike outer surface of analyzer.
- (C) If $v = \sqrt{\frac{2eE_0b}{m}}$ proton may strike inner surface of analyzer.
- (D) If an electron is released with zero initial velocity from inner surface of analyzer, it will strike outer surface with velocity $v = \sqrt{\frac{2eE_0b}{m_e}} \ln\left(\frac{b}{a}\right)$, where m_e is mass of electron.

63. Mark the correct option

- (A) If E_0 is made larger, then in order to maintain same trajectory initial speed has to be decreased.
- (B) If proton enters closer to the inner surface it will require smaller speed to follow circular trajectory.
- (C) It does not matter where the protons enter the device it requires same speed to follow circular trajectory.
- (D) A deuteron (charge $+e$, mass $2m$) will require greater speed as compared to proton to follow circular trajectory

Passage # 12 (Q. 64 to Q.65)

There is a fixed semicircular ring of radius R lying in y - z plane, with centre of arc at origin and it is uniformly charged with charge $+Q$. There is an insulated long hollow smooth pipe of very small radius fixed along x -axis from origin O as shown in figure. A small ball with charge $+q$ and mass m is projected from O in pipe with negligible velocity, ball can smoothly move in pipe. Whole arrangement lies in gravity free space.



64. The maximum acceleration of ball in pipe is :

- (A) $\frac{1}{4\pi\epsilon_0} \frac{Qq}{mR^2}$
- (B) $\frac{1}{12\sqrt{3}\pi\epsilon_0} \frac{Qq}{mR^2}$
- (C) $\frac{1}{6\sqrt{3}\pi\epsilon_0} \frac{Qq}{mR^2}$
- (D) None of these

65. The kinetic energy of particle when its acceleration is maximum is

- (A) $\frac{1}{4\pi\epsilon_0} \frac{Qq}{R} \left(1 - \sqrt{\frac{2}{3}}\right)$
- (B) $\frac{1}{4\pi\epsilon_0} \frac{Qq}{R} \left(\frac{1}{2}\right)$
- (C) $\frac{1}{4\pi\epsilon_0} \frac{Qq}{R} \left(\frac{1}{\sqrt{2}}\right)$
- (D) None of these

EXERCISE # 3

Question Column Match Type Questions

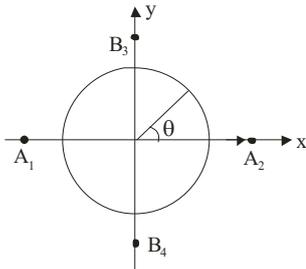
1. Column-I

- (A) If charges Q_1 and Q_2 are positive, then stable equilibrium will exist if a charge
- (B) If charge Q_1 and Q_2 are of opposite sign then stable equilibrium will occur... if Q_1 is negative
- (C) If charge Q_1 and Q_2 are of opposite sign then stable equilibrium will occur... if Q_1 is positive
- (D) If $Q_1 = 4Q_2$ and a charge q is placed between Q_1

Column-II

- (P) $-q$ is placed some where on the line joining Q_1, Q_2
- (Q) to the right of Q_2
- (R) to the left of Q_1
- (S) $q = -\frac{4}{9}Q$

2. A circular non-conducting ring has charge density $\lambda = \lambda_0 \sin\theta$ as shown in figure.



Column I (Point)

- (A) A_1
- (B) A_2
- (C) B_3
- (D) B_4

Column II (Direction of electric field)

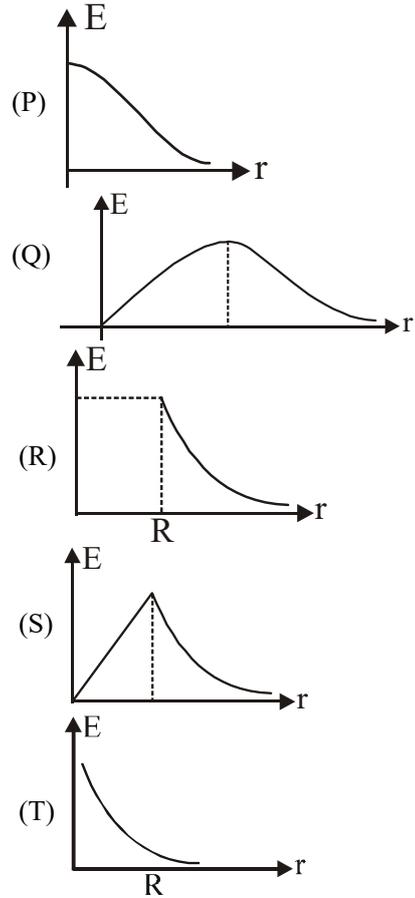
- (P) Positive x-direction
- (Q) Negative x-direction
- (R) Positive y-direction
- (S) Negative y-direction
- (T) Positive z-direction

3. Column II corresponds to the graph of magnitude of electric field versus distance from centre of charge distribution in Column I.

Column I

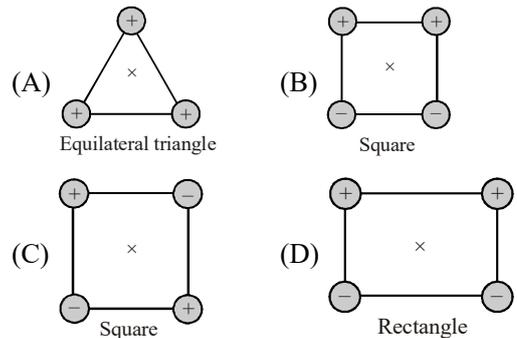
- (A) Ring along its axis
- (B) Uniformly charged solid sphere
- (C) Uniformly charged spherical shell
- (D) Combination of charge $+Q$ and $-Q$ at the perpendicular bisector

Column II



4. In the following diagrams, all the charges have equal magnitude

Column-I

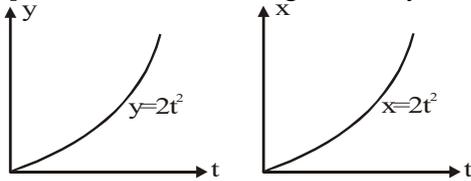


Column-II

- (P) The potential is zero at the centre
- (Q) The electric field is zero at the centre
- (R) The electric field at a point on the axis passing through the centre perpendicular to the plane of the figure is along the axis.
- (S) The electric field at a point on the axis passing through the centre perpendicular to the plane of the figure is perpendicular to the axis.
- (T) The potential energy of the system is negative.

5. A particle of mass & charge 1 unit each is moving in x-y plane having a uniform gravitational and electric field. The variation of y and x coordinates with time is as shown. Particle is released from the origin.

[Take SI units, consider $g = 10$ in $-y$ direction]



Column I

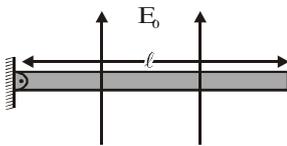
- (A) Speed of particle at $t=1$.
- (B) Magnitude of slope of equipotential surface
- (C) Magnitude of potential difference between points $(0,0)$ & $(2,0)$
- (D) Magnitude of slope of $vy-t$ graph in case of zero gravity.

Column II

- (P) $2/7$
- (Q) $4\sqrt{2}$
- (R) 14
- (S) 8

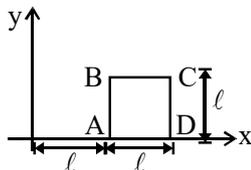
Question Numerical Type Questions

6. A thin insulating rod is hinged about one of its ends. It can rotate on a smooth horizontal surface.



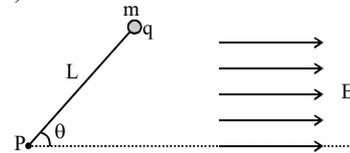
The charge density on the rod is defined as $\lambda = 15x^2$, $0 < x \leq \frac{l}{2} = -bx^n$, $\frac{l}{2} < x \leq l$ where b is a positive constant. An electric field E_0 in the horizontal direction and perpendicular to the rod is switched on. Find the value of $(b+n)^2$, if the rod has to remain stationary.

7. A square loop of side ' l ' having uniform linear charge density λ is placed in xy plane as shown in the figure.

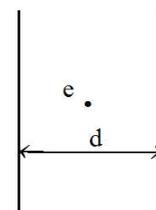


There is a non uniform electric field $\vec{E} = \frac{a}{\ell}(x + \ell)\hat{i}$ where a and ℓ are constants. The resultant electric force on the loop is having value $2na\lambda\ell$. Find value of n .

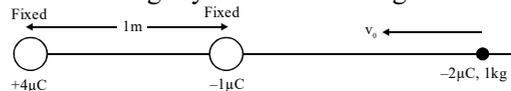
8. A particle having charge $q = +2.00 \mu\text{C}$ and mass $m = 0.0100 \text{ kg}$ is connected to a string having length $L = 1.50 \text{ m}$ and is tied to the pivot point P in the figure. The particle, string, and pivot point all lie on a frictionless horizontal table. The particle is released from rest when the string makes an angle $\theta = 60^\circ$ with a uniform electric field of magnitude $E = 300 \text{ V/m}$. The speed (in m/s) of the particle when the string is parallel to the electric field (shown in figure) is x then $10x$ is.



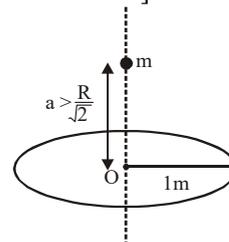
9. Two infinite rods with linear charge density $+\lambda$ are kept apart by distance d . An electron of mass ' m ', charge ' e ' is kept at the midpoint between the two rod. On being given slight vertical displacement (in the plane perpendicular to the plane of rods), the time period of this oscillatory motion is $2\pi\sqrt{\frac{\pi\epsilon_0 md^2}{x\lambda e}}$. Then x will be.



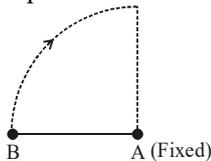
10. A negative charge $q = -2\mu\text{C}$ is projected from a large distance towards $-1\mu\text{C}$. Find the minimum value of speed (in m/s) that can be given to the charge, so that it crosses the point at which electric field is zero due to the two fixed charge system shown in figure.



11. A particle of mass 100 g & charge $\frac{\sqrt{2}}{9} \mu\text{C}$ is placed on the vertical axis of a uniformly charged ring of radius 1m. This particle is executing S.H.M. of small amplitude with time period 2s, above the centre of the ring a shown in figure. Then find the total charge (in mC) on the ring [Take $\pi^2 = 10$]



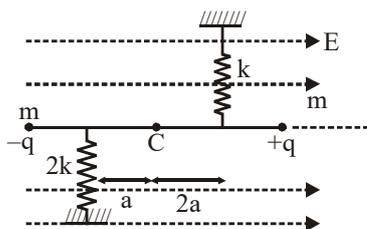
12. Two particles 'A' & 'B' having charge $\frac{1}{9}\mu\text{C}$ & $10\mu\text{C}$ respectively are connected through an inelastic & light string of length 1m. Particle 'A' is fixed and 'B' has mass $\frac{19}{3}$ kg. A vertical electric field 'E' is applied such that particle 'B' released from horizontal position with string remaining tight will move up and reaches to highest vertical position as shown in figure. When particle reaches the highest vertical position electric field is switch off but particle remains in circular motion all the time then find the least possible value of 'E' (in kN/C).



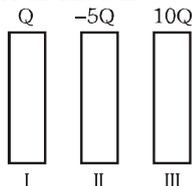
13. Two particles of mass 'm' each and having charge +q and -q respectively joined by a light rod of length 6a as shown in the figure. The whole system is kept on a horizontal frictionless surface and two spring are connected to the rod. Rod is hinged at centre and assume no energy loss takes place in form of electromagnetic wave during the motion of particles.

A uniform electric field exists in the region as shown in the figure in entire region. The rod is given a small angular displacement from equilibrium, then the frequency of small oscillation is f Hz. Find the value of 4f.

$$\left[\text{Given } m = \frac{k}{3\pi^2} \text{ kg \& } Eq = 8ka \right]$$

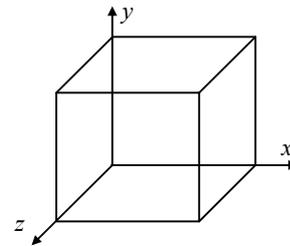


14. Three very large identical metal plates are given charges as shown.



The final charge on left surface of IInd plate is found to be NQ. Find out the value of N.

15. An electric field given by $\vec{E} = 4\tilde{i} - 3(y^2 + 2)\tilde{j}$ pierces Gaussian's cube of side 1m placed at origin such that its three sides represents x, y and z axes.

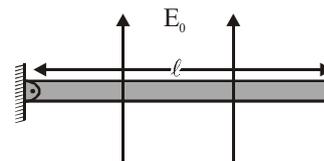


The net charge enclosed within the cube is given by $-n\epsilon_0$. Find the value of n.

16. A point charge +2e is placed on the top of a cone of semi vertex angle θ . The electric flux through the base of the cone is $\frac{\alpha e}{\epsilon_0} \left(\sin \frac{\theta}{\beta} \right)^\gamma$.

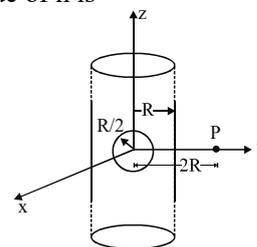
Determine the value of $(\alpha + \beta + \gamma)$.

17. A thin insulating uniformly charged (linearly charged density λ) rod is hinged about one of its ends. It can rotate in vertical plane. If rod is in equilibrium by applying vertical electric field E as shown in figure. Find the value of E (in N/C). (Given that mass of rod 2 kg, $\lambda = 10$ C/m, $\ell = 1$ m, $g = 10$ m/s²)

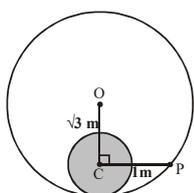


18. An infinitely long solid cylinder of radius R has a uniform volume charge density ρ . It has a spherical cavity of radius R/2 with its centre on the axis of the cylinder, as shown in the figure. The magnitude of the electric field at the point P, which is at a distance 2R from the axis of the cylinder, is given by the expression $\frac{23\rho R}{16n\epsilon_0}$.

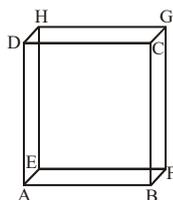
The value of n is



19. A uniformly charged sphere is placed inside a charged hollow sphere as shown in figure. O is the centre of hollow sphere and C is the centre of solid sphere. The magnitude of charge on both the spheres is $4\left(\sqrt{\frac{3}{7}}\right)\mu$. The electric field at point 'P' which lie just outside the hollow sphere is given by 3α kN/C. Find the value of α .

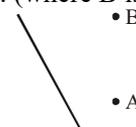


20. A charge Q is kept on the diagonal EC of the cube kept very close to E . The flux passing through surface $EFBA$ of the cube is given by $\frac{nQ}{24\epsilon_0}$. Find 'n'.

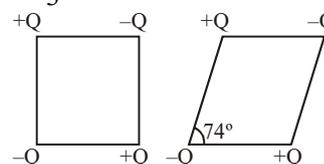


21. A negative charge particle is revolving around a fixed positive charge particle in an elliptical orbit. Minimum & maximum distance of $-ve$ charge particle from $+ve$ charge particle are r & $2r$ respectively. If maximum kinetic energy of $-ve$ charge particle is $4J$. Find the work done by electric force during motion of $-ve$ charge particle from B to A in joule.
22. A point charge exist at origin. If potential of point charge A & B separated by radial distance 2 m having potentials $2V$ & $1V$ respectively, what is the magnitude of \vec{E} (in volt/m) at point A . (A & B lies in same quadrant).
23. A particle of mass m carrying charge ' q ' is projected with velocity v from point P towards an infinite line charge from a distance ' a '. Its speed reduces to zero momentarily at point Q which is at a distance $a/2$ from the line charge. If another particle with mass m and charge $-q$ is projected with the same velocity v from point P towards the line charge. Its speed is found to be $\frac{Nv}{\sqrt{2}}$ at point Q . Find the value of N .
24. A nonconducting disc of radius R and uniform positive surface charge density σ is placed on the ground with its axis vertical. A particle of specific charge $\frac{q}{m} = \frac{4\epsilon_0 g}{\sigma}$ is dropped along the axis of the disc from a height h . The value of h if the particle just reaches the disc is $\left(2\sqrt{\frac{R}{3}}\right)^n$. Determine the value of n .

25. An infinite plane of charge with $\sigma = 2\epsilon_0 \frac{C}{m^2}$ is tilted at a 37° angle to the vertical direction as shown below. Find the potential difference, $V_A - V_B$ in volts, between points A and B at 5 m distance apart. (where B is vertically above A).



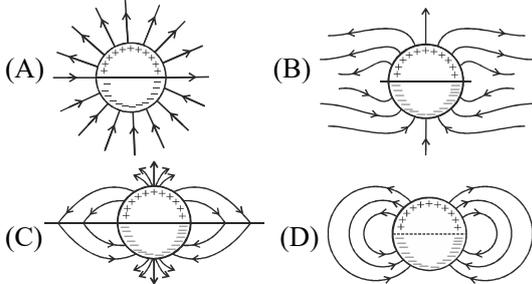
26. Three charges 0.1 coulomb each are placed on the corners of an equilateral triangle of side 1 m . If the energy is supplied to this system at the rate of 10 kW , how much time (in hour) would be required to move one of the charges onto the midpoint of the line joining the other two?
27. A particle is uncharged and is thrown vertically upward from ground level with a speed of $5\sqrt{5}\text{ m/s}$. As a result, it attains a maximum height h . The particle is then given a positive charge $+q$ and reaches the same maximum height h when thrown vertically upward with a speed of 13 m/s . Finally, the particle is given a negative charge $-q$. Ignoring air resistance, determine the speed (in m/s) with which the negatively charged particle must be thrown vertically upward, so that it attains exactly the same maximum height h .
28. A circular ring of radius a with uniform charge density λ is in the xy plane with centre at origin. A particle of mass m and charge q is projected from $P(0, 0, \sqrt{3})$ on $+z$ -axis towards origin with initial velocity u . The minimum value of the velocity so that the particle does not return to P is $\sqrt{\frac{\lambda q}{x\epsilon_0 m}}$. Find 'x'.
29. The radius and surface tension of a spherical soap bubble be r and T respectively. A charge is to be given to the bubble so that its radius will become $2r$. Here atmospheric pressure is P_0 , temperature of air inside bubble remains constant & charge is assumed to uniformly distributed on the surface of bubble. The final surface charge density is $\alpha \times 10^{-4}\text{ C/m}^2$. Find value of 2α . (Take : $P_0 = 10^4\text{ Pa}$, $T = 0.2\text{ N/m}$, $r = 0.12\text{ mm}$, $\epsilon_0 = 9 \times 10^{-12}\text{ C}^2/\text{Nm}^2$).
30. Two positive and two negative point charges ($|Q| = 0.01\text{ }\mu\text{C}$) are placed at the corners of a square insulator frame of side 5 m and the side of the frame are hinged together. The frame is deformed into a rhombus as shown. The new potential at the centre is given by α volt. Find value of $\frac{\alpha}{3}$.



EXERCISE # 4

Question Previous Year (JEE Main)

1. A long cylindrical shell carries positive surface charge σ in the upper half and negative surface charge $-\sigma$ in the lower half. The electric field lines around the cylinder will look like figure given in ; (figures are schematic and not drawn to scale) **[JEE Main-2015]**



2. A uniformly charged solid sphere of radius R has potential V_0 (measured with respect to ∞) on its surface. For this sphere the equipotential surfaces with potentials $\frac{3V_0}{2}, \frac{5V_0}{4}, \frac{3V_0}{4}$ and

$\frac{V_0}{4}$ have radius R_1, R_2, R_3 and R_4

respectively. Then **[JEE Main - 2015]**

- (A) $R_1 \neq 1$ and $(R_2 - R_1) > (R_4 - R_3)$
 (B) $R_1 = 0$ and $R_2 < (R_4 - R_3)$
 (C) $2R < R_4$
 (D) $R_1 = 0$ and $R_2 > (R_4 - R_3)$

3. The region between two concentric spheres of radii 'a' and 'b', respectively (see figure), has volume charge density $\rho = \frac{A}{r}$, where A is a

constant and r is the distance from the centre. At the centre of the spheres is a point charge Q. The value of A such that the electric field in the region between the spheres will be constant, is : **[JEE Main - 2016]**

- (A) $\frac{Q}{2\pi(b^2 - a^2)}$ (B) $\frac{2Q}{\pi(a^2 - b^2)}$
 (C) $\frac{2Q}{\pi a^2}$ (D) $\frac{Q}{2\pi a^2}$

4. An electric dipole has a fixed dipole moment \vec{p} , which makes angle θ with respect to x-axis, When subjected to an electric field $\vec{E}_1 = E_1 \hat{i}$, it experiences a torque $\vec{T}_1 = \tau \hat{k}$. When subjected to another electric field $\vec{E}_2 = \sqrt{3}E_1 \hat{j}$ it experiences a torque $\vec{T}_2 = -\vec{T}_1$. The angle θ is :

- [JEE Main - 2017]**
 (A) 30° (B) 45° (C) 60° (D) 90°

5. Three concentric metal shells A, B and C of respective radii a, b and c ($a < b < c$) have surface charge densities $+\sigma, -\sigma$ and $+\sigma$ respectively. The potential of shell B is:

[JEE Main - 2018]

- (A) $\frac{\sigma}{\epsilon_0} \left[\frac{b^2 - c^2}{b} + a \right]$ (B) $\frac{\sigma}{\epsilon_0} \left[\frac{b^2 - c^2}{c} + a \right]$
 (C) $\frac{\sigma}{\epsilon_0} \left[\frac{a^2 - b^2}{a} + c \right]$ (D) $\frac{\sigma}{\epsilon_0} \left[\frac{a^2 - b^2}{b} + c \right]$

6. Three charges $+Q, q, +Q$ are placed respectively, at distance, 0, $d/2$ and d from the origin, on the x-axis. If the net force experienced by $+Q$, placed at $x = 0$, is zero, then value of q is : **[JEE Main - 2019]**

- (A) $+Q/2$ (B) $-Q/2$ (C) $-Q/4$ (D) $+Q/4$

7. For a uniformly charged ring of radius R, the electric field on its axis has the largest magnitude at a distance h from its centre. Then value of h is: **[JEE Main - 2019]**

- (A) $R/\sqrt{5}$ (B) R
 (C) $R/\sqrt{2}$ (D) $R\sqrt{2}$

8. Two point charges $q_1(\sqrt{10} \mu\text{C})$ and $q_2(-25 \mu\text{C})$ are placed on the x-axis at $x = 1$ m and $x = 4$ m respectively. The electric field (in V/m) at a point $y = 3$ m on y-axis is, **[JEE Main - 2019]**

[Take $\frac{1}{4\pi\epsilon_0} = 9 \times 10^9 \text{ Nm}^2\text{C}^{-2}$]

- (A) $(-63\hat{i} + 27\hat{j}) \times 10^2$ (B) $(81\hat{i} - 81\hat{j}) \times 10^2$
 (C) $(63\hat{i} - 27\hat{j}) \times 10^2$ (D) $(-81\hat{i} + 81\hat{j}) \times 10^2$

9. Charge is distributed within a sphere of radius R with a volume charge density $\rho(r) = \frac{A}{r^2} e^{-2r/a}$, where A and a are constants.

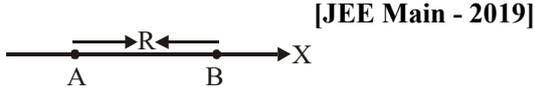
If Q is the total charge of this charge distribution, the radius R is : **[JEE Main - 2019]**

- (A) $\frac{a}{2} \log \left(1 - \frac{Q}{2\pi a A} \right)$ (B) $a \log \left(1 - \frac{Q}{2\pi a A} \right)$
 (C) $a \log \left(\frac{1}{1 - \frac{Q}{2\pi a A}} \right)$ (D) $\frac{a}{2} \log \left(\frac{1}{1 - \frac{Q}{2\pi a A}} \right)$

10. A charge Q is distributed over three concentric spherical shells of radii a, b, c ($a < b < c$) such that their surface charge densities are equal to one another. The total potential at a point at distance r from their common centre, where $r < a$, would be **[JEE Main - 2019]**

- (A) $\frac{Q}{4\pi\epsilon_0(a+b+c)}$ (B) $\frac{Q(a+b+c)}{4\pi\epsilon_0(a^2+b^2+c^2)}$
 (C) $\frac{Q}{12\pi\epsilon_0} \frac{ab+bc+ca}{abc}$ (D) $\frac{Q}{4\pi\epsilon_0} \frac{(a^2+b^2+c^2)}{(a^3+b^3+c^3)}$

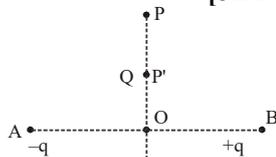
11. Two electric dipoles, A, B with respective dipole moments $\vec{d}_A = -4qa\hat{i}$ and $\vec{d}_B = -2qa\hat{i}$ placed on the x-axis with a separation R, as shown in the figure. The distance from A at which both of them produce the same potential is :



[JEE Main - 2019]

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

12. Charges $-q$ and $+q$ located at A and B, respectively, constitute an electric dipole. Distance $AB = 2a$, O is the mid point of the dipole and OP is perpendicular to AB. A charge Q is placed at P where $OP = y$ and $y \gg 2a$. The charge Q experiences an electrostatic force F. If Q is now moved along the equatorial line to P' such that $OP' = y/3$, the force on Q will be close to : ($y/3 \gg 2a$)



[JEE Main - 2019]

- (A) $F/3$ (B) $3F$ (C) $9F$ (D) $27F$

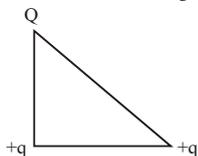
13. Four equal point charges Q each are placed in the xy plane at (0, 2), (4, 2), (4, -2) and (0, -2). The work required to put a fifth charge Q at the origin of the coordinate system will be :

[JEE Main - 2019]

- (A) $\frac{Q^2}{2\sqrt{2}\pi\epsilon_0}$ (B) $\frac{Q^2}{4\pi\epsilon_0} \left(1 + \frac{1}{\sqrt{5}}\right)$
 (C) $\frac{Q^2}{4\pi\epsilon_0} \left(1 + \frac{1}{\sqrt{3}}\right)$ (D) $\frac{Q^2}{4\pi\epsilon_0}$

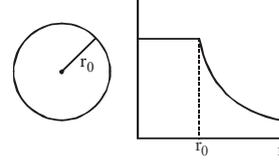
14. The charges $Q + q$ and $+q$ are placed at the vertices of a right-angle isosceles triangle as shown below. The net electrostatic energy of the configuration is zero, if the value of Q is :

[JEE Main - 2019]



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

15. The given graph shows variation (with distance r from centre) of : [JEE Main - 2019]



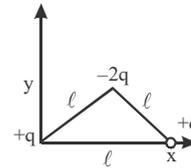
- (A) Potential of a uniformly charged sphere.
 (B) Potential of a uniformly charged spherical shell.
 (C) Electric field of uniformly charged spherical shell.
 (D) Electric field of uniformly charged sphere.

16. An electric field of 1000 V/m is applied to an electric dipole at angle of 45° . The value of electric dipole moment is 10^{-29} C.m. What is the potential energy of the electric dipole ?

[JEE Main 2019]

- (A) -9×10^{-20} J (B) -7×10^{-27} J
 (C) -10×10^{-29} J (D) -20×10^{-18} J

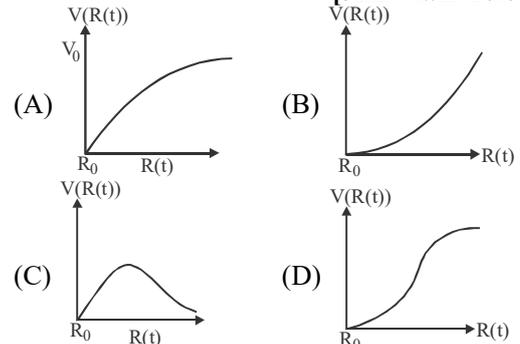
17. Determine the electric dipole moment of the system of three charges, placed on the vertices of an equilateral triangle, as shown in the figure: [JEE Main - 2019]



- (A) $(q\ell) \frac{\hat{i} + \hat{j}}{\sqrt{2}}$ (B) $\sqrt{3}q\ell \frac{\hat{j} - \hat{i}}{\sqrt{2}}$ (C) $-\sqrt{3}q\ell \hat{j}$ (D) $2q\ell \hat{j}$

18. There is a uniform spherically symmetric surface charge density at a distance R_0 from the origin. The charge distribution is initially at rest and starts expanding because of mutual repulsion. The figure that represents best the speed $V(R(t))$ of the distribution as a function of its instantaneous radius $R(t)$ is :

[JEE Main-2019]



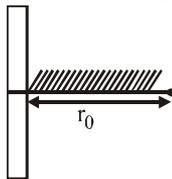
19. The bob of a simple pendulum has mass $2g$ and a charge of $5.0 \mu\text{C}$. It is at rest in a uniform horizontal electric field of intensity 2000 V/m . At equilibrium, the angle that the pendulum makes with the vertical is : (take $g = 10 \text{ m/s}^2$)
[JEE Main - 2019]
 (A) $\tan^{-1}(5.0)$ (B) $\tan^{-1}(2.0)$
 (C) $\tan^{-1}(0.5)$ (D) $\tan^{-1}(0.2)$

20. A solid conducting sphere, having a charge Q , is surrounded by an uncharged conducting hollow spherical shell. Let the potential difference between the surface of the solid sphere and that of the outer surface of the hollow shell be V . If the shell is now given a charge of $-4Q$, the new potential difference between the same two surfaces is:
[JEE Main - 2019]
 (A) V (B) $2V$ (C) $-2V$ (D) $4V$

21. An electric dipole is formed by two equal and opposite charges q with separation d . The charges have same mass m . It is kept in a uniform electric field E . If it is slightly rotated from its equilibrium orientation, then its angular frequency ω is:-
[JEE Main - 2019]
 (A) $\sqrt{\frac{qE}{2md}}$ (B) $2\sqrt{\frac{qE}{md}}$ (C) $\sqrt{\frac{2qE}{md}}$ (D) $\sqrt{\frac{qE}{md}}$

22. A positive point charge is released from rest at a distance r_0 from a positive line charge with uniform density. The speed (v) of the point charge, as a function of instantaneous distance r from line charge, is proportional to :

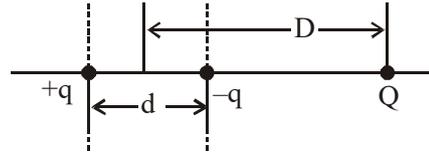
[JEE Main - 2019]



- (A) $v \propto e^{+r/r_0}$ (B) $v \propto \ln\left(\frac{r}{r_0}\right)$
 (C) $v \propto \left(\frac{r}{r_0}\right)$ (D) $v \propto \sqrt{\ln\left(\frac{r}{r_0}\right)}$

23. The electric field in a region is given by $\vec{E} = (Ax + B)\hat{i}$, where E is in NC^{-1} and x is in metres. The values of constants are $A = 20 \text{ SI unit}$ and $B = 10 \text{ SI unit}$. If the potential at $x = 1$ is V_1 and that at $x = -5$ is V_2 , then $V_1 - V_2$ is :
[JEE Main - 2019]
 (A) -48 V (B) -520 V (C) 180 V (D) 320 V

24. A system of three charges are placed as shown in the figure :



If $D \gg d$, the potential energy of the system is best given by : **[JEE Main - 2019]**

- (A) $\frac{1}{4\pi\epsilon_0} \left[-\frac{q^2}{d} - \frac{qQd}{2D^2} \right]$ (B) $\frac{1}{4\pi\epsilon_0} \left[+\frac{q^2}{d} + \frac{qQd}{D^2} \right]$
 (C) $\frac{1}{4\pi\epsilon_0} \left[-\frac{q^2}{d} + \frac{2qQd}{D^2} \right]$ (D) $\frac{1}{4\pi\epsilon_0} \left[-\frac{q^2}{d} - \frac{qQd}{D^2} \right]$

25. Four point charges $-q, +q, +q$ and $-q$ are placed on y -axis at $y = -2d, y = -d, y = +d$ and $y = +2d$, respectively. The magnitude of the electric field E at a point on the x -axis at $x = D$, with $D \gg d$, will behave as:
[JEE Main - 2019]
 (A) $E \propto 1/D$ (B) $E \propto 1/D^3$
 (C) $E \propto 1/D^2$ (D) $E \propto 1/D^4$

26. A uniformly charged ring of radius $3a$ and total charge q is placed in xy -plane centred at origin. A point charge q is moving towards the ring along the z -axis and has speed u at $z = 4a$. The minimum value of u such that it crosses the origin is : **[JEE Main - 2019]**

- (A) $\sqrt{\frac{2}{m} \left(\frac{1}{15} \frac{q^2}{4\pi\epsilon_0 a} \right)^{1/2}}$ (B) $\sqrt{\frac{2}{m} \left(\frac{2}{15} \frac{q^2}{4\pi\epsilon_0 a} \right)^{1/2}}$
 (C) $\sqrt{\frac{2}{m} \left(\frac{4}{15} \frac{q^2}{4\pi\epsilon_0 a} \right)^{1/2}}$ (D) $\sqrt{\frac{2}{m} \left(\frac{1}{5} \frac{q^2}{4\pi\epsilon_0 a} \right)^{1/2}}$

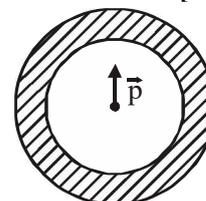
27. In free space, a particle A of charge $1 \mu\text{C}$ is held fixed at a point P. Another particle B of the same charge and mass $4 \mu\text{g}$ is kept at a distance of 1 mm from P. If B is released, then its velocity at a distance of 9 mm from P is :
[JEE Main - 2019]

[Take $\frac{1}{4\pi\epsilon_0} = 9 \times 10^9 \text{ Nm}^2 \text{ C}^{-2}$]

- (A) $2.0 \times 10^3 \text{ m/s}$ (B) $3.0 \times 10^4 \text{ m/s}$
 (C) $1.5 \times 10^2 \text{ m/s}$ (D) 1.0 m/s

28. Shown in the figure is a shell made of a conductor. It has inner radius a and outer radius b , and carries charge Q . At its centre is a dipole \vec{p} as shown. In this case:

[JEE Main - 2019]



- (A) Electric field outside the shell is the same as that of a point charge at the centre of the shell.
- (B) Surface charge density on the inner surface of the shell is zero everywhere.
- (C) Surface charge density on the inner surface is uniform and equal to $\frac{(Q/2)}{4\pi a^2}$.
- (D) Surface charge density on the outer surface depends on $|\vec{p}|$.

29. A point dipole $\vec{p} = -p_0\hat{x}$ is kept at the origin. The potential and electric field due to this dipole on the y-axis at a distance d are, respectively: [JEE Main - 2019]
(Take $V = 0$ at infinity) :

- (A) $\frac{|\vec{p}|}{4\pi\epsilon_0 d^2}, \frac{-\vec{p}}{4\pi\epsilon_0 d^3}$
- (B) $0, \frac{\vec{p}}{4\pi\epsilon_0 d^3}$
- (C) $\frac{|\vec{p}|}{4\pi\epsilon_0 d^2}, \frac{\vec{p}}{4\pi\epsilon_0 d^3}$
- (D) $0, \frac{-\vec{p}}{4\pi\epsilon_0 d^3}$

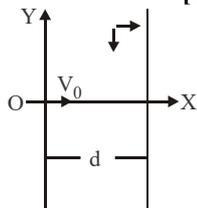
30. Let a total charge 2Q be distributed in a sphere of radius R, with the charge density given by $\rho(r) = kr$, where r is the distance from the centre. Two charges A and B, of -Q each, are placed on diametrically opposite points, at equal distance, a, from the centre. If A and B do not experience any force, then:

[JEE Main - 2019]

- (A) $a = 3R / 2^{1/4}$
- (B) $a = R / \sqrt{3}$
- (C) $a = 8^{-1/4} R$
- (D) $a = 2^{-1/4} R$

31. A charged particle (mass m and charge q) moves along X axis with velocity V_0 . When it passes through the origin it enters a region having uniform electric field $\vec{E} = -E\hat{j}$ which extends upto $x = d$. Equation of path of electron in the region $x > d$ is:

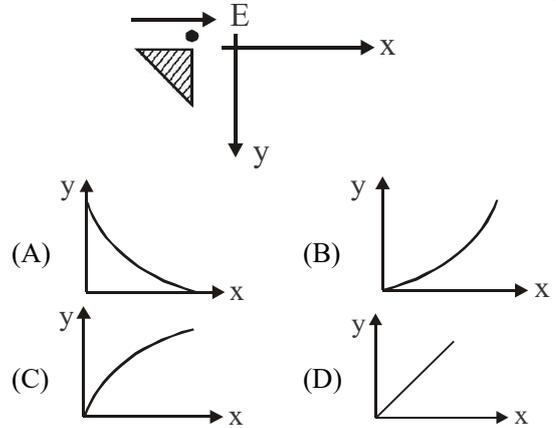
[JEE Main - 2020]



- (A) $y = \frac{qEd}{mV_0^2} \left(\frac{d}{2} - x \right)$
- (B) $y = \frac{qEd}{mV_0^2} (x - d)$
- (C) $y = \frac{qEd}{mV_0^2} x$
- (D) $y = \frac{qEd^2}{mV_0^2} x$

32. A small point mass carrying some positive charge on it, is released from the edge of a table. There is a uniform electric field in this region in the horizontal direction. Which of the following options then correctly describe the trajectory of the mass ? (Curves are drawn schematically and are not to scale).

[JEE Main - 2020]

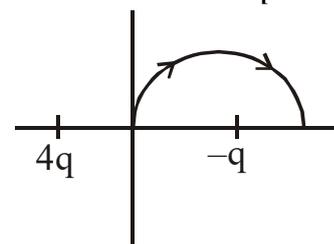


33. A wire of density $9 \times 10^{-3} \text{ kg cm}^{-3}$ is stretched between two clamps 1 m apart. The resulting strain in the wire is 4.9×10^{-4} . The lowest frequency of the transverse vibrations in the wire is (Young's modulus of wire $Y = 9 \times 10^{10} \text{ Nm}^{-2}$), (to the nearest integer), _____.

[JEE Main - 2020]

34. A two point charges $4q$ and $-q$ are fixed on the x-axis at $x = -d/2$ and $x = d/2$, respectively. If a third point charge 'q' is taken from the origin to $x = d$ along the semicircle as shown in the figure, the energy of the charge will :

[JEE Main - 2020]



- (A) increase by $\frac{2q^2}{3\pi\epsilon_0 d}$
- (B) increase by $\frac{3q^2}{4\pi\epsilon_0 d}$
- (C) decrease by $\frac{4q^2}{3\pi\epsilon_0 d}$
- (D) decrease by $\frac{q^2}{4\pi\epsilon_0 d}$

35. Concentric metallic hollow spheres of radii R and $4R$ hold charges Q_1 and Q_2 respectively. Given that surface charge densities of the concentric spheres are equal, the potential difference $V(R) - V(4R)$ is:

[JEE Main - 2020]

- (A) $\frac{3Q_1}{16\pi\epsilon_0 R}$ (B) $\frac{Q_2}{4\pi\epsilon_0 R}$
 (C) $\frac{3Q_1}{4\pi\epsilon_0 R}$ (D) $\frac{3Q_2}{4\pi\epsilon_0 R}$

36. A particle of charge q and mass m is subjected to an electric field $E = E_0(1 - ax^2)$ in the x -direction, where a and E_0 are constants. Initially the particle was at rest at $x = 0$. Other than the initial position the kinetic energy of the particle becomes zero when the distance of the particle from the origin is

[JEE Main - 2020]

- (A) $\sqrt{2/a}$ (B) $\sqrt{1/a}$
 (C) a (D) $\sqrt{3/a}$

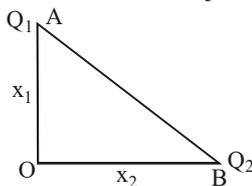
37. Ten charges are placed on the circumference of a circle of radius R with constant angular separation between successive charges. Alternate charges 1, 3, 5, 7, 9 have charge $(+q)$ each, while 2, 4, 6, 8, 10 have charge $(-q)$ each. The potential V and the electric field E at the centre of the circle are respectively:

(Take $V = 0$ at infinity) [JEE Main - 2020]

- (A) $V = \frac{10q}{4\pi\epsilon_0 R}, E = \frac{10q}{4\pi\epsilon_0 R^2}$
 (B) $V = 0, E = \frac{10q}{4\pi\epsilon_0 R^2}$
 (C) $V = 0, E = 0$
 (D) $V = \frac{10q}{4\pi\epsilon_0 R}, E = 0$

38. Charges Q_1 and Q_2 are at points A and B of a right angle triangle OAB (see figure). The resultant electric field at point O is perpendicular to the hypotenuse, then Q_1/Q_2 is proportional to :

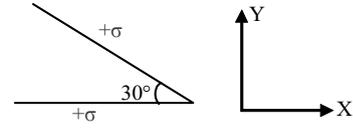
[JEE Main - 2020]



- (A) $\frac{x_2^2}{x_1^2}$ (B) $\frac{x_1^3}{x_2^3}$ (C) $\frac{x_1}{x_2}$ (D) $\frac{x_2}{x_1}$

39. There are two infinite plane sheets each having uniform surface charge density $+\sigma$ C/m². They are inclined to each other at an angle 30° as shown in the figure. The electric field in the region shown between them is given by:

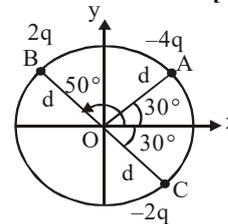
[JEE Main - 2020]



- (A) $\frac{\sigma}{2\epsilon_0} \left[\left(1 - \frac{\sqrt{3}}{2}\right) \hat{y} - \frac{1}{2} \hat{x} \right]$
 (B) $\frac{\sigma}{2\epsilon_0} \left[\left(1 + \frac{\sqrt{3}}{2}\right) \hat{y} - \frac{1}{2} \hat{x} \right]$
 (C) $\frac{\sigma}{2\epsilon_0} \left[\left(1 - \frac{\sqrt{3}}{2}\right) \hat{y} + \frac{1}{2} \hat{x} \right]$
 (D) $\frac{\sigma}{2\epsilon_0} \left[\left(1 + \frac{\sqrt{3}}{2}\right) \hat{y} + \frac{1}{2} \hat{x} \right]$

40. Three charged particles A, B and C with charges $-4q, 2q$ and $-2q$ are present on the circumference of a circle of radius d . The charged particles A, C and centre O of the circle formed an equilateral triangle as shown in figure. Electric field at O along x -direction is

[JEE Main - 2020]



- (A) $\frac{2\sqrt{3}q}{\pi\epsilon_0 d^2}$ (B) $\frac{\sqrt{3}q}{4\pi\epsilon_0 d^2}$
 (C) $\frac{3\sqrt{3}q}{4\pi\epsilon_0 d^2}$ (D) $\frac{\sqrt{3}q}{\pi\epsilon_0 d^2}$

41. An electric field $\vec{E} = 4x\hat{i} - (y^2 + 1)\hat{j}$ N/C passes through the box shown in figure. The flux of the electric field through surfaces ABCD and BCGF are marked as ϕ_I and ϕ_{II} respectively. The difference between $(\phi_I - \phi_{II})$ is (in Nm²/C) _____.

[JEE Main - 2020]

42. A body of mass $m = 10$ kg is attached to one end of a wire of length 0.3 m. The maximum angular speed (in rad s⁻¹) with which it can be rotated about its other end in space station is (Breaking stress of wire = 4.8×10^7 Nm⁻² and area of cross-section of the wire = 10^{-2} cm²) is:

[JEE Main - 2020]

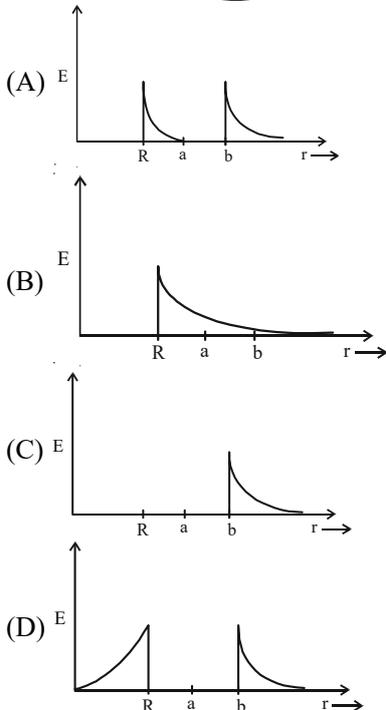
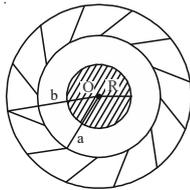
43. The two thin coaxial rings, each of radius 'a' and having charges +Q and -Q respectively are separated by a distance of 's'. The potential difference between the centres of the two rings is: [JEE Main - 2021]

(A) $\frac{Q}{2\pi\epsilon_0} \left[\frac{1}{a} - \frac{1}{\sqrt{s^2+a^2}} \right]$ (B) $\frac{Q}{2\pi\epsilon_0} \left[\frac{1}{a} + \frac{1}{\sqrt{s^2+a^2}} \right]$
 (C) $\frac{Q}{4\pi\epsilon_0} \left[\frac{1}{a} + \frac{1}{\sqrt{s^2+a^2}} \right]$ (D) $\frac{Q}{4\pi\epsilon_0} \left[\frac{1}{a} - \frac{1}{\sqrt{s^2+a^2}} \right]$

44. If the maximum value of accelerating potential provided by a radio frequency oscillator is 12 kV. The number of revolution made by a proton in a cyclotron to achieve one sixth of the speed of light is _____.

$[m_p = 1.67 \times 10^{-27} \text{ kg}, e = 1.6 \times 10^{-19} \text{ C}, \text{Speed of light} = 3 \times 10^8 \text{ m/s}]$ [JEE Main - 2021]

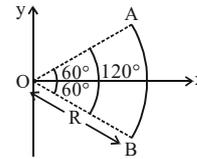
45. A solid metal sphere of radius R having charge q is enclosed inside the concentric spherical shell of inner radius a and outer radius b as shown in figure. The approximate variation electric field \vec{E} as a function of distance r from centre O is given by: [JEE Main - 2021]



46. A uniformly charged disc of radius R having surface charge density is placed in the xy plane with its center at the origin. Find the electric field intensity along the z-axis at a distance Z from origin: [JEE Main - 2021]

(A) $E = \frac{\sigma}{2\epsilon_0} \left(1 - \frac{Z}{(Z^2 + R^2)^{1/2}} \right)$
 (B) $E = \frac{2\epsilon_0}{\sigma} \left(\frac{1}{(Z^2 + R^2)^{1/2}} + Z \right)$
 (C) $E = \frac{\sigma}{2\epsilon_0} \left(\frac{1}{(Z^2 + R^2)} + \frac{1}{Z^2} \right)$
 (D) $E = \frac{\sigma}{2\epsilon_0} \left(1 + \frac{Z}{(Z^2 + R^2)^{1/2}} \right)$

47. Figure shows a rod AB, which is bent in a 120° circular arc of radius R. A charge (-Q) is uniformly distributed over rod AB. What is the electric field at the centre of curvature O?



[JEE Main - 2021]

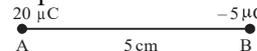
(A) $\frac{3\sqrt{3}Q}{8\pi^2\epsilon_0R^2}(\hat{i})$ (B) $\frac{3\sqrt{3}Q}{8\pi^2\epsilon_0R^2}(-\hat{i})$
 (C) $\frac{3\sqrt{3}Q}{8\pi\epsilon_0R^2}(\hat{i})$ (D) $\frac{3\sqrt{3}Q}{16\pi^2\epsilon_0R^2}(\hat{i})$

48. Choose the **incorrect** statement:
 (a) The electric lines of force entering into a Gaussian surface provide negative flux.
 (b) A charge 'q' is placed at the centre of a cube. The flux through all the faces will be the same.
 (c) In a uniform electric field net flux through a closed Gaussian surface containing no net charge, is zero.
 (d) When electric field is parallel to a Gaussian surface, it provides a finite non-zero flux.

Choose the most appropriate answer from the options given below: [JEE Main - 2021]

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

49. Two particles A and B having charges 20 μC and -5μC respectively are held fixed with a separation of 5 cm. At what position a third charged particle should be placed so that it does not experience a net electric force?

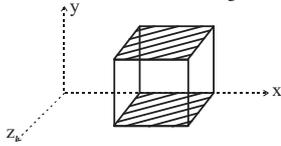


[JEE Main - 2021]

- (A) At 5 cm from -5 μC on the right side
- (B) At 1.25 cm from a -5 μC between two charges
- (C) At 5 cm from 20 μC on the left side of system
- (D) At midpoint between two charges

50. A cube is placed inside an electric field, $\vec{E} = 150y^2\hat{j}$. The side of the cube is 0.5 m and is placed in the field as shown in the given figure. The charge inside the cube is:

[JEE Main - 2021]



- (A) 8.3×10^{-11} C (B) 3.8×10^{-11} C
(C) 8.3×10^{-12} C (D) 3.8×10^{-12} C

51. A charge of $4 \mu\text{C}$ is to be divided into two. The distance between the two divided charges is constant. The magnitude of the divided charges so that the force between them is maximum, will be:

[JEE Main -2022]

- (A) $1 \mu\text{C}$ and $3 \mu\text{C}$ (B) $2 \mu\text{C}$ and $2 \mu\text{C}$
(C) 0 and $4 \mu\text{C}$ (D) $1.5 \mu\text{C}$ and $2.5 \mu\text{C}$

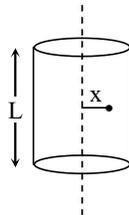
52. Two identical positive charges Q each are fixed at a distance of '2a' apart from each other. Another point charge q_0 with mass 'm' is placed at midpoint between two fixed charges. For a small displacement along the line joining the fixed charges, the charge q_0 executes SHM. The time period of oscillation of charge q_0 will be

[JEE Main - 2022]

- (A) $\sqrt{\frac{4\pi^3 \epsilon_0 m a^3}{q_0 Q}}$ (B) $\sqrt{\frac{q_0 Q}{4\pi^3 \epsilon_0 m a^3}}$
(C) $\sqrt{\frac{2\pi^2 \epsilon_0 m a^3}{q_0 Q}}$ (D) $\sqrt{\frac{8\pi^3 \epsilon_0 m a^3}{q_0 Q}}$

53. A long cylindrical volume contains a uniformly distributed charge of density $\rho \text{ Cm}^{-3}$. The electric field inside the cylindrical volume at a distance $x = \frac{2\epsilon_0}{\rho} \text{ m}$ from its axis is Vm^{-1}

[JEE Main -2022]



54. Two point charges A and B of magnitude $+8 \times 10^{-6} \text{ C}$ and $-8 \times 10^{-6} \text{ C}$ respectively are placed at a distance d apart. The electric field at the middle point O between the charges is $6.4 \times 10^4 \text{ NC}^{-1}$. The distance 'd' between the point charges A and B is:

[JEE Main -2022]

- (A) 2.0 m (B) 3.0 m (C) 1.0 m (D) 4.0 m

55. Given below are two statements

Statement-I: A point charge is brought in an electric field. The value of electric field at a point near to the charge may increase if the charge is positive.

Statement-II: An electric dipole is placed in a non-uniform electric field. The net electric force on the dipole will not be zero.

Choose the correct answer from the options given below

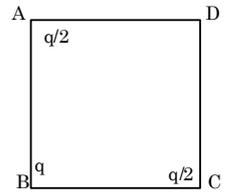
[JEE Main -2022]

- (A) Both statement-I and statement-II are true
(B) Both statement-I and statement-II are false
(C) Statement-I is true but statement-II is false
(D) Statement-I is false but statement-II is true

56. The three charges $\frac{q}{2}$, q and $\frac{q}{2}$ are placed at the corners A, B and C of a square of side 'a' as shown in figure. The magnitude of electric field (E) at the corner D of the square is

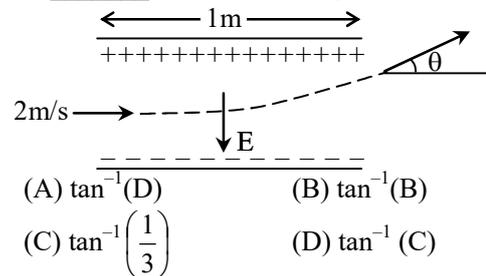
[JEE Main -2022]

- (A) $\frac{q}{4\pi \epsilon_0 a^2} \left(\frac{1}{\sqrt{2}} + \frac{1}{2} \right)$
(B) $\frac{q}{4\pi \epsilon_0 a^2} \left(1 + \frac{1}{\sqrt{2}} \right)$
(C) $\frac{q}{4\pi \epsilon_0 a^2} \left(1 - \frac{1}{\sqrt{2}} \right)$
(D) $\frac{q}{4\pi \epsilon_0 a^2} \left(\frac{1}{\sqrt{2}} - \frac{1}{2} \right)$



57. A uniform electric field $E = (8m/e) \text{ V/m}$ is created between two parallel plates of length 1 m as shown in figure, (where $m =$ mass of electron and $e =$ charge of electron). An electron enters the field symmetrically between the plates with a speed of 2 m/s. The angle of the deviation (θ) of the path of the electron as it comes out of the field will be _____.

[JEE Main -2022]



- (A) $\tan^{-1}(D)$ (B) $\tan^{-1}(B)$
(C) $\tan^{-1}\left(\frac{1}{3}\right)$ (D) $\tan^{-1}(C)$

58. Two electric dipoles of dipole moments $1.2 \times 10^{-30} \text{ C-m}$ and $2.4 \times 10^{-30} \text{ C-m}$ are placed in two different uniform electric fields of strength $5 \times 10^4 \text{ NC}^{-1}$ and $15 \times 10^4 \text{ NC}^{-1}$ respectively. The ratio of maximum torque experienced by the electric dipoles will be $\frac{1}{x}$. The value of x is _____.

[JEE Main -2022]

59. Two point charges Q each are placed at a distance d apart. A third point charge q is placed at a distance x from mid-point on the perpendicular bisector. The value of x at which charge q will experience the maximum Coulombs force is : **[JEE Main -2022]**

- (A) $x = d$ (B) $x = \frac{d}{2}$
 (C) $x = \frac{d}{\sqrt{2}}$ (D) $x = \frac{d}{2\sqrt{2}}$

60. The electric field at a point associated with a light wave is given by

$$E = 200[\sin(6 \times 10^{15}t) + \sin(9 \times 10^{15}t)] \text{ Vm}^{-1}$$

Given : $h = 4.14 \times 10^{-15} \text{ eVs}$

If this light falls on a metal surface having a work function of 2.50 eV, the maximum kinetic energy of the photoelectrons will be

- [JEE Main -2022]**
 (A) 1.90 eV (B) 3.27 eV
 (C) 3.60 eV (D) 3.42 eV

61. If the electric potential at any point (x, y, z)m in space is given by $V = 3x^2$ volt. The electric field at the point (1, 0, 3)m will be

- [JEE Main -2022]**
 (A) 3 Vm^{-1} , directed along positive x-axis
 (B) 3 Vm^{-1} , directed along negative x-axis
 (C) 6 Vm^{-1} , directed along positive x-axis
 (D) 6 Vm^{-1} , directed along negative x-axis

62. A positive charge particle of 100 mg is thrown in opposite direction to a uniform electric field of strength $1 \times 10^5 \text{ NC}^{-1}$. If the charge on the particle is $40 \mu\text{C}$ and the initial velocity is 200 ms^{-1} , how much distance it will travel before coming to the rest momentarily?

- [JEE Main -2022]**
 (A) 1 m (B) 5 m (C) 10 m (D) 0.5 m

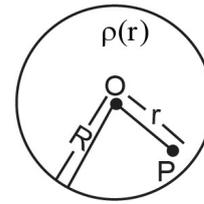
63. Two identical metallic spheres A and B when placed at certain distance in air repel each other with a force of F. Another identical uncharged sphere C is first placed in contact with A and then in contact with B and finally placed at midpoint between spheres A and B. The force experienced by sphere C will be :

- [JEE Main -2022]**
 (A) $3F/2$ (B) $3F/4$ (C) F (D) $2F$

64. A spherically symmetric charge distribution is considered with charge density varying as

$$\rho(r) = \begin{cases} \rho_0 \left(\frac{3}{4} - \frac{r}{R} \right) & \text{for } r \leq R \\ \text{Zero} & \text{for } r > R \end{cases}$$

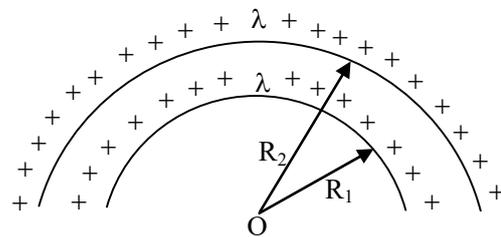
Where, $r(r < R)$ is the distance from the centre O (as shown in figure). The electric field at point P will be : **[JEE Main -2022]**



- (A) $\frac{\rho_0 r}{4\epsilon_0} \left(\frac{3}{4} - \frac{r}{R} \right)$ (B) $\frac{\rho_0 r}{3\epsilon_0} \left(\frac{3}{4} - \frac{r}{R} \right)$
 (C) $\frac{\rho_0 r}{4\epsilon_0} \left(1 - \frac{r}{R} \right)$ (D) $\frac{\rho_0 r}{5\epsilon_0} \left(1 - \frac{r}{R} \right)$

65. The electric potential at the centre of two concentric half rings of radii R_1 and R_2 , having same linear charge density λ is:

[JEE Main-2023]



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

66. Given below are two statements: One is labelled as Assertion A and the other is labelled as Reason R. **[JEE Main- 2023]**

Assertion A : Two metallic spheres are charged to the same potential. One of them is hollow and another is solid, and both have the same radii. Solid sphere will have lower charge than the hollow one.

Reason R: Capacitance of metallic spheres depend on the radii of spheres.

In the light of the above statements, choose the correct answer from the options given below:

- (A) Both A and R are true but R is not the correct explanation of A
 (B) A is false but R is true
 (C) Both A and R are true but R is the correct explanation of A
 (D) A is true but R is false

67. A cubical volume is bounded by the surfaces $x = 0, x = a, y = 0, y = a, z = 0, z = a$. The electric field in the region is given by

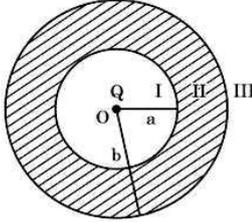
$\vec{E} = E_0 x \hat{i}$. Where $E_0 = 4 \times 10^4 \text{ NC}^{-1}\text{m}^{-1}$. If $a = 2 \text{ cm}$, the charge contained in the cubical volume is $Q \times 10^{-14} \text{ C}$. The value of Q is _____ . (Take $\epsilon_0 = 9 \times 10^{-12} \text{ C}^2/\text{Nm}^2$)

[JEE Main- 2023]

68. As shown in the figure, a point charge Q is placed at the centre of conducting spherical shell of inner radius a and outer radius b. The electric field due to charge Q in three different regions I, II and III is given by:

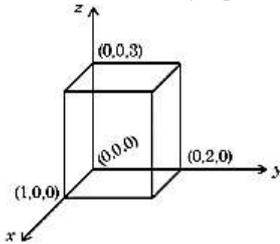
[JEE Main- 2023]

(I : $r < a$, II : $a < r < b$, III : $r > a$)

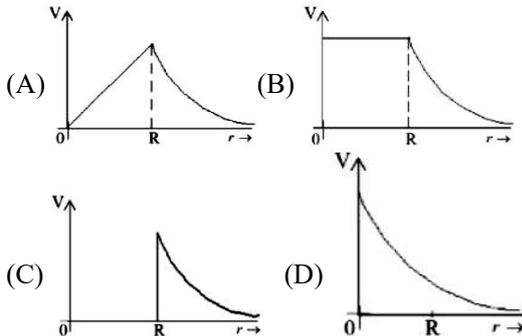


- (A) $E_I \neq 0, E_{II} = 0, E_{III} \neq 0$
- (B) $E_I = 0, E_{II} = 0, E_{III} = 0$
- (C) $E_I \neq 0, E_{II} = 0, E_{III} = 0$
- (D) $E_I = 0, E_{II} = 0, E_{III} \neq 0$

69. As shown in figure, a cuboid lies in a region with electric field $E = 2x^2\hat{i} - 4y\hat{j} + 6k\frac{N}{C}$. The magnitude of charge within the cuboid is $n\epsilon_0 C$. The value of n is _____ (if dimension of cuboid is $1 \times 2 \times 3 \text{ m}^3$). [JEE Main- 2023]



70. Which of the following correctly represents the variation of electric potential(V) of a charged spherical conductor of radius (R) with radial distance (r) from the center? [JEE Main- 2023]

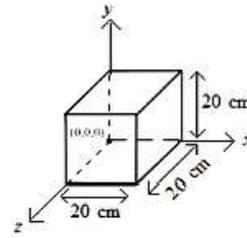


71. In a medium the speed of light wave decreases to 0.2 times to its speed in free space. The ratio of relative permittivity to the refractive index of the medium is $x : 1$. [JEE Main- 2023]

The value of x is _____.
(Given speed of light in free space = $3 \times 10^8 \text{ ms}^{-1}$ and for the given medium $\mu_1 = 1$)

72. Expression for an electric field is given by $\vec{E} = 4000x^2 \hat{i} - \frac{V}{m}$. The electric flux through the cube of side 20 cm when placed in electric field (as shown in the figure) is _____ V cm.

[JEE Main- 2023]



73. If two charges q_1 and q_2 are separated with distance 'd' and placed in a medium of dielectric constant K. What will be the equivalent distance between charges in air for the same electrostatic force?

[JEE Main- 2023]

- (A) $2d\sqrt{k}$ (B) $d\sqrt{k}$ (C) $1.5d\sqrt{k}$ (D) $k\sqrt{d}$

74. A stream of a positively charged particles having $\frac{q}{m} = 2 \times 10^{11} \frac{C}{kg}$ and velocity $\vec{v}_0 = 3 \times 10^7 \hat{i} \text{ m/s}$ is deflected by an electric field $1.8\hat{j} \text{ kV/m}$. The electric field exists in a region of 10 cm along x direction. Due to the electric field, the deflection of the charge particles in the y direction is _____ mm.

[JEE Main- 2023]

75. Two isolated metallic solid spheres of radii R and 2R are charged such that both have same charge density σ . The spheres are then connected by a thin conducting wire. If the new charge density of the bigger sphere is σ' . The ratio $\frac{\sigma'}{\sigma}$ is [JEE Main- 2023]

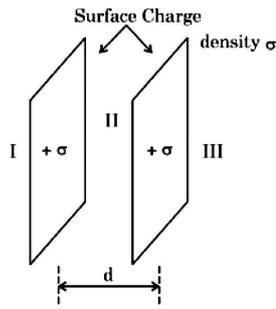
- (A) $\frac{5}{6}$ (B) $\frac{4}{3}$ (C) $\frac{5}{3}$ (D) $\frac{9}{4}$

76. Electric field in a certain region is given by $\vec{E} = \left(\frac{A}{x^2} \hat{i} + \frac{B}{y^2} \hat{j} \right)$. The SI unit of A and B are.

[JEE Main- 2023]

- (A) $\text{Nm}^3\text{C}; \text{Nm}^2\text{C}$ (B) $\text{Nm}^2\text{C}; \text{Nm}^3\text{C}$
- (C) $\text{Nm}^2\text{C}^{-1}; \text{Nm}^2\text{C}^{-1}$ (D) $\text{Nm}^3\text{C}^{-1}; \text{Nm}^2\text{C}^{-1}$

77. Let σ be the uniform surface charge density of two infinite thin plane sheets shown in figure. Then the electric fields in three different region E_I, E_{II} and E_{III} are : [JEE Main- 2023]



- (A) $\vec{E}_I = 0, \vec{E}_{II} = \frac{\sigma}{\epsilon_0} \hat{n}, E_{III} = 0$
- (B) $\vec{E}_I = -\frac{\sigma}{\epsilon_0} \hat{n}, \vec{E}_{II} = 0, \vec{E}_{III} = \frac{\sigma}{\epsilon_0} \hat{n}$
- (C) $\vec{E}_I = -\frac{2\sigma}{2\epsilon_0} \hat{n}, \vec{E}_{II} = 0, \vec{E}_{III} = \frac{2\sigma}{\epsilon_0} \hat{n}$
- (D) $\vec{E}_I = -\frac{\sigma}{2\epsilon_0} \hat{n}, \vec{E}_{II} = 0, \vec{E}_{III} = \frac{\sigma}{\epsilon_0} \hat{n}$

78. Two equal positive point charges are separated by a distance $2a$. The distance of a point from the centre of the line joining two charges on the equatorial line (perpendicular bisector) at which force experienced by a test charge q_0 becomes maximum is $\frac{a}{\sqrt{x}}$. The value of x is _____ .
[JEE Main- 2023]

79. Considering a group of positive charges, which of the following statements is correct?
[JEE Main- 2023]

- (A) Net potential of the system cannot be zero at a point but net electric field can be zero at that point.
- (B) Both the net potential and the net field can be zero at a point.
- (C) Net potential of the system at a point can be zero but net electric field can't be zero at that point.
- (D) Both the net potential and the net electric field cannot be zero at a point.

80. An electric field is given by $(6\hat{i} + 5\hat{j} + 3\hat{k})$ N/C. The electric flux through a surface area $30\hat{i} \text{ m}^2$ lying in YZ-plane (in SI unit) is :
[JEE Main- 2024]

(A) 180 (B) 60 (C) 150 (D) 90

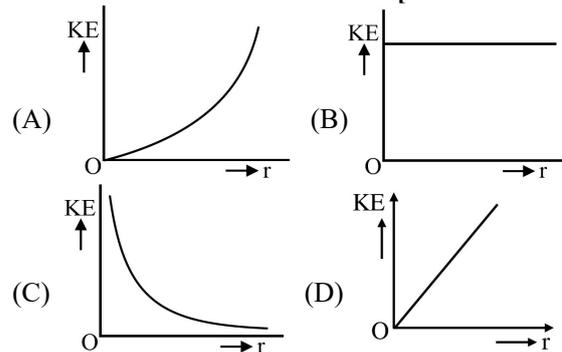
81. Given below are two statements : one is labelled as **Assertion (A)** and the other is labelled as **Reason (R)**.
Assertion (A) : Work done by electric field on moving a positive charge on an equipotential surface is always zero.
Reason (R) : Electric lines of forces are always perpendicular to equipotential surfaces.

In the light of the above statements, choose the **most appropriate** answer from the options given below.
[JEE Main- 2024]

- (A) (A) is correct but (R) not correct
- (B) (A) is not correct but (R) is correct
- (C) Both (A) and (R) are true and (R) is the correct explanation of (A)
- (D) Both (A) and (R) are true and (R) is not the correct explanation of (A)

82. Two charges of $-4\mu\text{C}$ and $+4\mu\text{C}$ are placed at the point A(1, 0, 4) m and B(2, -1, 5) m located in an electric field $\vec{E} = 0.20 \hat{i}$ V/cm. The magnitude of the torque acting on the dipole is $8\sqrt{\alpha} \times 10^{-5} \text{ Nm}$, where $\alpha = \underline{\hspace{1cm}}$.
[JEE Main- 2024]

83. An infinitely long positively charged straight thread has a linear charge density $\lambda \text{ Cm}^{-1}$. An electron revolves along a circular path having axis along the length of the wire. The graph that correctly represents the variation of the kinetic energy of electron as a function of radius of circular path from the wire is :
[JEE Main- 2024]

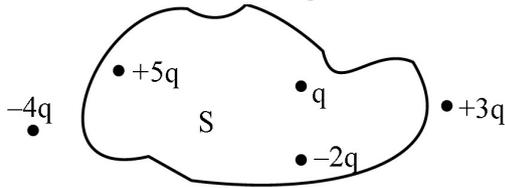


84. An infinite plane sheet of charge having uniform surface charge density $+\sigma_s \text{ C/m}^2$ is placed on x-y plane. Another infinitely long line charge having uniform linear charge density $+\lambda_e \text{ C/m}$ is placed at $z = 4\text{m}$ plane and parallel to y-axis. If the magnitude value $|\sigma_s| = 2|\lambda_e|$ then at point (0, 0, 2), the ratio of magnitudes of electric field values due to sheet charge to that of line charge is $\pi\sqrt{n} : 1$. The value of n is _____ .
[JEE Main- 2024]

85. The magnetic field in a plane electromagnetic wave is $B_y = (3.5 \times 10^{-7}) \sin (1.5 \times 10^3 x + 0.5 \times 10^{11} t) \text{ T}$. The corresponding electric field will be
[JEE Main- 2024]

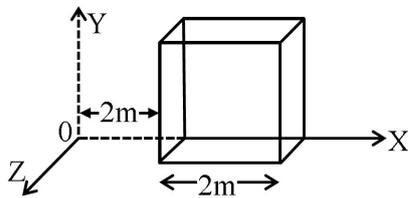
- (A) $E_y = 1.17 \sin (1.5 \times 10^3 x + 0.5 \times 10^{11} t) \text{ Vm}^{-1}$
- (B) $E_z = 105 \sin (1.5 \times 10^3 x + 0.5 \times 10^{11} t) \text{ Vm}^{-1}$
- (C) $E_z = 1.17 \sin (1.5 \times 10^3 x + 0.5 \times 10^{11} t) \text{ Vm}^{-1}$
- (D) $E_y = 10.5 \sin (1.5 \times 10^3 x + 0.5 \times 10^{11} t) \text{ Vm}^{-1}$

86. Five charges $+q, +5q, -2q, +3q$ and $-4q$ are situated as shown in the figure. The electric flux due to this configuration through the surface S is [JEE Main- 2024]



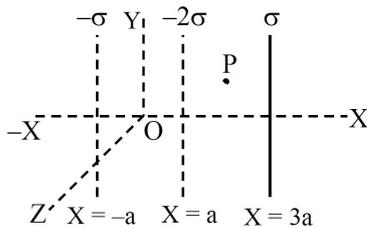
- (A) $\frac{5q}{\epsilon_0}$ (B) $\frac{4q}{\epsilon_0}$ (C) $\frac{3q}{\epsilon_0}$ (D) $\frac{q}{\epsilon_0}$

87. An electric field $\vec{E} = (2x\hat{i}) \text{ NC}^{-1}$ exists in space. A cube of side $2m$ is placed in the space as per figure given below. The electric flux through the cube is Nm^2/C . [JEE Main- 2024]



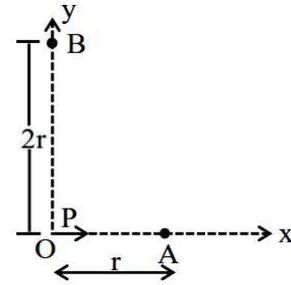
88. σ is the uniform surface charge density of a thin spherical shell of radius R . The electric field at any point on the surface of the spherical shell is : [JEE Main- 2024]
 (A) $\sigma/\epsilon_0 R$ (B) $\sigma/2\epsilon_0$ (C) σ/ϵ_0 (D) $\sigma/4\epsilon_0$

89. Three infinitely long charged thin sheets are placed as shown in figure. The magnitude of electric field at the point P is $\frac{x\sigma}{\epsilon_0}$. The value of x is _____ (all quantities are measured in SI units). [JEE Main- 2024]



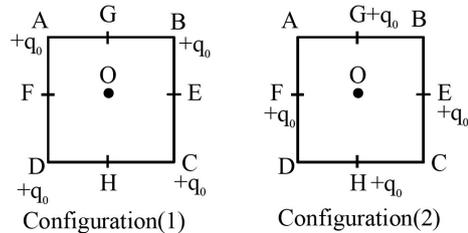
90. An electron is made to enter symmetrically between two parallel and equally but oppositely charged metal plates, each of 10 cm length. The electron emerges out of the field region with a horizontal component of velocity 10^6 m/s . If the magnitude of the electric field between the plates is 9.1 V/cm , then the vertical component of velocity of electron is (mass of electron = $9.1 \times 10^{-31} \text{ kg}$ and charge of electron = $1.6 \times 10^{-19} \text{ C}$) [JEE Main 2025]
 (A) $1 \times 10^6 \text{ m/s}$ (B) 0
 (C) $16 \times 10^6 \text{ m/s}$ (D) $16 \times 10^4 \text{ m/s}$

91. For a short dipole placed at origin O , the dipole moment P is along x -axis, as shown in the figure. If the electric potential and electric field at A are V_0 and E_0 , respectively, then the correct combination of the electric potential and electric field, respectively, at point B on the y -axis is given by [JEE Main 2025]



- (A) $\frac{V_0}{2}$ and $\frac{E_0}{16}$ (B) zero and $\frac{E_0}{8}$
 (C) zero and $\frac{E_0}{16}$ (D) V_0 and $\frac{E_0}{4}$

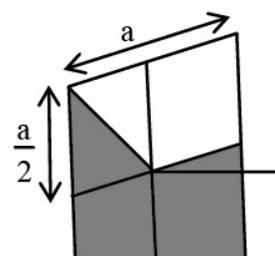
- 92.



- In the first configuration (1) as shown in the figure, four identical charges (q_0) are kept at the corners A, B, C and D of square of side length ' a '. In the second configuration (2), the same charges are shifted to mid points G, E, H and F , of the square, If $K = \frac{1}{4\pi\epsilon_0}$, the difference between the potential energies of configuration (2) and (1) is given by :

- [JEE Main 2025]
 (1) $\frac{Kq_0^2}{a}(4\sqrt{2} - 2)$ (2) $\frac{Kq_0^2}{a}(3 - \sqrt{2})$
 (3) $\frac{Kq_0^2}{a}(4 - 2\sqrt{2})$ (4) $\frac{Kq_0^2}{a}(3\sqrt{2} - 2)$

93. A square loop of sides $a = 1 \text{ m}$ is held normally in front of a point charge $q = 1 \text{ C}$. The flux of the electric field through the shaded region is $\frac{5}{p} \times \frac{1}{\epsilon_0} \frac{\text{Nm}^2}{\text{C}}$, where the value of p is ____.



[JEE Main 2025]

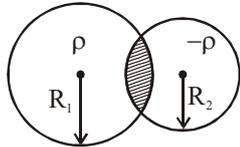
Question Previous Year (JEE Advanced)

94. Two non-conducting solid spheres of radii R and $2R$, having uniform volume charge densities ρ_1 and ρ_2 respectively, touch each other. The net electric field at a distance $2R$ from the centre of the smaller sphere, along the line joining the centres of the spheres, is zero. The ratio $\frac{\rho_1}{\rho_2}$ can be

- (A) -4 (B) $-\frac{32}{25}$ (C) $\frac{32}{25}$ (D) 4

[JEE Advanced-2013]

95. Two non-conducting spheres of radii R_1 and R_2 and carrying uniform volume charge densities $+\rho$ and $-\rho$, respectively, are placed such that they partially overlap, as shown in the figure. At all points in the overlapping region :



[JEE Advanced-2013]

- (A) the electrostatic field is zero
 (B) the electrostatic potential is constant
 (C) the electrostatic field is constant in magnitude
 (D) the electrostatic field has same direction

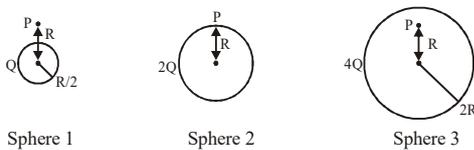
96. Let $E_1(r)$, $E_2(r)$ and $E_3(r)$ be the respective electric fields at a distance r from a point charge Q , an infinitely long wire with constant linear charge density λ , and an infinite plane with uniform surface charge density σ . If $E_1(r_0) = E_2(r_0) = E_3(r_0)$ at a given distance r_0 , then

[JEE Advanced-2014]

- (A) $Q = 4\sigma\pi r_0^2$
 (B) $r_0 = \frac{\lambda}{2\pi\sigma}$
 (C) $E_1(r_0/2) = 2E_2(r_0/2)$
 (D) $E_2(r_0/2) = 4E_3(r_0/2)$

97. Charges Q , $2Q$ and $4Q$ are uniformly distributed in three dielectric solid spheres 1, 2 and 3 of radii $R/2$, R and $2R$ respectively, as shown in figure. If magnitudes of the electric fields at point P at a distance R from the centre of spheres 1, 2 and 3 are E_1 , E_2 and E_3 respectively, then

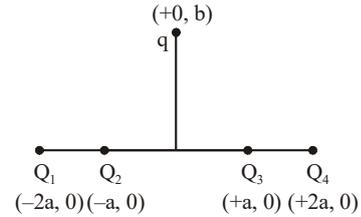
[JEE Advanced--2014]



- (A) $E_1 > E_2 > E_3$ (B) $E_3 > E_1 > E_2$
 (C) $E_2 > E_1 > E_3$ (D) $E_3 > E_2 > E_1$

98. Four charges Q_1, Q_2, Q_3 and Q_4 of same magnitude are fixed along the x axis at $x = -2a, -a, +a$ and $+2a$, respectively. A positive charge q is placed on the positive y axis at a distance $b > 0$. Four options of the signs of these charges are given in List I. The direction of the forces on the charge q is given in List II. Match List I with List II and select the correct answer using the code given below the lists.

[JEE Advanced-2014]



List I

List II

- P. Q_1, Q_2, Q_3, Q_4 all positive 1. $+x$
 Q. Q_1, Q_2 positive; Q_3, Q_4 negative 2. $-x$
 R. Q_1, Q_4 positive ; Q_2, Q_3 negative 3. $+y$
 S. Q_1, Q_3 positive; Q_2, Q_4 negative 4. $-y$

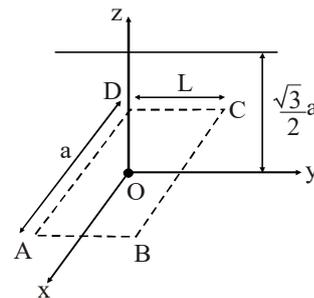
Code:

- (A) P-3, Q-1, R-4, S-2
 (B) P-4, Q-2, R-3, S-1
 (C) P-3, Q-1, R-2, S-4
 (D) P-4, Q-2, R-1, S-3

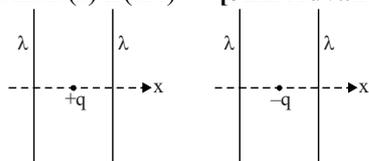
99. An infinitely long uniform line charge distribution of charge per unit length λ lies parallel to the y -axis in the y - z plane at $z = \frac{\sqrt{3}}{2}a$ (see figure). If the magnitude of the flux of the electric field through the rectangular surface $ABCD$ lying in the x - y plane with its center at the origin is $\frac{\lambda L}{n\epsilon_0}$

(ϵ_0 = permittivity of free space), then the value of n is

[JEE Advanced-2015]

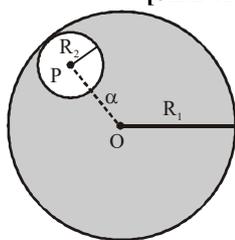


100. The figures below depict two situations in which two infinitely long static line charges of constant positive line charge density are kept parallel to each other. In their resulting electric field, point charges q and $-q$ are kept in equilibrium between them. The point charges are confined to move in the x direction only. If they are given a small displacement about their equilibrium positions, then the correct statement(s) is(are) [JEE Advanced- 2015]



- (A) Both charges execute simple harmonic motion.
 (B) Both charges will continue moving in the direction of their displacement.
 (C) Charge $+q$ executes simple harmonic motion while charge $-q$ continues moving in the direction of its displacement.
 (D) Charge $-q$ executes simple harmonic motion while charge $+q$ continues moving in the direction of its displacement.

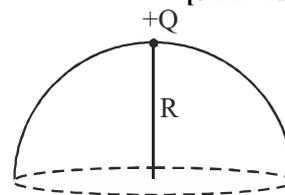
101. Consider a uniform spherical charge distribution of radius R_1 centred at the origin O . In this distribution, a spherical cavity of radius R_2 , centred at P with distance $OP = \alpha = R_1 - R_2$ (see figure) is made. If the electric field inside the cavity at position \vec{r} is $\vec{E}(\vec{r})$, then the correct statement(s) is(are) [JEE Advanced- 2015]



- (A) \vec{E} is uniform, its magnitude is independent of R_2 but its direction depends on \vec{r}
 (B) \vec{E} is uniform, its magnitude depends on R_2 and its direction depends on \vec{r}
 (C) \vec{E} is uniform, its magnitude is independent of α but its direction depends on $\vec{\alpha}$
 (D) \vec{E} is uniform and both its magnitude and direction depend on $\vec{\alpha}$

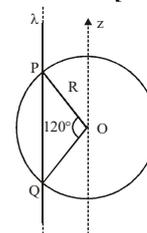
102. A point charge $+Q$ is placed just outside an imaginary hemispherical surface of radius R as shown in the figure. Which of the following statements is/are correct?

[JEE Advanced- 2017]



- (A) The electric flux passing through the curved surface of the hemisphere is $-\frac{Q}{2\epsilon_0} \left(1 - \frac{1}{\sqrt{2}}\right)$
 (B) Total flux through the curved and the flat surfaces is $\frac{Q}{\epsilon_0}$
 (C) The component of the electric field normal to the flat surface is constant over the surface
 (D) The circumference of the flat surface is an equipotential

103. An infinitely long thin non-conducting wire is parallel to the z -axis and carries a uniform line charge density λ . It pierces a thin non-conducting spherical shell of radius R in such a way that the arc PQ subtends an angle 120° at the centre O of the spherical shell, as shown in the figure. The permittivity of free space is ϵ_0 . Which of the following statements is (are) true? [JEE Advanced- 2018]



- (A) The electric flux through the shell is $\sqrt{3}R\lambda / \epsilon_0$
 (B) The z -component of the electric field is zero at all the points on the surface of the shell.
 (C) The electric flux through the shell is $\sqrt{2}R\lambda / \epsilon_0$
 (D) The electric field is normal to the surface of the shell at all points

104. A particle, of mass 10^{-3} kg and charge 1.0 C, is initially at rest. At time $t = 0$, the particle comes under the influence of an electric field $\vec{E}(t) = E_0 \sin \omega t \hat{i}$, where $E_0 = 1.0 \text{ NC}^{-1}$ and $\omega = 10^3 \text{ rad s}^{-1}$. Consider the effect of only the electrical force on the particle. Then the maximum speed, in ms^{-1} , attained by the particle at subsequent times is ____.

[JEE Advanced- 2018]

105. The electric field E is measured at a point $P(0, 0, d)$ generated due to various charge distributions and the dependence of E on d is found to be different for different charge distributions. List-I contains different relations between E and d . List-II describes different electric charge distributions, along with their locations. Match the functions in List-I with the related charge distributions in List-II.

[JEE Advanced- 2018]

List-I

P. E is independent of d

Q. $E \propto 1/d$

R. $E \propto 1/d^2$

S. $E \propto 1/d^3$

List-II

1. A point charge Q at the origin
2. A small dipole with point charges Q at $(0, 0, \ell)$ and $-Q$ at $(0, 0, -\ell)$ Take $2\ell \ll d$
3. An infinite line charge coincident with the x -axis, with uniform linear charge density λ .
4. Two infinite wires carrying uniform linear charge density parallel to the x -axis. The one along $(y = 0, z = \ell)$ has a charge density $+\lambda$ and the one along $(y = 0, z = -\ell)$ has a charge density $-\lambda$. Take $2\ell \ll d$.
5. Infinite plane charge coincident with the xy -plane with uniform surface charge density.

- (A) P - 5; Q - 3, 4; R - 1; S - 2
 (B) P - 5; Q - 3; R - 1, 4; S - 2
 (C) P - 5; Q - 3; R - 1, 2; S - 4
 (D) P - 4; Q - 2, 3; R - 1; S - 5

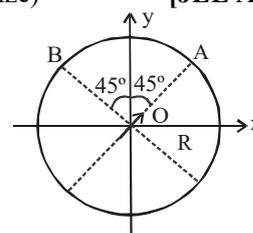
106. A thin spherical insulating shell of radius R carries a uniformly distributed charge such that the potential at its surface is V_0 . A hole with a small area $\alpha 4\pi R^2$ ($\alpha \ll 1$) is made on the shell without affecting the rest of the shell. Which one of the following statements is correct? [JEE Advanced- 2019]

- (A) The ratio of the potential at the center of the shell to that of the point at $R/2$ from center towards the hole will be $\frac{1-\alpha}{1-2\alpha}$.
- (B) The magnitude of electric field at the center of the shell is reduced by $\frac{\alpha V_0}{2R}$.
- (C) The magnitude of electric field at a point, located on a line passing through the hole and shell's center on a distance $2R$ from the center of the spherical shell will be reduced by $\frac{\alpha V_0}{2R}$.
- (D) The potential at the center of the shell is reduced by $2\alpha V_0$.

107. A charged shell of radius R carries a total charge Q . Given F as the flux of electric field through a closed cylindrical surface of height h , radius r and with its center same as that of the shell. Here, center of the cylinder is a point on the axis of the cylinder which is equidistant from its top and bottom surfaces. Which of the following option(s) is/are correct? [ϵ_0 is the permittivity of free space] [JEE Advanced- 2019]

- (A) If $h > 2R$ and $r > R$ then $\phi = \frac{Q}{\epsilon_0}$
- (B) If $8R/5$ and $r = 3R/5$ then $\phi = 0$
- (C) If $h > 2R$ and $r = 4R/5$ then $\phi = \frac{Q}{5\epsilon_0}$
- (D) If $h > 2R$ and $r = 3R/5$ then $\phi = \frac{Q}{5\epsilon_0}$

108. An electric dipole with dipole moment $\frac{P_0}{\sqrt{2}}(\hat{i} + \hat{j})$ is held fixed at the origin O in the presence of an uniform electric field of magnitude E_0 . If the potential is constant on a circle of radius R centered at the origin as shown in figure, then the correct statement(s) is/are: (ϵ_0 is permittivity of free space, $R \gg$ dipole size) [JEE Advanced- 2019]

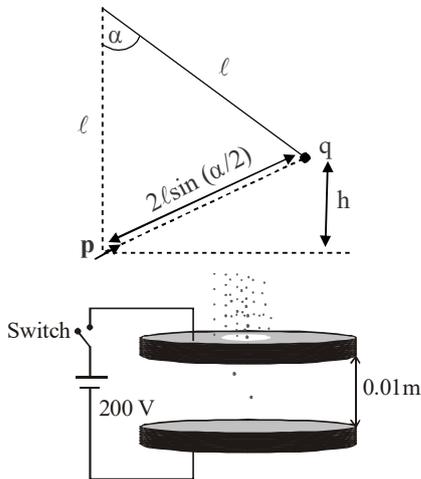


- (A) $R = \left(\frac{P_0}{4\pi\epsilon_0 E_0} \right)^{1/3}$
- (B) The magnitude of total electric field on any two points of the circle will be same.
- (C) Total electric field at point A is $\vec{E}_A = \sqrt{2}E_0(\hat{i} + \hat{j})$
- (D) Total electric field at point B is $\vec{E}_B = 0$

109. Two large circular discs separated by a distance of 0.01 m are connected to a battery via a switch as shown in the figure. Charged oil drops of density 900 kg m^{-3} are released through a tiny hole at the center of the top disc. Once some oil drops achieve terminal velocity, the switch is closed to apply a voltage of 200 V across the discs. As a result, an oil drop of radius 8×10^{-7} m stops moving vertically and floats between the discs. The number of electrons present in this oil drop is _____. (neglect the buoyancy force, take acceleration due to gravity $= 10 \text{ ms}^{-2}$ and charge on an electron (e) $= 1.6 \times 10^{-19} \text{ C}$) [JEE Advanced-2020]

110. A point charge q of mass m is suspended vertically by a string of length ℓ . A point dipole of dipole moment is now brought towards q from infinity so that the charge moves away. The final equilibrium position of the system including the direction of the dipole, the angles and distances is shown in the figure below.

If the work done in bringing the dipole to this position is $N \times (mgh)$, where g is the acceleration due to gravity, then the value of N is _____. (Note that for three coplanar forces keeping a point mass in equilibrium, $\frac{F}{\sin \theta}$ is the same for all forces, where F is any one of the forces and θ is the angle between the other two forces) [JEE Advanced-2020]



111. Two identical non-conducting solid spheres of same mass and charge are suspended in air from a common point by two non-conducting, massless strings of same length. At equilibrium, the angle between the strings is α . The spheres are now immersed in a dielectric liquid of density 800 kg m^{-3} and dielectric constant 21. If the angle between the strings remains the same after the immersion, then

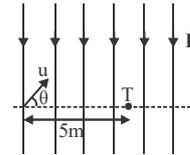
[JEE Advanced-2020]

- (A) Electric force between the spheres remains unchanged.
- (B) Electric force between the spheres reduces.
- (C) Mass density of the spheres is 840 kg m^{-3} .
- (D) The tension in the strings holding the spheres remains unchanged.

112. A uniform electric field, $\vec{E} = -400\sqrt{3}\hat{y} \text{ NC}^{-1}$ is applied in a region. A charged particle of mass m carrying positive charge q is projected in this region with an initial speed of $2\sqrt{10} \times 10^6 \text{ m/s}$. This particle is aimed to hit a target T, which is 5 m away from its entry point into the field as shown schematically in the figure.

Take $\frac{q}{m} = 10^{10} \text{ C kg}^{-1}$. Then-

[JEE Advanced-2020]

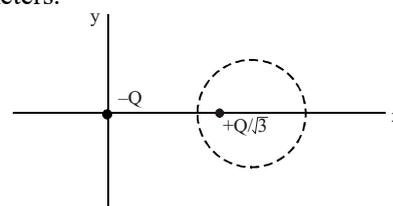


- (A) the particle will hit T if projected at an angle 45° from the horizontal.
- (B) the particle will hit T if projected either at an angle 30° or 60° from the horizontal.
- (C) time taken by the particle to hit T could be $\sqrt{\frac{5}{6}}\mu\text{s}$ as well as $\sqrt{\frac{5}{2}}\mu\text{s}$.
- (D) time taken by the particle to hit T is $\sqrt{\frac{5}{3}}\mu\text{s}$

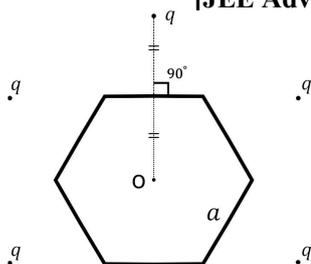
113. A circular disc of radius R carries surface charge density $\sigma(r) = \sigma_0 \left(1 - \frac{r}{R}\right)$, where σ_0 is a constant and r is the distance from the center of the disc. Electric flux through a large spherical surface that encloses the charged disc completely is ϕ_0 . Electric flux through another spherical surface of radius $R/4$ and concentric with the disc is ϕ . Then the ratio ϕ_0 / ϕ is _____. [JEE Advanced-2020]

Question Stem for Question Nos. 114 and 115

Two point charges $-Q$ and $+Q/\sqrt{3}$ are placed in the xy -plane at the origin $(0, 0)$ and a point $(2, 0)$, respectively, as shown in the figure. This results in an equipotential circle of radius R and potential $V = 0$ in the xy -plane with its center at $(b, 0)$. All lengths are measured in meters.



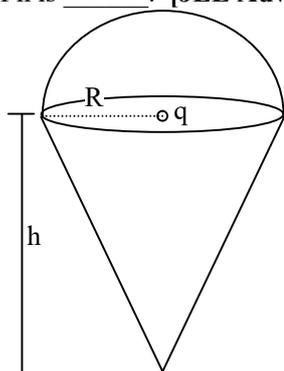
114. The value of R is ___ meter. [JEE Advanced-2021]
115. The value of b is ___ meter. [JEE Advanced-2021]
116. Six charges are placed around a regular hexagon of side length a as shown in the figure. Five of them have charge q, and the remaining one has charge x. The perpendicular from each charge to the nearest hexagon side passes through the center O of the hexagon and is bisected by the side. [JEE Advanced-2022]



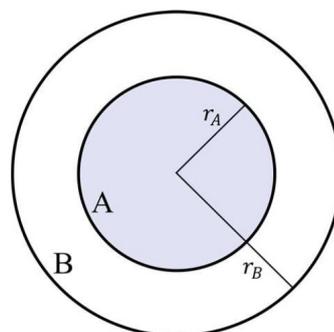
Which of the following statement(s) is(are) correct in SI units?

- (A) When $x = q$, the magnitude of the electric field at O is zero.
- (B) When $x = -q$, the magnitude of the electric field at O is $\frac{q}{6\pi\epsilon_0 a^2}$.
- (C) When $x = 2q$, the potential at O is $\frac{7q}{4\sqrt{3}\pi\epsilon_0 a}$.
- (D) When $x = -3q$, the potential at O is $-\frac{3q}{4\sqrt{3}\pi\epsilon_0 a}$.

117. A charge q is surrounded by a closed surface consisting of an inverted cone of height h and base radius R, and a hemisphere of radius R as shown in the figure. The electric flux through the conical surface is $\frac{nq}{6\epsilon_0}$ (in SI units). The value of n is _____. [JEE Advanced-2022]



118. In the figure, the inner (shaded) region A represents a sphere of radius $r_A = 1$, within which the electrostatic charge density varies with the radial distance r from the center as $\rho_A = kr$, where k is positive. In the spherical shell B of outer radius r_B , the electrostatic charge density varies as $\rho_B = \frac{2k}{r}$. Assume that dimensions are taken care of. All physical quantities are in their SI units. [JEE Advanced-2022]



Which of the following statement(s) is (are) correct ?

- (A) If $r_B = \sqrt{\frac{3}{2}}$, then the electric field is zero everywhere outside B.
- (B) If $r_B = \frac{3}{2}$, then the electric potential just outside B is $\frac{k}{\epsilon_0}$.
- (C) If $r_B = 2$, then the total charge of the configuration is $15\pi k$.
- (D) If $r_B = \frac{5}{2}$, then the magnitude of the electric field just outside B is $\frac{13\pi k}{\epsilon_0}$.

119. A disk of radius R with uniform positive charge density σ is placed on the xy plane with its center at the origin. The Coulomb potential along the z-axis is

$$V(z) = \frac{\sigma}{2\epsilon_0} \left(\sqrt{R^2 + z^2} - z \right).$$

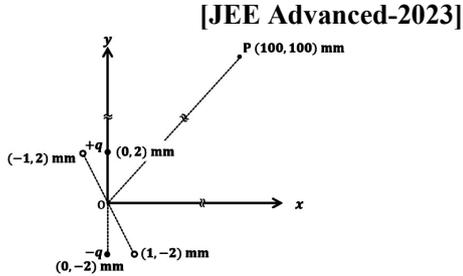
A particle of positive charge q is placed initially at rest at a point on the z axis with $z = z_0$ and $z_0 > 0$. In addition to the Coulomb force, the particle experiences a vertical force $\vec{F} = -c\hat{k}$ with $c > 0$.

Let $\beta = \frac{2c\epsilon_0}{q\sigma}$. Which of the following statements (s) is (are) correct ?

[JEE Advanced-2022]

- (A) For $\beta = \frac{1}{4}$ and $z_0 = \frac{25}{7} R$, the particle reaches the origin.
- (B) For $\beta = \frac{1}{4}$ and $z_0 = \frac{3}{7} R$, the particle reaches the origin.
- (C) For $\beta = \frac{1}{4}$ and $z_0 = \frac{R}{\sqrt{3}}$, the particle returns back to $z = z_0$.
- (D) For $\beta > 1$ and $z_0 > 0$, the particle always reaches the origin.

120. An electric dipole is formed by two charges $+q$ and $-q$ located in xy -plane at $(0, 2)$ mm and $(0, -2)$ mm, respectively, as shown in the figure. The electric potential at point P $(100, 100)$ mm due to the dipole is V_0 . The charges $+q$ and $-q$ are then moved to the points $(-1, 2)$ mm and $(1, -2)$ mm, respectively. What is the value of electric potential at P due to the new dipole?



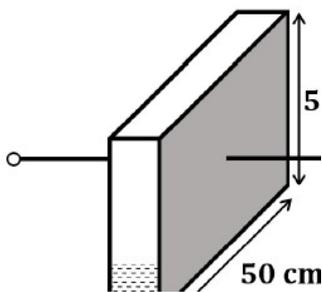
[JEE Advanced-2023]

- (A) $V_0 / 4$
- (B) $V_0 / 2$
- (C) $V_0 / \sqrt{2}$
- (D) $3V_0 / 4$

121. A container has a base of $50 \text{ cm} \times 50 \text{ cm}$ and height 50 cm , as shown in the figure. It has two parallel electrically conducting walls each of area $50 \text{ cm} \times 50 \text{ cm}$. The remaining walls of the container are thin and non-conducting. The container is being filled with a liquid of dielectric constant 3 at a uniform rate of $250 \text{ cm}^3 \text{ s}^{-1}$. What is the value of the capacitance of the container after 10 seconds?

[JEE Advanced-2023]

[Given: Permittivity of free space $\epsilon_0 = 9 \times 10^{-12} \text{ C}^2 \text{N}^{-1} \text{m}^{-2}$, the effects of the non-conducting walls on the capacitance are negligible]



- (A) 27 pF
- (B) 63 pF
- (C) 81 pF
- (D) 135 pF

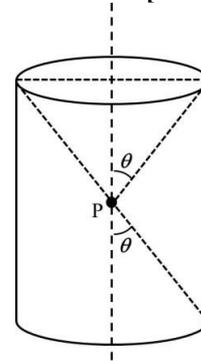
122. Two beads, each with charge q and mass m , are on a horizontal, frictionless, non-conducting, circular hoop of radius R . One of the beads is glued to the hoop at some point, while the other one performs small oscillations about its equilibrium position along the hoop. The square of the angular frequency of the small oscillations is given by $[\epsilon_0$ is the permittivity of free space.]

[JEE Advanced-2024]

- (A) $q^2 / (4\pi\epsilon_0 R^3 m)$
- (B) $q^2 / (32\pi\epsilon_0 R^3 m)$
- (C) $q^2 / (8\pi\epsilon_0 R^3 m)$
- (D) $q^2 / (16\pi\epsilon_0 R^3 m)$

123. A charge is kept at the central point P of a cylindrical region. The two edges subtend a half-angle θ at P, as shown in the figure. When $\theta = 30^\circ$, then the electric flux through the curved surface of the cylinder is Φ . If $\theta = 60^\circ$, then the electric flux through the curved surface becomes Φ / \sqrt{n} , where the value of n is _____.

[JEE Advanced-2024]

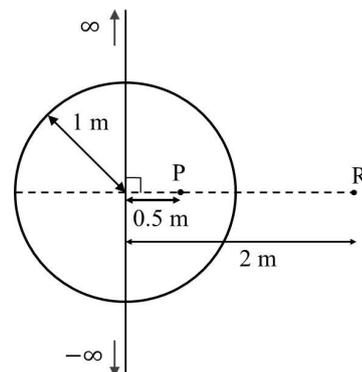


124. An infinitely long thin wire, having a uniform charge density per unit length of 5 nC/m , is passing through a spherical shell of radius 1 m , as shown in the figure. A 10 nC charge is distributed uniformly over the spherical shell. If the configuration of the charges remains static, the magnitude of the potential difference between points P and R, in Volt, is _____.

[Given: In SI units $\frac{1}{4\pi\epsilon_0} = 9 \times 10^9$, $\ln 2 = 0.7$.

Ignore the area pierced by the wire.]

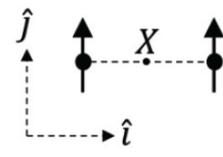
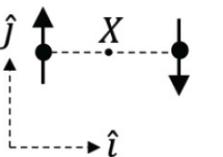
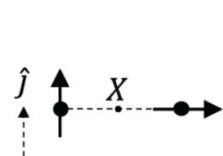
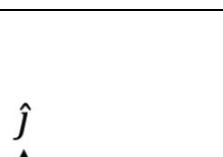
[JEE Advanced-2024]



125. List-I shows four configurations, each consisting of a pair of ideal electric dipoles. Each dipole has a dipole moment of magnitude P , oriented as marked by arrows in the figures. In all the configurations the dipoles are fixed such that they are at a distance $2r$ apart along the x direction.

The midpoint of the line joining the two dipoles is X . The possible resultant electric fields \vec{E} at X are given in List-II.

Choose the option that describes the correct match between the entries in List-I to those in List-II. [JEE Advanced-2025]

List-I	List-II
(P) 	(1) $\vec{E} = 0$
(Q) 	(2) $\vec{E} = -\frac{p}{2\pi\epsilon_0 r^3} \hat{j}$
(R) 	(3) $\vec{E} = -\frac{p}{4\pi\epsilon_0 r^3} \hat{i}$
(S) 	(4) $\vec{E} = -\frac{p}{4\pi\epsilon_0 r^3} (2\hat{i})$
	(5) $\vec{E} = -\frac{p}{\pi\epsilon_0 r^3} \hat{i}$

- (A) P→3, Q→1, R→2, S→4
- (B) P→4, Q→5, R→3, S→1
- (C) P→2, Q→1, R→4, S→5
- (D) P→2, Q→1, R→3, S→5

126. A positive point charge of 10^{-8} C is kept at a distance of 20 cm from the center of a neutral conducting sphere of radius 10 cm. The sphere is then grounded and the charge on the sphere is measured. The grounding is then removed and subsequently the point charge is moved by a distance of 10 cm further away from the center of the sphere along the radial direction.

Taking $\frac{1}{4\pi\epsilon_0} = 9 \times 10^9 \text{ Nm}^2/\text{C}^2$ (where ϵ_0 is the permittivity of free space), which of the following statements is/are correct?

[JEE Advanced-2025]

- (A) Before the grounding, the electrostatic potential of the sphere is 450 V.
- (B) Charge flowing from the sphere to the ground because of grounding is 5×10^{-9} C.
- (C) After the grounding is removed, the charge on the sphere is -5×10^{-9} C.
- (D) The final electrostatic potential of the sphere is 300 V.

127. Two co-axial conducting cylinders of same length ℓ with radii $\sqrt{2}R$ and $2R$ are kept, as shown in Fig. 1. The charge on the inner cylinder is Q and the outer cylinder is grounded. The annular region between the cylinders is filled with a material of dielectric constant $k = 5$. Consider an imaginary plane of the same length ℓ at a distance R from the common axis of the cylinders. This plane is parallel to the axis of the cylinders. The cross-sectional view of this arrangement is shown in Fig. 2. Ignoring edge effects, the flux of the electric field through the plane is (ϵ_0 is the permittivity of free space):

[JEE Advanced-2025]

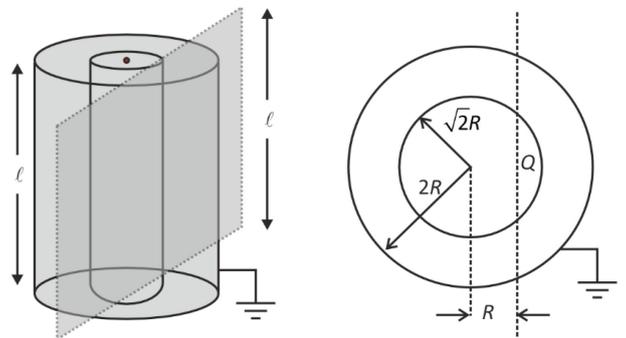


Fig. 1

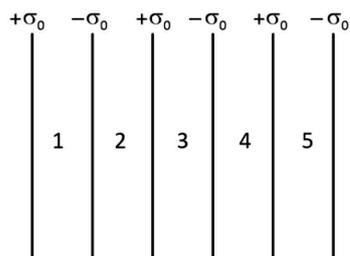
Fig. 2

- (A) $\frac{Q}{30\epsilon_0}$
- (B) $\frac{Q}{15\epsilon_0}$
- (C) $\frac{Q}{60\epsilon_0}$
- (D) $\frac{Q}{120\epsilon_0}$

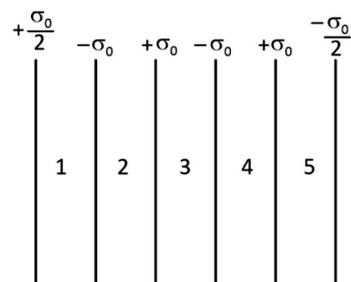
128. Six infinitely large and thin non-conducting sheets are fixed in configurations I and II. As shown in the figure, the sheets carry uniform surface charge densities which are indicated in terms of σ_0 . The separation between any two consecutive sheets is $1 \mu\text{m}$. The various regions between the sheets are denoted as 1, 2, 3, 4 and 5. If $\sigma_0 = 9 \mu\text{C}/\text{m}^2$, then which of the following statements is/are correct?

(Take permittivity of free space $\epsilon_0 = 9 \times 10^{-12}$ F/m)

[JEE Advanced-2025]



Configuration I



Configuration II

- (A) In region 4 of the configuration I, the magnitude of the electric field is zero.
- (B) In region 3 of the configuration II, the magnitude of the electric field is $\frac{\sigma_0}{\epsilon_0}$.
- (C) Potential difference between the first and the last sheets of the configuration I is 5 V.
- (D) Potential difference between the first and the last sheets of the configuration II is zero.

ANSWER KEY

EXERCISE-1

Qus.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Ans.	A	C	D	A	D	C	A	A	B	C	B	C	C	B	D	D	C	D	C	D
Qus.	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
Ans.	A	B	B	D	A	B	C	D	C	B	C	D	A	C	A	A	B	C	B	A
Qus.	41	42	43	44	45															
Ans.	B	A	B	B	C															

EXERCISE-2

Qus.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Ans.	ABD	AC	AB	ABCD	ACD	BC	ABD	AB	ABC	AC	BD	AD	AC	AC	AC
Qus.	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Ans.	ABC	AD	ABCD	AB	ACD	ACD	ABC	ABC	ABC	ACD	AD	BC	ABD	ABC	AC
Qus.	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
Ans.	AD	A	A	B	C	B	D	C	B	D	A	B	B	B	D
Qus.	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
Ans.	A	A	B	B	A	C	C	C	B	B	C	B	C	A	B
Qus.	61	62	63	64	65										
Ans.	D	C	C	C	A										

EXERCISE-3

1. (A) → P, (B) → R, (C) → Q, (D) → P, S 2. [A] → P, [B] → R, [C] → Q, [D] → P, S
 3. (A) → Q; (B) → S; (C) → R; (D) → P 4. (A) → (Q, R); (B) → (P, S, T); (C) → (P, Q, T); (D) → (P, S)
 5. (A) → (Q); (B) → (P); (C) → (S); (D) → (R)

Qus.	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Ans.	9	5	3	4	0	2	9	6	2	3	6	2	6	9	7	3	1	2	2	3
Qus.	26	27	28	29	30															
Ans.	5	9	2	9	5															

EXERCISE-4

Qus.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Ans.	D	B,C	D	C	D	C	C	C	D	B	C	D	B	A	B	B	C	A	C	A
Qus.	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
Ans.	C	D	C	D	D	B	A	A	D	C	A	D	35	C	A	D	C	C	A	D
Qus.	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
Ans.	48	4	A	543	A	A	A	A	A	A	B	A	1	B	A	A	B	6	D	D
Qus.	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
Ans.	D	D	B	C	B	B	288	A	12	B	5	640	B	2	A	C	B	2	A	A
Qus.	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
Ans.	C	2.00	B	16	NA	B	16	C	2.00	C	C	D	48.00	B,D	C,D	C	C	A	6	C
Qus.	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120
Ans.	D	A,D	A,B	2	B	A	A,B,D	A,D	6	2	A,C	B,C	6.40	1.73	3.00	A,B,C	3	B	A,C,D	B
Qus.	121	122	123	124	125	126	127	128												
Ans.	B	B	3	171	C	A,B,D	C	A												