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PHYSICS

For NEET (UG)

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ELECTROSTATICS

1. Electrostatics

1. INTRODUCTION

The branch of physics which deals with electric effect of static charge is called electrostatics.

2. ELECTRIC CHARGE

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

Charge is a derived physical quantity. Charge is measured in coulomb in S.I. unit. In practice we use mC (10^{-3}C), μC (10^{-6}C), nC(10^{-9}C) etc.

C.G.S. unit of charge = electrostatic unit = esu.

1 coulomb = 3×10^{9} esu of charge

Dimensional formula of charge = $[M^oL^oT^1I^1]$

2.1 Properties of Charge

(i) Charge is a scalar quantity: It adds algebraically and represents excess, or deficiency of electrons.

(ii) Charge is of two types :

- **(i) Positive charge and Negative charge**
- **(ii) Charging a Body :** 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 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 = 1.6×10^{-19} coulomb). So charge on anybody Q = ± ne, where n is an integer and e is the charge of the electron.

- **Millikan's oil drop** experiment proved the quantization of charge or atomicity of charge

Note : Recently, the existence of particles of charge $\pm\frac{1}{3}e$ and $\pm\frac{2}{3}e$ has been postulated. These particles are called quarks but still this is not considered as the quantum of charge because these are unstable (They have very short span of life).

(v) Like point charges repel each other while unlike point charges attract each other.

(vi) Charge is always associated with mass, i.e., charge can not exist without mass though mass can exist without charge. The particle such as photon or neutrino which have no (rest) mass can never have a charge.

(vii) Charge is relativistically invariant: This means that charge is independent of frame of reference, i.e., charge on a body does not change whatever be its speed. This property is worth mentioning as in contrast to charge, the mass of a body depends on its speed and increases with increase in speed.

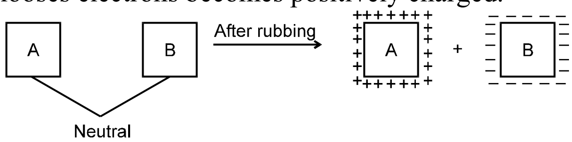
(viii) A charge at rest produces only electric field around itself; a charge having uniform motion produces electric as well as magnetic field around itself while a charge having accelerated motion emits electromagnetic radiation.

2.2 Charging of a body

A body can be charged by means of(a) friction, (b) conduction, (c) induction, (d) thermionic ionization or thermionic emission (e) photoelectric effect and (f) field emission.

(a) Charging by Friction :

When a neutral body is rubbed against other neutral body then some electrons are transferred from one body to other. The body which can hold electrons tightly, draws some electrons and the body which cannot hold electrons tightly, looses some electrons. The body which draws electrons becomes negatively charged and the body which looses electrons becomes positively charged.



For example : Suppose a glass rod is rubbed with a silk cloth. As the silk can hold electrons more tightly and a glass rod can hold electrons less tightly (due to their chemical properties), some electrons will leave the glass rod and gets transferred to the silk. So in the glass rod their will be deficiency of electrons, therefore it will become positively charged. And in the silk there will be some extra electrons, so it will become negatively charged

(b) Charging by conduction (flow): There are three types of material in nature

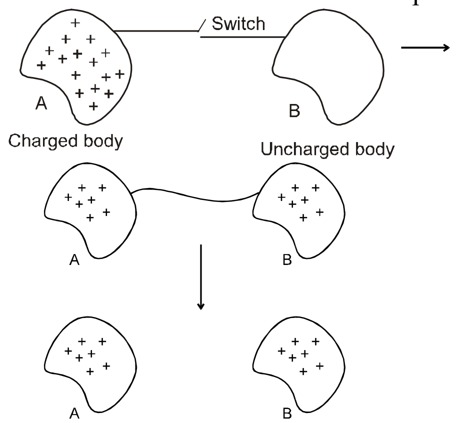
(i) Conductor : Conductors are the material in which the outer most electrons are very loosely bounded, so they are free to move (flow). So in a conductors, there are large number of free electrons.

Ex. Metals like Cu, Ag, Fe, Al... etc.

(ii) Insulator or Dielectric or Nonconductor: Non-conductors are the materials in which outer most electrons are very tightly bounded, so they cannot move (flow). Hence in a non-conductor there is no free electrons. Ex. plastic, rubber, wood etc.

(iii) Semi conductor : Semiconductor are the materials which have free electrons but very less in number.

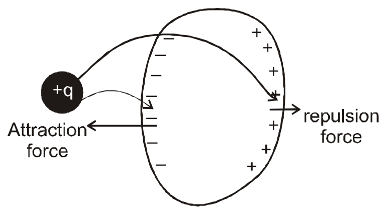
Now lets see how the charging is done by conduction. In this method we take a charged conductor 'A' and an uncharged conductor 'B'. When both are connected some charge will flow from the charged body to the uncharged body. If both the conductors are identical & kept at large distance, if connected to each other, then charge will be divided equally in both the conductors otherwise they will flow till their electric potential becomes same. Its detailed study will be done in last section of this chapter.



Example : 1

If a charged body is placed near a neutral conductor, will it attract the conductor or repel it?

Solution :



If a charged body (+ve) is placed left side near a neutral conductor, (–ve) charge will induce at left surface and (+ve) charge will induce at right surface. Due to positively charged body –ve induced charge will feel attraction and the +ve induced charge will feel repulsion. But as the –ve induced charge is nearer, so the attractive force will be greater than the repulsive force. So the net force on the conductor due to positively charged body will be attractive. Similarly we can prove for negatively charged body also.

From the above example we can conclude that. "A charged body can attract a neutral body."

If there is attraction between two bodies then one of them may be neutral. But if there is repulsion between two bodies, both must be charged (similarly charged). So **"repulsion is the sure test of electrification".**

Example : 2

A positively charged body 'A' attracts a body 'B' then charge on body 'B' may be:

(1) Positive **(2) negative**

(3) Zero **(4) can't say**

Ans. 2, 3

Example : 3

Five styrofoam balls A, B, C, D and E are used in an experiment. Several experiments are performed on the balls and the following observations are made : (i) Ball A repels C and attracts B.

(ii) Ball D attracts B and has no effect on E.

(iii) A negatively charged rod attracts both A and E.

For your information, an electrically neutral styrofoam ball is very sensitive to charge induction, and gets attracted considerably, if placed nearby a charged body. What are the charges, if any, on each ball?

	A	B	C	D	E
(1)	+	–	+	0	+
(2)	+	–	+	+	0
(3)	+	–	+	0	0
(4)	–	+	–	0	0

Solution: (3)

From (i), As A repels C, so both A and C must be charged similarly. Either both are +ve or both are –ve. As A also attract B, so charge on B should be opposite of A or B may be uncharged conductor.

From (ii), As D has no effect on E, so both D and E should be uncharged, and as B attracts uncharged D, so B must be charged and D must be on uncharged conductor.

From (iii), a –ve charged rod attract the charged ball A, so A must be +ve, and from exp. (i) C must also be +ve and B must be –ve.

Example : 4

Charge conservation is always valid. Is it also true for mass?

Solution.

No, mass conservation is not always. In some nuclear reactions, some mass is lost and it is converted into energy.

Example : 5

What are the differences between charging by induction and charging by conduction ?

Solution.

Major differences between two methods of charging are as follows :

(i) In induction, two bodies are close to each other but do not touch each other while in conduction they touch each other. (or they are connected by a metallic wire)

(ii) In induction, total charge of a body remains unchanged while in conduction it changes.

(iii) In induction, induced charge is always opposite in nature to that of source charge while in conduction charge on two bodies finally is of same nature.

Example : 6

If a glass rod is rubbed with silk it acquires a positive charge because :

(1) protons are added to it

(2) protons are removed from it

(3) electrons are added to it

(4) electrons are removed from it.

Solution: (4)

3. COULOMB'S LAW (INVERSE SQUARE 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.

i.e. $F \propto q_1q_2$ and $F \propto \frac{1}{r^2} \Rightarrow F \propto \frac{q_1q_2}{r^2}$

$\Rightarrow F = \frac{Kq_1q_2}{r^2}$

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 $\frac{1}{4\pi\varepsilon_0}$ and in any other medium expressed as $\frac{1}{4\pi\varepsilon}$. If charges are dipped in a medium then electrostatic force on one charge is $\frac{1}{4\pi\varepsilon_0\varepsilon_r}\frac{q_1q_2}{r^2}$. ε_0 and ε are called permittivity of vacuum and absolute permittivity of the medium respectively. The ratio $\varepsilon/\varepsilon_0 = \varepsilon_r$ 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 can have values between 1 to ∞. 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. For metals the value of ε_r is ∞ and for water is 81. The material in which more charge can induce ε_r will be higher.

(iv) The value of $\frac{1}{4\pi\varepsilon_0} = 9 \times 10^9\ Nm^2\ C^{-2}$

$\Rightarrow \varepsilon_0 = 8.855 \times 10^{-12}\ C^2/Nm^2$.

Dimensional formula of ε is $M^{-1}\ L^{-3}\ T^4\ A^2$

(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 close loop of any shape is zero.

(vii) Since the force is a central force, in the absence of any other external force, angular momentum of one particle w.r.t. the other particle (in two particle system) is conserved,

(viii) In vector form formula can be given as below.

$$\vec{F} = \frac{1}{4\pi\varepsilon_0\varepsilon_r}\frac{q_1q_2}{|\vec{r}|^3}\vec{r} = \frac{1}{4\pi\varepsilon_0\varepsilon_r}\frac{q_1q_2}{|\vec{r}|^2}\hat{r}$$

(q_1& q_2 are to be substituted with sign.)

here is position vector of the test charge (on which force is to be calculated) with respect to the source charge (due to which force is to be calculated).

Example : 7

Find out the electrostatics force between two point charges placed in air (each of +1 C) if they are separated by 1m .

Solution.

$F_e = \frac{kq_1q_2}{r^2} = \frac{9\times10^9\times1\times1}{1^2} = 9\times10^9$ N

From the above result we can say that 1 C charge is too large to realize. In nature, charge is usually of the order of μC

Example : 8

Two particles having charges q_1 and q_2 when kept at a certain distance, exert a force F on each other. If the distance between the two particles is reduced to half and the charge on each particle is doubled then what will be the force between the particles :

Ans. 16 F

Solution.

$\because\ F = \frac{kq_1q_2}{r^2}$

If $q'_1 = 2q_1$, $q'_2 = 2q_2$ $r' = \frac{r}{2}$,

then $F' = \frac{kq'_1q'_2}{r'^2} = \frac{k(2q_1)(2q_2)}{\left(\frac{r}{2}\right)^2}$

$F' = \frac{16kq_1q_2}{r^2}$ $F' = 16F$

Example : 9

A particle of mass m carrying charge q_1 is revolving around a fixed charge $-q_2$ in a circular path of radius r. Calculate the period of revolution and its speed also.

Solution.

$$\frac{1}{4\pi\varepsilon_0} = mr\omega^2 = \frac{4\pi^2 mr}{T^2},$$

$$T^2 = \frac{(4\pi\varepsilon_0)r^2(4\pi^2 mr)}{q_1q_2} \quad \text{or} \quad T = 4\pi r\sqrt{\frac{\pi\varepsilon_0 mr}{q_1q_2}}$$

and also we can say that

$$\frac{q_1q_2}{4\pi\varepsilon_0 r^2} = \frac{mv^2}{r} \quad \Rightarrow \quad V = \sqrt{\frac{q_1q_2}{4\pi\varepsilon_0 mr}}$$

Example : 10

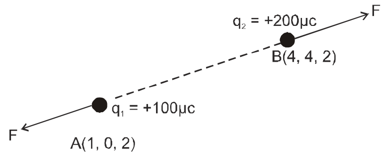
A point charge q_A = + 100 μc is placed at point A (1, 0, 2) m and an another point charge q_B = +200μc is placed at point B (4, 4, 2) m. Find :

(i) Magnitude of Electrostatic interaction force acting between them

(ii) Find $\vec{F}_A$ (force on A due to B) and $\vec{F}_B$ (force on B due to A) in vector form

Solution:

(i)



Value of

$$F: |F| = \frac{kq_Aq_B}{r^2} = \frac{(9\times10^9)(100\times10^{-6})(200\times10^{-6})}{\sqrt{(4-1)^2+(4-0)^2+(2-2)^2}}$$

= 7.2N

(ii) Force on B $\vec{F}_B = \dfrac{kq_Aq_B}{|\vec{r}|^3}\vec{r}$

$$= \frac{(9\times10^9)(100\times10^{-6})(200\times10^{-6})}{\sqrt{(4-1)^2+(4-0)^2+(2-2)^2}}\left[(4-1)\hat{i}+(4-0)\hat{j}+(2-2)\hat{k}\right]$$

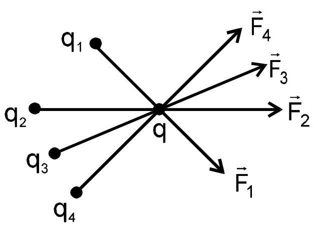
$$= 7.2\left(\frac{3}{5}\hat{i}+\frac{4}{5}\hat{j}\right)N$$

Similarly $\vec{F}_A = 7.2\left(-\frac{3}{5}\hat{i}-\frac{4}{5}\hat{j}\right)N$

Action ($\vec{F}_A$) and Reaction ($\vec{F}_B$) are equal but in opposite direction.

4. PRINCIPLE OF SUPERPOSITION

The electrostatic force is a two body interaction, i.e., electrical force



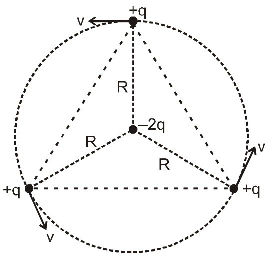
between two point charges is independent of presence or absence of other charges and so the principle of superposition is valid, i.e., force on charged particle due to number of point charges is the resultant of forces due to individual point charges, therefore, force on a point test charge due to many charges is given by.

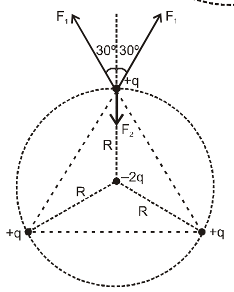
$\vec{F} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 + ...$

Example : 11

Three equal point charges of charge +q are moving along a circle of radius R and a point charge –2q is also placed at the centre of circle as (shown in figure), if charges are revolving with constant and same speed then calculate speed

Solution:





$$F_2 - 2F_1\cos 30 = \frac{mv^2}{R}$$

$$\Rightarrow \frac{K(q)(2q)}{R^2} - \frac{2(Kq^2)}{(\sqrt{3}R)^2}\cos 30 = \frac{mv^2}{R}$$

$$\Rightarrow v = \sqrt{\frac{kq^2}{Rm}\left[2-\frac{1}{\sqrt{3}}\right]}$$

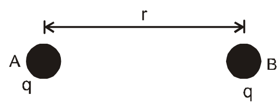
Example : 12

Two equally charged identical small metallic spheres A and B repel each other with a force 2 × 10^{-5}N when placed in air (neglect gravitation attraction). Another identical uncharged sphere C is touched to B and then placed at the mid-point of line joining A and B. What is the net electrostatic force on C?

Solution:

Let initially the charge on each sphere be q and separation between their centres be r; then according to given problem.

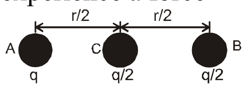
$$F = \frac{1}{4\pi\varepsilon_0}\frac{q\times q}{r^2} = 2\times10^{-5}\,N$$



When sphere C touches B, the charge of B, q will distribute equally on B and C as sphere are identical conductors, i.e., now charges on spheres;

$q_B = q_C = (q/2)$

So sphere C will experience a force



$F_{CA} = \frac{1}{4\pi\varepsilon_0}\frac{q(q/2)}{(r/2)^2} = 2F$ along $\overrightarrow{AB}$ due to charge on A

and, $F_{CB} = \frac{1}{4\pi\varepsilon_0}\frac{(q/2)(q/2)}{(r/2)^2} = F$ along $\overrightarrow{BA}$ due to charge on B

So the net force F_C on C due to charges on A and B,

$F_C = F_{CA} - F_{CB} = 2F - F = 2 \times 10^{-5}$ N along $\overrightarrow{AB}$.

Example : 13

Five point charges, each of value q are placed on five vertices of a regular hexagon of side L. What is the magnitude of the force on a point charge of value –q coulomb placed at the centre of the hexagon?

Solution:

Method : I

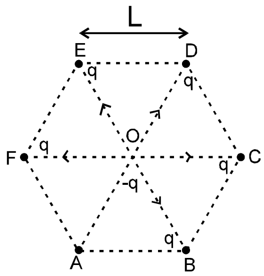
If there had been a sixth charge +q at the remaining vertex of hexagon force due to all the six charges on –q at O would be zero (as the forces due to individual charges will balance each other), i.e.,

$\overrightarrow{F_R} = 0$

Now if $\vec{f}$ is the force due to sixth charge and $\vec{F}$ due to remaining five charges.

$\vec{F} + \vec{f} = 0$ i.e. $\vec{F} = -\vec{f}$

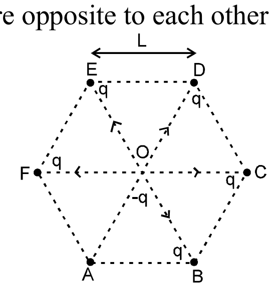
or, $|F| = |f| = \frac{1}{4\pi\varepsilon_0}\frac{q \times q}{L^2} = \frac{1}{4\pi\varepsilon_0}\frac{q^2}{L^2}$



$\vec{F}_{Net} = \vec{F}_{CO} = \frac{1}{4\pi\varepsilon_0}\frac{q^2}{L^2}$ along CO

Method : II

In the diagram we can see that force due to charge A and D are opposite to each other



$\vec{F}_{DO} + \vec{F}_{AO} = 0$ ....(i)

Similarly $\vec{F}_{BO} + \vec{F}_{EO} = 0$ ....(ii)

So $\vec{F}_{AO} + \vec{F}_{BO} + \vec{F}_{CO} + \vec{F}_{DO} + \vec{F}_{EO} = \vec{F}_{Net}$

Using (i) and (ii) $\vec{F}_{Net} = \vec{F}_{CO} = \frac{1}{4\pi\varepsilon_0}\frac{q^2}{L^2}$ along CO.

Note :

(1) The total charge of the rod cannot be considered to be placed at the centre of the rod as we do in mechanics for mass in many problems.

Note:

(2) If a >>l then

$F = \frac{KQq}{a^2}$ behaviour of the rod is just like a point charge.

5. ELECTROSTATIC EQUILIBRIUM

The point where the resultant force on a charged particle becomes zero is called equilibrium position.

5.1 Stable Equilibrium:

A charge is initially in equilibrium position and is displaced by a small distance. If the charge tries to return back to the same equilibrium position then this equilibrium is called position of stable equilibrium.

5.2 Unstable Equilibrium:

If charge is displaced by a small distance from its equilibrium position and the charge has no tendency to return to the same equilibrium position. Instead it goes away from the equilibrium position.

5.3 Neutral Equilibrium:

If charge is displaced by a small distance and it is still in equilibrium condition then it is called neutral equilibrium.

Example : 14

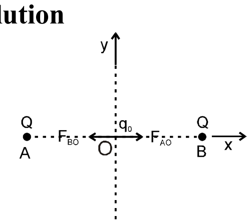
Two equal positive point charges 'Q' are fixed at points B(a, 0) and A(–a, 0). Another test charge q_0 is also placed at O(0, 0). Show that the equilibrium at 'O' is

(i) stable for displacement along X-axis.

(ii) unstable for displacement along Y-axis.

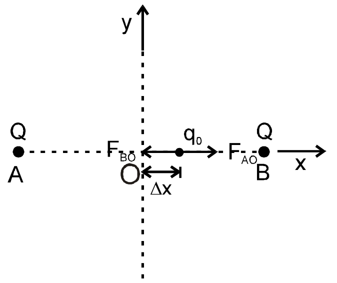
Solution

(i)



Initially $\vec{F}_{AO} + \vec{F}_{BO} = 0 \Rightarrow |\vec{F}_{AO}| = |\vec{F}_{BO}| = \frac{KQq_0}{a^2}$

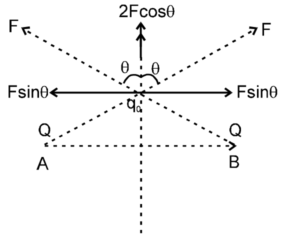
When charge is slightly shifted towards + x axis by a small distance Δx, then.



$|\vec{F}_{AO}| < |\vec{F}_{BO}|$

Therefore the particle will move towards origin (its original position) hence the equilibrium is stable.

(ii) When charge is shifted along y axis



After resolving components net force will be along y axis so the particle will not return to its original position so it is unstable equilibrium. Finally the charge will move to infinity.

Example : 15

Two point charges of charge q_1 and q_2 (both of same sign) and each of mass m are placed such that gravitation attraction between them balances the electrostatic repulsion. Are they in stable equilibrium? If not then what is the nature of equilibrium?

Solution:

In given example :

$$\frac{K q_1 q_2}{r^2} = \frac{Gm^2}{r^2}$$

We can see that irrespective of distance between them charges will remain in equilibrium. If now distance is increased or decreased then there is no effect in their equilibrium. Therefore it is a neutral equilibrium.

Example : 16

A particle of mass m and charge q is located midway between two fixed charged particles each having a charge q and a distance 2ℓ apart. Prove that the motion of the particle will be SHM if it is displaced slightly along the line connecting them and released. Also find its time period.

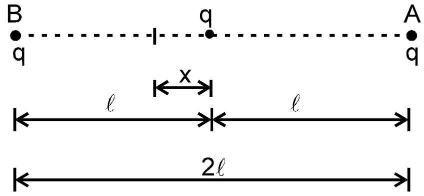
Solution:

Let the charge q at the mid-point the displaced slightly to the left.

The force on the displaced charge q due to charge q at A,

$$F_1 = \frac{1}{4\pi\varepsilon_0}\frac{q^2}{(\ell + x)^2}$$

The force on the displaced charge q due to charge at B,



$$F_2 = \frac{1}{4\pi\varepsilon_0}\frac{q^2}{(\ell - x)^2}$$

Net restoring force on the displaced charge q.

$$F = F_2 - F_1 \text{ or } F = \frac{1}{4\pi\varepsilon_0}\frac{q^2}{(\ell - x)^2} - \frac{1}{4\pi\varepsilon_0}\frac{q^2}{(\ell + x)^2}$$

$$\text{or} \quad F = \frac{q^2}{4\pi\varepsilon_0}\left[\frac{1}{(\ell - x)^2} - \frac{1}{(\ell + x)^2}\right]$$

$$= \frac{q^2}{4\pi\varepsilon_0}\frac{4\ell x}{(\ell^2 - x^2)^2}$$

Since $\ell >> x$, $\therefore F = \frac{q^2 \ell x}{\pi\varepsilon_0 \ell^4}$ or $F = \frac{q^2 x}{\pi\varepsilon_0 \ell^3}$

We see that $F \propto x$ and it is opposite to the direction of displacement. Therefore, the motion is SHM.

$$T = 2\pi\sqrt{\frac{m}{k}}, \text{ here } k = \frac{q^2}{\pi \in_0 \ell^3} \quad = 2\pi\sqrt{\frac{m\pi \in_0 \ell^3}{q^2}}$$

Example : 17

Two identical charged spheres are suspended by strings of equal length. Each string makes an angle θ with the vertical. When suspended in a liquid of density σ = 0.8 gm/cc, the angle remains the same. What is the dielectric constant of the liquid? (Density of the material of sphere is ρ = 1.6 gm/cc.)

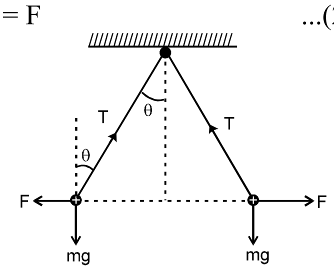
Solution:

Initially as the forces acting on each ball are tension T, weight mg and electric force F, for its equilibrium along vertical,

$T \cos\theta = mg$ ...(1)

and along horizontal

$T \sin\theta = F$ ...(2)



Dividing Eqn. (2) by (1), we have

$\tan\theta = \frac{F}{mg}$ ... (3)

When the balls are suspended in a liquid of density σ and dielectric constant K, the electric force will become (1/K) times, i.e., F' = (F/K) while weight

$mg' = mg - F_B = mg - V\sigma g$ [as $F_B = V\sigma g$, where σ is density of material of sphere]

i.e., $mg' = mg\left[1 - \frac{\sigma}{\rho}\right]$ $\left[\text{as } V = \frac{m}{\rho}\right]$

So for equilibrium of ball,

$$\tan\theta' = \frac{F'}{mg'} = \frac{F}{Kmg[1-(\sigma/\rho)]} \quad ...(4)$$

According to given information θ' = θ; so from equations (4) and (3), we have

$$K = \frac{\rho}{(\rho-\sigma)} = \frac{1.6}{(1.6-0.8)} = 2$$ **Ans.**

6. ELECTRIC FIELD

Electric field is the region around charged particle or charged body in which if another charge is placed, it experiences electrostatic force.

6.1 Electric field intensity $\vec{E}$:

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 $\vec{E} = \frac{\vec{F}}{q_0}$;

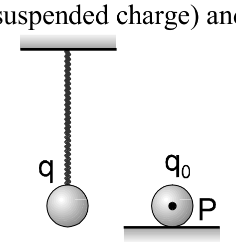
If the $\vec{E}$ is to be determined practically then the test charge q_0 should be small otherwise it will affect the charge distribution on the source which is producing the electric field and hence modify the quantity which is measured.

Example : 18

A positively charged ball hangs from a long silk thread. We wish to measure E at a point P in the same horizontal plane as that of the hanging charge. To do so, we put a positive test charge q_0 at the point and measure F/q_0. Will F/q_0 be less than, equal to, or greater than E at the point in question?

Solution:

When we try to measure the electric field at point P then after placing the test charge at P it repels the source charge (suspended charge) and the measured



Value of electric field $E_{measured} = \frac{F}{q_0}$ will be less than the actual value E_{act} that we wanted to measure.

6.2 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) Direction of 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 is $\vec{E}$ 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.

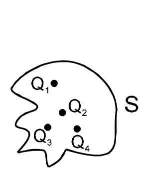
(vi) It obeys the superposition principle, that is, the field intensity at a point due to a system of charges is vector sum of the field intensities due to individual point charges.

$\vec{E} = \vec{E}_1 + \vec{E}_2 + \vec{E}_3 + ...$

(vii) It is produced by source charges. The electric field will be a fixed value at a point unless we change the distribution of source charges.

Example : 19

Electrostatic force experienced by –3μC charge placed at point 'P' due to a system 'S' of fixed point charges as shown in figure is μN.



(i) Find out electric field intensity at point P due to S.

(ii) If now 2μC charge is placed and –3 $\vec{F} = (21\hat{i} + 9\hat{j})$ μC is removed at point P then force experienced by it will be.

Solution:

(i) $\vec{F} = q\vec{E} \Rightarrow (21\hat{i} + 9\hat{j})\mu N = -3\mu C\,(\vec{E}) \Rightarrow \vec{E} = -7\hat{i} - 3\hat{j}\ \frac{\mu N}{C}$

(ii) Since the source charges are not disturbed the electric field intensity at 'P' will remain same.

$\vec{F}_{2\mu C} = +2(\vec{E}) = 2(-7\hat{i} - 3\hat{j}) = -14\hat{i} - 6\hat{j}\ \mu N$

Example : 20

Calculate the electric field intensity which would be just sufficient to balance the weight of a particle of charge –10 μc and mass 10 mg. (take g = 10 ms^2)

Solution:

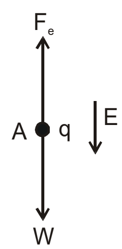
As force on a charge q in an electric field $\vec{E}$ is

$\vec{F}_q = q\vec{E}$

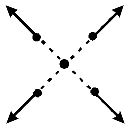
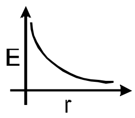
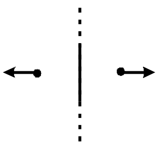
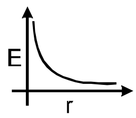
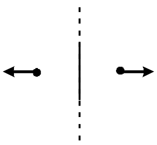
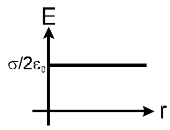
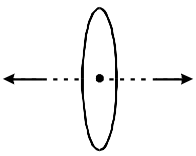
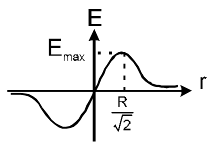
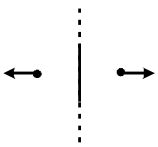
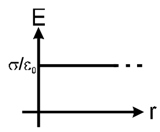
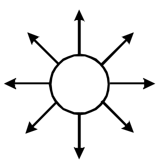
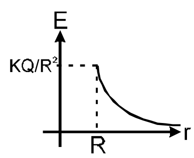
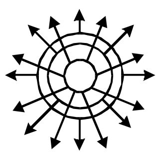
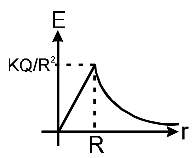
So according to given problem

$|\vec{F}_q| = |\vec{W}|$ i.e., $|q|E = mg$

i.e., $E = \frac{mg}{|q|}$ = 10 N/C., in downward direction.

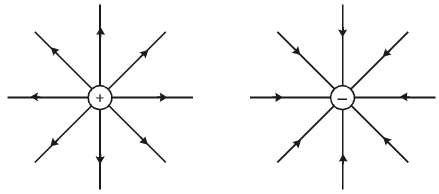


- **List of formula for Electric Field Intensity due to various types of charge distribution :**

Name / Type	Formula	Note	Graph
Point charge 	$\vec{E}=\dfrac{Kq}{\lvert\vec{r}\rvert^2}\cdot\hat{r}$	* q is source charge. * $\vec{r}$ is vector drawn from source charge to the test point. outwards due to +charges & inwards due to –charges.	
Infinitely long line charge 	$\dfrac{\lambda}{2\pi\varepsilon_0 r}\hat{r}=\dfrac{2K\lambda\hat{r}}{r}$	* q is linear charge density (assumed uniform) * r is perpendicular distance of point from line charge. * is radial unit vector drawn from the charge to test point.	
Infinite non-conducting thin sheet 	$\dfrac{\sigma}{2\varepsilon_0}\hat{n}$	* σ is surface charge density. (assumed uniform) * is unit normal vector. * x = distance of point on the axis from centre of the ring. * electric field is always along the axis.	
Uniformly charged ring 	$E=\dfrac{KQx}{\left(R^2+x^2\right)^{3/2}}$ $E_{centre}=0$	* Q is total charge of the ring * x = distance of point on the axis from centre of the ring. * electric field is always along the axis.	
Infinitely large charged conducting sheet 	$\dfrac{\sigma}{\varepsilon_0}\hat{n}$	* σ is the surface charge . density (assumed uniform) * $\hat{n}$ is the unit vector perpendicular is the surface.	
Uniformly charged hollow conducting/ nonconducting /solid conducting sphere 	(i) for $r \geq R$ $\vec{E}=\dfrac{kQ}{\lvert\vec{r}\rvert^2}\hat{r}$ (ii) for r < R E = 0	* R is radius of the sphere. * $\vec{r}$ is vector drawn from centre of sphere to the point. * Sphere acts like a point charge. placed at centre for points outside the sphere. * $\vec{E}$ is always along radial direction. * Q is total charge ($=\sigma 4\pi R^2$). (σ = surface charge density)	
Uniformly charged solid nonconducting sphere (insulating material) 	(i) for $r \geq R$ $\vec{E}=\dfrac{kQ}{\lvert\vec{r}\rvert^2}\hat{r}$ (ii) for $r \leq R$ $\vec{E}=\dfrac{kQ}{R^3}\vec{r}$	$\vec{r}$ is vector drawn from centre of sphere to the point * Sphere acts like a point charge placed at the centre for points outside the sphere $\vec{E}$ is always along radial dir^n * Q is total charge $(\rho.\frac{4}{3}\pi R^3)$. ($\rho$ = volume charge density) * Inside the sphere $E \propto r$. * Outside the sphere $E \propto 1/r^2$.	

- **Electric field due to point charge**

$E = \frac{kq}{r^2} \qquad \vec{E} = \frac{kq}{r^2}\hat{r} \qquad \vec{E} = \frac{kq}{r^3}\vec{r}$



$\vec{r}$ = position vector of test point with respect to source charge

$\vec{r} = \vec{r}_{\text{test point}} - \vec{r}_{\text{source charge}}$

Example : 21

Find out electric field intensity at point A (0, 1m, 2m) due to a point charge –20μC situated at point B($\sqrt{2}$ m, 0, 1m).

Solution:

$E = \frac{KQ}{|\vec{r}|^3}\vec{r} = \frac{KQ}{|\vec{r}|^2}\hat{r}$

$\Rightarrow$ $\vec{r}$ = P.V. of A – P.V. of B (P.V.=Position vector)

$= (-\sqrt{2}\,\hat{i} + \hat{j} + \hat{k})$

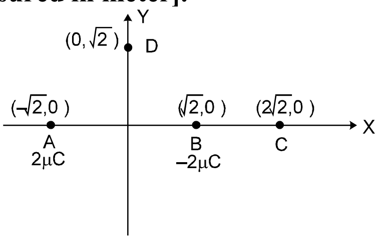
$|\vec{r}| = \sqrt{(\sqrt{2})^2 + (1)^2 + (1)^2} = 2$

$\vec{E} = \frac{9\times10^9 \times (-20\times10^{-6})}{8}\ (-\sqrt{2}\,\hat{i} + \hat{j} + \hat{k})$

$= -22.5 \times 10^3 (-\sqrt{2}\,\hat{i} + \hat{j} + \hat{k})$N/C.

Example : 22

Two point charges 2μc and – 2μc are placed at point A and B as shown in figure. Find out electric field intensity at points C and D. [All the distances are measured in meter].



Solution

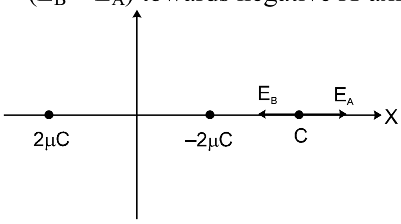
Electric field at point C

(E_A, E_B are magnitudes only and arrows represent directions)

Electric field due to positive charge is away from it while due

to negative charge it is towards the charge. It is clear that $E_B > E_A$.

$\therefore$ $E_{Net} = (E_B - E_A)$ towards negative X-axis



$= \frac{K(2\mu c)}{(\sqrt{2})^2} - \frac{K(2\mu c)}{(3\sqrt{2})^2}$ towards negative X-axis

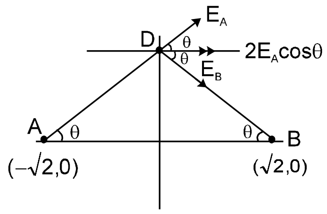
$= 8000\,(-\hat{i})$ N/C

Electric field at point D :

Since magnitude of charges are same and also AD = BD

So $E_A = E_B$

Vertical components of $\vec{E}_A$ and $\vec{E}_B$ cancel each other while horizontal components are in the same direction.

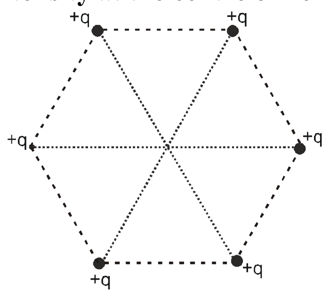


So, $E_{net} = 2E_A \cos\theta = \frac{2.K(2\mu c)}{2^2}\cos45^0$

$= \frac{K\times10^{-6}}{\sqrt{2}} = \frac{9000}{\sqrt{2}}\hat{i}$ N/C.

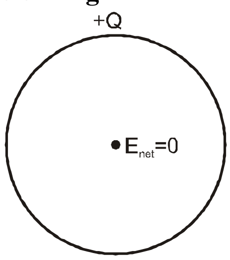
Example : 23

Six equal point charges are placed at the corners of a regular hexagon of side 'a'. Calculate electric field intensity at the centre of hexagon?



Solution: Zero

Similarly electric field due to a uniformly charged ring at the centre of ring :



Note:

(i) Net charge on a conductor remains only on the outer surface of a conductor.

(ii) On the surface of isolated spherical conductor charge is uniformly distributed.

6.3 Electric field due to a uniformly charged ring and arc.

Example : 24

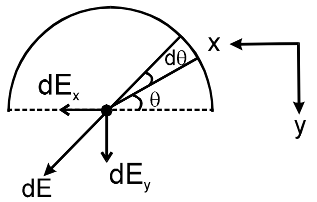
Find out electric field intensity at the centre of uniformly charged semicircular ring of radius R and linear charge density λ.

Solution:

λ = linear charge density.

The arc is the collection of large no. of point charges.

Consider a part of ring as an element of length $Rd\theta$ which subtends an angle $d\theta$ at centre of ring and it lies between θ and $\theta + d\theta$



$\overrightarrow{dE} = dE_x\hat{i} + dE_y\hat{j}$ $E_x = \int dE_x = 0$ (due to symmetry)

$$E_y = \int dE_y = \int_0^{\pi} dE\sin\theta = \frac{K\lambda}{R}\int_0^{\pi}\sin\theta . d\theta = \frac{2K\lambda}{R}$$

Example : 25

Find out electric field intensity at the centre of uniformly charged quarter ring of radius R and linear charge density λ.

Solution:

Refer to the previous equation $\overrightarrow{dE} = dE_x\hat{i} + dE_y\hat{j}$ on solving $E_{net} = \dfrac{K\lambda}{R} = (\hat{i}+\hat{j})$,

Electric field due to ring on its axis :

$$E_{net} = \frac{KQx}{[R^2 + x^2]^{3/2}}$$

E will be max when $\dfrac{dE}{dx} = 0$, that is at $x = \dfrac{R}{\sqrt{2}}$ and

$$E_{max} = \frac{2KQ}{3\sqrt{3}\,R^2}$$

Case (i):

If $x >> R$, $E = \dfrac{KQ}{x^2}$ Hence the ring will act like a point charge

Case (ii): if $x << R$, $E = \dfrac{KQ\,x}{R^3}$

Example : 26

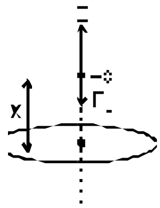
Positive charge Q is distributed uniformly over a circular ring of radius R. A point particle having a mass m and a negative charge –q, is placed on its axis at a distance x from the centre. Find the force on the particle. Assuming x << R, find the time period of oscillation of the particle if it is released from there. (Neglect gravity)

Solution:

When the negative charge is shifted at a distance x from the centre of the ring along its axis then force acting on the point charge due to the ring:

$F_E = qE$ (towards centre)

$$= q\left[\frac{KQx}{(R^2+x^2)^{3/2}}\right]$$



if $R >> x$ then

$R^2 + x^2 \simeq R^2$

$$F_E = \frac{1}{4\pi\varepsilon_0}\frac{Qqx}{R^3} \text{ (Towards centre)}$$

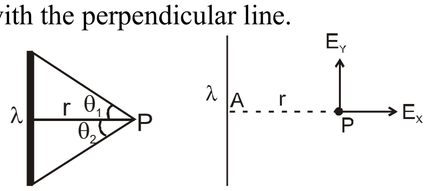
Since restoring force $F_E \propto x$, therefore motion of charge the particle will be S.H.M.

Time period of SHM.

$$T = 2\pi\sqrt{\frac{m}{k}} = 2\pi\sqrt{\frac{m}{\left(\dfrac{Qq}{4\pi\varepsilon_0 R^3}\right)}} = \left[\frac{16\pi^3\varepsilon_0 mR^3}{Qq}\right]^{1/2}$$

6.4 Electric field due to uniformly charged wire

(i) Line charge of finite length : Derivation of expression for intensity of electric field at a point due to line charge of finite size of uniform linear charge density λ. The perpendicular distance of the point from the line charge is r and lines joining ends of line charge distribution make angle θ_1 and θ_2 with the perpendicular line.



$\mathbf{E_x = K\lambda/r\ [\sin\theta_1+\sin\theta_2]}$ ....(1)

$\mathbf{E_y = K\lambda/r\ [\cos\theta_2 - \cos\theta_1]}$

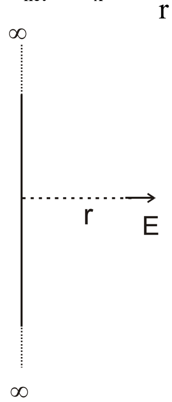
Net electric field at the point

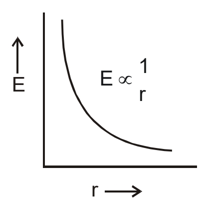
$$E_{net} = \sqrt{E_x^2 + E_y^2}$$

(ii) We can derive a result for infinitely long line charge

In above eq. (1) & (2) if we put $\theta_1 = \theta_2 = 90°$ we can get required result.

$$E_{net} = E_x = \frac{2K\lambda}{r}$$

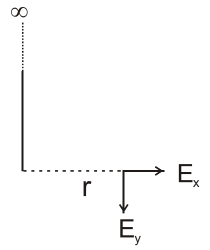




(iii) For Semi- infinite wire

$\theta_1 = 90^o$ and $\theta_2 = 0^o$ so

$$E_x = \frac{K\lambda}{r}, E_y = \frac{K\lambda}{r}$$



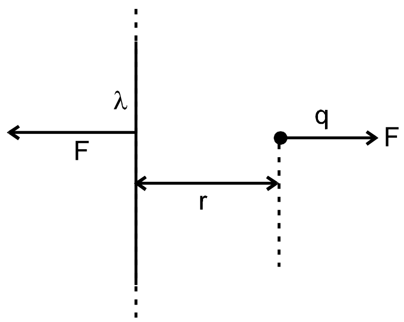
Example : 27

A point charge q is placed at a distance r from a very long charge thread of uniform linear charge density λ. Find out total electric force experienced by the line charge due to the point charge. (Neglect gravity).

Solution.

Force on charge q due to the thread,

$$F = \left(\frac{2K\lambda}{r}\right).q$$



By Newton's III law, every action has equal and opposite reaction so force on the thread = $\frac{2K\lambda}{r}.q$ (away from point charge)

6.5 Electric field due to uniformly charged infinite sheet

$E_{net} = \frac{\sigma}{2\varepsilon_o}$ toward normal direction

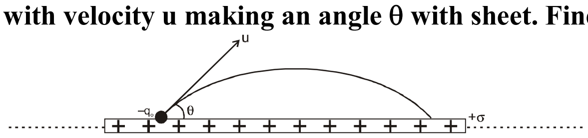
Note:

(1) The direction of electric field is always perpendicular to the sheet.

(2) The magnitude of electric field is independent of distance from sheet.

Example : 28

An infinitely large plate of surface charge density +σ is lying in horizontal xy plane. A particle having charge $-q_o$ and mass m is projected from the plate with velocity u making an angle θ with sheet. Find :

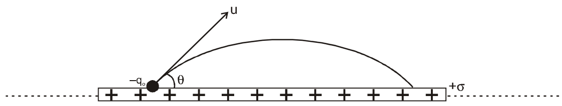


(i) The time taken by the particle to return on the plate.

(ii) Maximum height achieved by the particle.

(iii) At what distance will it strike the plate (Neglect gravitational force on the particle)

Solution:



Electric force acting on the particle $F_e = q_oE : F_e = (q_o)\left(\frac{\sigma}{2\varepsilon_o}\right)$ downward

So acceleration of the particle:

$$a = \frac{F_e}{m} = \frac{q_o\sigma}{2\varepsilon_o m} = \text{uniform}$$

This acceleration will act like 'g' (acceleration due to gravity)

So the particle will perform projectile motion.

(i) $T = \frac{2u\sin\theta}{g} = \frac{2u\sin\theta}{\left(\frac{q_o\sigma}{2\varepsilon_o m}\right)}$

(ii) $H = \frac{u^2\sin^2\theta}{2g} = \frac{u^2\sin^2\theta}{2\left(\frac{q_0\sigma}{2\varepsilon_0 m}\right)}$

(iii) $R = \frac{u^2\sin 2\theta}{g} = \frac{u^2\sin 2\theta}{\left(\frac{q_o\sigma}{2\varepsilon_o m}\right)}$

Example : 29

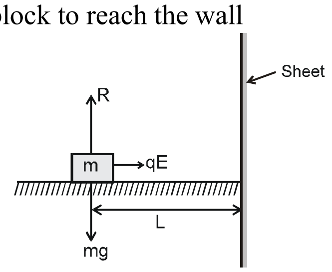
A block having mass m and charge –q is resting on a frictionless plane at a distance L from fixed large non-conducting infinite sheet of uniform charge density σ as shown in Figure. Discuss the motion of the block assuming that collision of the block with the sheet is perfectly elastic. Is it SHM?

Solution

The situation is shown in Figure. Electric force produced by sheet will accelerate the block towards the sheet producing acceleration. Acceleration will be uniform because electric field E due to the sheet is uniform.

$a = \frac{F}{m} = \frac{qE}{m}$, where $E = \sigma/2\varepsilon_0$

As initially the block is at rest and acceleration is constant, from second equation of motion, time taken by the block to reach the wall



$L = \frac{1}{2}at^2$ i.e., $t = \sqrt{\frac{2L}{a}} = \sqrt{\frac{2mL}{qE}} = \sqrt{\frac{4m\varepsilon_0 L}{q\sigma}}$

As collision with the wall is perfectly elastic, the block will rebound with same speed and as now its motion is opposite to the acceleration, it will come to rest after travelling same distance L in same time t. After stopping it will be again accelerated towards the wall and so the block will execute oscillatory motion with 'span' L and time period.

$T = 2t = 2\left(\sqrt{\frac{2mL}{qE}}\right) = 2\left(\sqrt{\frac{4m\varepsilon_0 L}{q\sigma}}\right)$

However, as the restoring force F = qE is constant and not proportional to displacement x, the motion is not simple harmonic.

Example : 30

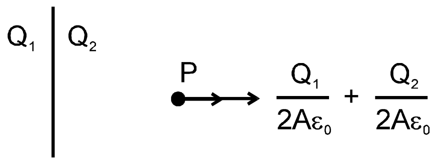
If an isolated infinite sheet contains charge Q_1 on its one surface and charge Q_2 on its other surface then prove that electric field intensity at a point in front of sheet will be $\frac{Q}{2A\varepsilon_0}$, where $Q = Q_1 + Q_2$

Solution

Electric field at point P :

$\vec{E} = \vec{E}_{Q_1} + \vec{E}_{Q_2}$

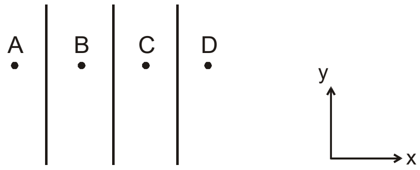
$= \frac{Q_1}{2A\varepsilon_0}\hat{n} + \frac{Q_2}{2A\varepsilon_0}\hat{n} = \frac{Q_1 + Q_2}{2A\varepsilon_0}\hat{n} = \frac{Q}{2A\varepsilon_0}\hat{n}$



[This shows that the resultant field due to a sheet depends only on the total charge of the sheet and not on the distribution of charge on individual surfaces].

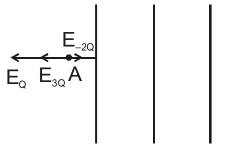
Example : 31

Three large conducting parallel sheets are placed at a finite distance from each other as shown in figure. Find out electric field intensity at point A, B, C & D.



Solution:

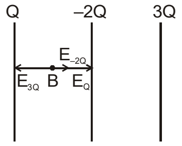
For point A



$\vec{E}_{net} = \vec{E}_Q + \vec{E}_{3Q} + \vec{E}_{-2Q} = -\frac{Q}{2A\varepsilon_0}\hat{i} - \frac{3Q}{2A\varepsilon_0}\hat{i} + \frac{2Q}{2A\varepsilon_0}\hat{i}$

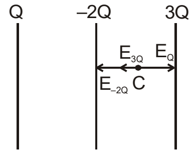
$= -\frac{Q}{A\varepsilon_0}\hat{i}$

for point B



$\vec{E}_{net} = \vec{E}_{3Q} + \vec{E}_{-2Q} + \vec{E}_Q = -\frac{3Q}{2A\varepsilon_0}\hat{i} + \frac{2Q}{2A\varepsilon_0}\hat{i} + \frac{Q}{2A\varepsilon_0}\hat{i} = 0$

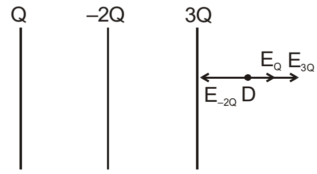
for point C



$\vec{E}_{net} = \vec{E}_Q + \vec{E}_{3Q} + \vec{E}_{-2Q} = +\frac{Q}{2A\varepsilon_0}\hat{i} - \frac{3Q}{2A\varepsilon_0}\hat{i} - \frac{2Q}{2A\varepsilon_0}\hat{i}$

$= -\frac{2Q}{A\varepsilon_0}$

for point D



$\vec{E}_{net} = \vec{E}_Q + \vec{E}_{3Q} + \vec{E}_{-2Q}$

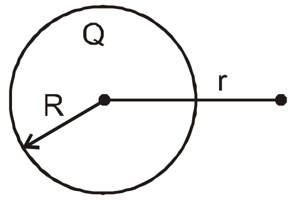
$= +\frac{Q}{2A\varepsilon_0}\hat{i} + \frac{3Q}{2A\varepsilon_0}\hat{i} - \frac{2Q}{2A\varepsilon_0}\hat{i} = \frac{Q}{A\varepsilon_0}\hat{i}$

6.6 Electric field due to uniformly charged spherical shell

$E = \frac{KQ}{r^2}$ $r \geq R$

⇒For the out side points & point on the surface the uniformly charged spherical shell behaves as a point charge placed at the centre

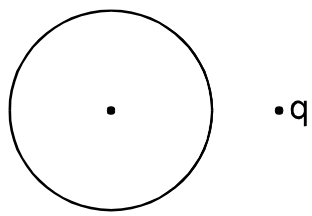
$E = 0$ $r < R$



Electric field due to spherical shell out side it is always along the radial direction.

Example: 32

Figure shows a uniformly charged sphere of radius R and total charge Q. A point charge q is situated outside the sphere at a distance r from centre of sphere. Find out the following:



(i) Force acting on the point charge q due to the sphere.

(ii) Force acting on the sphere due to the point charge.

Solution:

(i) Electric field at the position of point charge

$$\vec{E} = \frac{KQ}{r^2}\hat{r}$$

So, $\vec{F} = \frac{KqQ}{r^2}\hat{r}$ $\quad |\vec{F}| = \frac{KqQ}{r^2}$

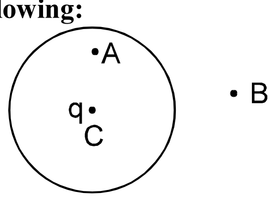
(ii) Since we know that every action has equal and opposite reaction so

$$\vec{F}_{sphere} = -\frac{KqQ}{r^2}\hat{r} \quad |\vec{F}_{sphere}| = \frac{KqQ}{r^2}.$$

Example : 33

Figure shows a uniformly charged thin sphere of total charge Q and radius R. A point charge q is also situated at the centre of the sphere.

Find out the following:



(i) Force on charge q

(ii) Electric field intensity at A.

(iii) Electric field intensity at B.

Solution:

(i) Electric field at the centre of the uniformly charged hollow sphere = 0

So force on charge q = 0

(ii) Electric field at A

$$\vec{E}_A = \vec{E}_{Sphere} + \vec{E}_q = 0 + \frac{Kq}{r^2} \quad ; \ r = CA$$

E due to sphere = 0, because point lies inside the charged hollow sphere.

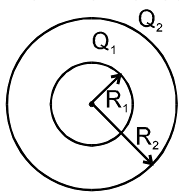
(iii) Electric field $\vec{E}_B$ at point B = $\vec{E}_{Sphere} + \vec{E}_q$

$$= \frac{KQ}{r^2}.\hat{r} + \frac{Kq}{r^2}.\hat{r} = \frac{K(Q+q)}{r^2}.\hat{r} \ ; \ r = CB$$

Note : Here we can also assume that the total charge of sphere is concentrated at the centre, for calculation of electric field at B.

Example : 34

Two concentric uniformly charged spherical shells of radius R_1 and R_2 ($R_2 > R_1$) have total charges Q_1 and Q_2 respectively. Derive an expression of electric field as a function of r for following positions.



(i) $r < R_1$ (ii) $R_1 \le r < R_2$ (iii) $r \ge R_2$

Solution:

(i) for $r < R_1$,

therefore point lies inside both the spheres

$E_{net} = E_{Inner} + E_{outer} = 0 + 0$

(ii) for $R_1 \le r < R_2$,

therefore point lies outside inner sphere but inside outer sphere:

$$E_{net} = E_{inner} + E_{outer} = \frac{KQ_1}{r^2}\hat{r} + 0 = \frac{KQ_1}{r^2}\hat{r}$$

(iii) for $r \ge R_2$

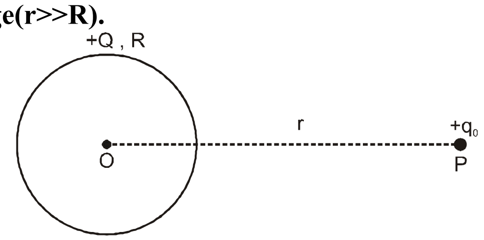
point lies outside inner as well as outer sphere therefore.

$$E_{Net} = E_{inner} + E_{outer} = \frac{KQ_1}{r^2}\hat{r} + \frac{KQ_2}{r^2}\hat{r}$$

$$= \frac{K(Q_1 + Q_2)}{r^2}\hat{r}$$

Example : 35

A spherical shell having charge +Q (uniformly distributed) and a point charge + q_0 are placed as shown. Find the force between shell and the point charge(r>>R).



(i) Force on the point charge + q_0 due to the shell = q_0

$$\vec{E}_{shell} = (q_0)\left(\frac{KQ}{r^2}\right)\hat{r} = \frac{KQq_0}{r^2}\hat{r}$$ where $\hat{r}$ is unit vector along OP.

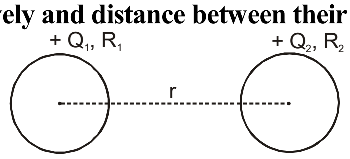
From action - reaction principle, force on the shell due to the point charge will also be

$$F_{shell} = \frac{KQq_0}{r^2}(-\hat{r})$$

Conclusion - To find the force on a hollow sphere due to outside charges , we can replace the sphere by a point charge kept at centre.

Example : 36

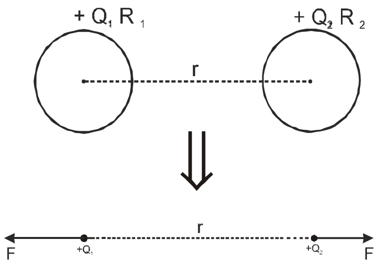
Find force acting between two shells of radius R_1 and R_2 which have uniformly distributed charges Q_1 and Q_2 respectively and distance between their centre is r.



Solution:

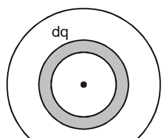
The shells can be replaced by point charges kept at centre so force between them

$$F = \frac{KQ_1Q_2}{r^2}$$



6.7 Electric field due to uniformly charged solid sphere

Derive an expression for electric field due to solid sphere of radius R and total charge Q which is uniformly distributed in the volume,
at a point which is at a distance r from centre for given two cases.



(i) r ≥ R (ii) r ≤ R

Assume an elementary concentric shell of charge dq. Due to this shell
the electric field at the point (r > R) will be

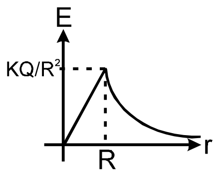
$dE = \frac{Kdq}{r^2}$ [from above result of hollow sphere]

$E_{net} = \int dE = \frac{KQ}{r^2}$

For r < R, there will be no electric field due to shell of radius greater than r, so electric field at the point will be present only due to shells having radius less than r.

$E'_{net} = \frac{KQ'}{r^2}$

here $Q' = \frac{Q}{\frac{4}{3}\pi R^3} \times \frac{4}{3}\pi r^3 = \frac{Qr^3}{R^3}$



$E'_{net} = \frac{KQ'}{r^2} = \frac{KQr}{R^3}$ away from the centre.

Note :

The electric field inside and outside the sphere is always in radial direction.

7. ELECTRIC POTENTIAL

In electrostatic field the electric potential (due to some source charges) at a point P is defined as the work done by external agent in taking a point unit positive charge from a reference point (generally taken at infinity) to that point P without changing its kinetic energy.

7.1 Mathematical representation:

If $(W_{\infty \to P})_{ext}$ is the work required in moving a point charge q from infinity to a point P, the electric potential of the point P is

$$V_p = \left.\frac{W_{\infty p})_{ext}}{q}\right]_{\Delta K=0} = \frac{-W_{elc})_{\infty \to p}}{q}$$

Note:

(i) $(W_{\infty \to P})_{ext}$ can also be called as the work done by external agent against the electric force on a unit positive charge due to the source charge.

(ii) Write both W and q with proper sign.

7.2 Properties :

(i) Potential is a scalar quantity, its value may be positive, negative or zero.

(ii) S.I. Unit of potential is volt = $\frac{\text{joule}}{\text{coulmb}}$ and its dimensional formula is $[M^1L^2T^{-3}I^{-1}]$.

(iii) Electric potential at a point is also equal to the negative of the work done by the electric field in taking the point charge from reference point (i.e. infinity) to that point.

(iv) Electric potential due to a positive charge is always positive and due to negative charge it is always negative except at infinite. (Taking $V_\infty=0$).

(v) Potential decreases in the direction of electric field.

(vi) $V = V_1 + V_2 + V_3 + ...$

7.3 Use of potential :

If we know the potential at some point (In terms of numerical value or in terms of formula) then we can find out the work done by electric force when charge moves from point 'P' to ∞ by the formula

$W_{el})_{p\infty} = qV_p$

Example : 37

A charge 2μC is taken from infinity to a point in an electric field, without changing its velocity. If work done against electrostatic forces is –40μJ then find the potential at that point.

Solution: $V = \frac{W_{ext}}{q} = \frac{-40\mu J}{2\mu C} = -20\ V$

Example : 38

When charge 10 μC is shifted from infinity to a point in an electric field, it is found that work done by electrostatic forces is –10 μJ. If the charge is doubled and taken again from infinity to the same point without accelerating it, then find the amount of work done by electric field and against electric field.

Solution:

$W_{ext})_{\infty p} = -W_{el})_{\infty p} = W_{el})_{p\,\infty} = 10\ \mu J$ because $\Delta KE = 0$

$V_p = \frac{W_{ext})_{\infty p}}{q} = \frac{10\mu J}{10\mu C} = 1V$

So if now the charge is doubled and taken from infinity then

$1 = \frac{W_{ext})_{\infty p}}{20\mu C} \Rightarrow W_{ext})_{\infty P} = 20\ \mu J \Rightarrow W_{el})_{\infty P} = -20\ \mu J$

Example : 39

A charge 3μC is released at rest from a point P where electric potential is 20 V then its kinetic energy when it reaches to infinite is :

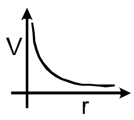
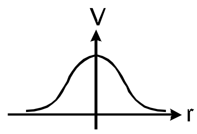
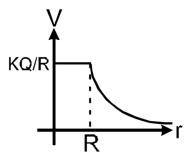
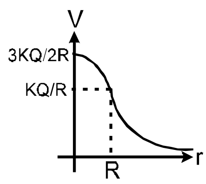
Solution

$W_{el} = \Delta K = K_f - 0$

$W_{el})_{P \to \infty} = qV_P = 60\ \mu J$

so, $K_f = 60\ \mu J$

Electric Potential due to various charge distributions are given in table.

Name / Type	Formula	Note	Graph
Point charge	$\frac{Kq}{r}$	* q is source charge. * r is the distance of the point from the point charge.	
Ring (uniform/nonuniform charge distribution)	at centre $\frac{KQ}{R}$ at the axis $\frac{KQ}{\sqrt{R^2+x^2}}$	* Q is source charge. *x is the distance of the point on the axis	
Uniformly charged hollow conducting/nonconducting /solid conducting sphere	for $r \geq R$ $V = \frac{kQ}{r}$ for $r \leq R$ $V = \frac{kQ}{R}$	* R is radius of sphere * r is the distance from centre of sphere to the point * Q is total charge = $\sigma 4\pi R^2$.	
Uniformly charged solid nonconducting	for $r \geq R$ $V = \frac{kQ}{r}$ for $r \leq R$ $\frac{KQ(3R^2-r^2)}{2R^3}$ $= \frac{KQ(3R^2-r^2)}{2R^3}$	* R is radius of sphere * r is distance from centre to the point * $V_{centre} = 3/2 \times V_{surface}$. * Q is total charge $=\rho \times 4/3 \times \pi R^3$. * Inside sphere potential varies parabolically * outside potential varies hyperbolically.	
Infinite line charge	Not defined	* Absolute potential is not defined. * Potential difference between two points is given by formula $v_B - v_A = -2K\lambda \ln(r_B/r_A)$	
Infinite nonconducting thin sheet	Not defined	* Absolute potential is not defined. * Potential difference between two points is given by formula $v_A - v_B = (-)\frac{\sigma}{2t_0}(r_B - r_A)$	

7.4 Potential due to a point charge:

Derivation of expression for potential due to point charge Q, at a point which is at a distance r from the point charge.

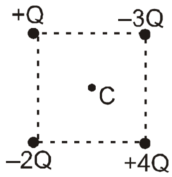
from definition potential

$$V = \frac{W_{ext(\infty \to p)}}{q_o} = \frac{-\int_{\infty}^{r} (q_0\vec{E})\cdot\Delta\vec{r}}{q_o} = -\int_{\infty}^{r}\vec{E}\cdot\vec{dr}$$

$$\Rightarrow V = -\int_{\infty}^{r}\frac{KQ}{r^2}(-dr)\cos180^o = \frac{KQ}{r}$$

Example : 40

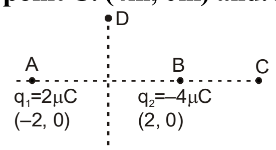
Four point charges are placed at the corners of a square of side ℓ calculate potential at the centre of square.



Solution V d= 0 at 'C'.

Example : 41

Two point charges 2μC and – 4μC are situated at points (–2m, 0m) and (2m, 0m) respectively. Find out potential at point C. (4m, 0m) and. D (0m, $\sqrt{5}$ m).



Solution

Potential at point C

$$V_C = V_{q_1} + V_{q_2} = \frac{K(2\mu C)}{6} + \frac{K(-4\mu C)}{2}$$

$$= \frac{9\times10^9\times2\times10^{-6}}{6} - \frac{9\times10^9\times4\times10^{-6}}{2} = -15000 \text{ V.}$$

Similarly, $V_D = V_{q_1} + V_{q_2} = \frac{K(2\mu C)}{\sqrt{(\sqrt{5})^2+2^2}} +$

$$\frac{K(-4\mu C)}{\sqrt{(\sqrt{5})^2+2^2}} = \frac{K(2\mu C)}{3} + \frac{K(-4\mu C)}{3} = -\ 6000 \text{ V.}$$

Finding potential due to continuous charges

If formula of E is tought, then we take a small element and integrate	If formula of E is easy then we use
$v = \int dv$	$v = -\int_{r\to\infty}^{r=r}\vec{E}\cdot\vec{dr}$ (i.e. for sphere, plate infinite wire etc.)

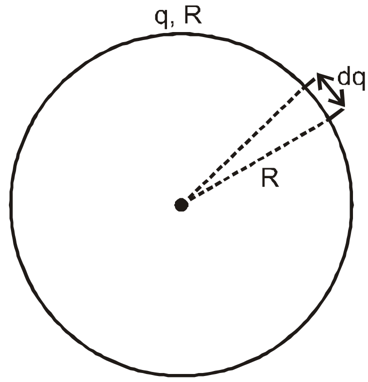
7.5 Potential due to a ring :

(i) Potential at the centre of uniformly charged ring:

Potential due to the small element dq

$$dV = \frac{Kdq}{R}$$

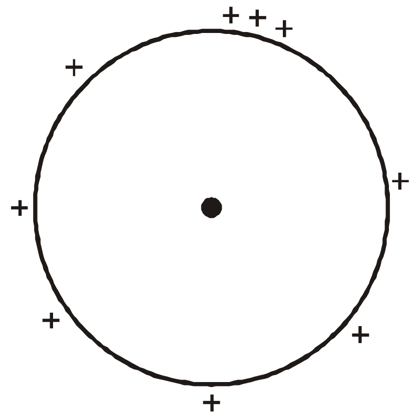
Net potential $\quad V = \int\frac{Kdq}{R}$



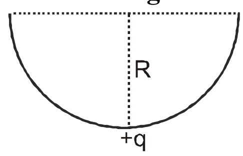
$$V = \frac{K}{R}\int dq = \frac{Kq}{R}$$

(ii) For non-uniformly charged ring potential at the center is

$$V = \frac{Kq_{total}}{R}$$

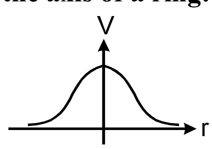


(iii) Potential due to half ring at center is:



$$V = \frac{Kq}{R}$$

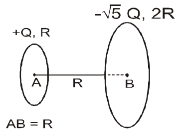
(iv) Potential at the axis of a ring:



$$V = \frac{KQ}{\sqrt{R^2+x^2}}$$

Example : 42

Figure shows two rings having charges Q and $-\sqrt{5}$ Q. Find Potential difference between A and B ($V_A - V_B$).



Solution:

$$V_A = \frac{KQ}{R} + \frac{K\left(-\sqrt{5}\,Q\right)}{\sqrt{(2R)^2+(R)^2}} \quad V_B = \frac{K\left(-\sqrt{5}\,Q\right)}{2\,R} + \frac{K(\,Q)}{\sqrt{(R)^2+(R)^2}}$$

From above we can easily find $V_A - V_B$.

Example : 43

A point charge q_0 is placed at the centre of uniformly charged ring of total charge Q and radius R. If the point charge is slightly displaced with negligible force along axis of the ring then find out its speed when it reaches to a large distance.

Solution:

Only electric force is acting on q_0

$$\therefore \quad W_{el} = \Delta K \quad = \frac{1}{2}mv^2 - 0$$

$$\Rightarrow \text{Now } W_{el})_{c\to\infty} = q_0\,V_c = q_0\,.\frac{KQ}{R}$$

$$\therefore \quad \frac{Kq_0Q}{R} = \frac{1}{2}mv^2 \qquad \Rightarrow v = \sqrt{\frac{2Kq_0Q}{mR}}$$

7.6 Potential due to uniformly charged disc:

$V = \frac{\sigma}{2\varepsilon_0}\left(\sqrt{R^2+x^2} - x\right)$, where σ is the charged density and x is the distance of the point on the axis from the center of the disc, R is the radius of disc.

7.7 Potential Due To Uniformly Charged Spherical shell:

Derivation of expression for potential due to uniformly charged hollow sphere of radius R and total charge Q, at a point which is at a distance r from centre for the following situation

(i) r > R **(ii) r < R**

As the formula of E is easy, we use $V = -\int_{r\to\infty}^{r=r} \vec{E}\cdot d\vec{r}$

(i) At outside point (r $\geq$ R):

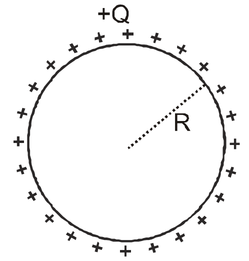
$$V_{out} = -\int_{r\to\infty}^{r=r}\left(\frac{KQ}{r^2}\right)dr$$

$$\Rightarrow V_{out} = \frac{KQ}{r} = \frac{KQ}{(\text{Distance from centre})}$$

For outside point, the hollow sphere act like a point charge.

(ii) Potential at the centre of the sphere (r=0) :

As all the charges Are at a distance R from the centre,

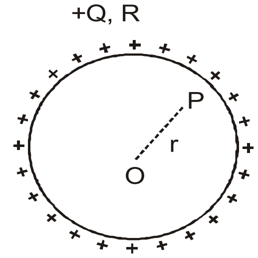


$$\text{So } V_{centre} = \frac{KQ}{R} = \frac{KQ}{(\text{Radius of the sphere})}$$

(iii) Potential at inside point (r<R) :

Suppose we want to find potential at point P , inside the sphere.

Potential difference between Point P and O :

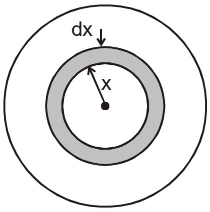


$$V_P - V_O = -\int_O^P \vec{E}_{in}\cdot d\vec{r} \text{ Where } E_{in} = 0$$

$$\text{So } V_P - V_O = 0 \qquad \Rightarrow V_P = V_O = \frac{KQ}{R}$$

$$\Rightarrow V_{In} = \frac{KQ}{R} = \frac{KQ}{(\text{Radius of the sphere})}$$

7.8 Potential Due To Uniformly Charged Solid Sphere:



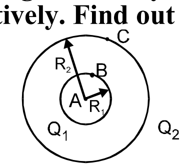
(i) for $r \geq R$ (outside) $V = \frac{KQ}{r}$

(ii) for $r \leq R$ (inside) $V = \frac{KQ}{2R^3}$

$(3R^2 - r^2) \quad \Rightarrow \text{Here } \rho = \frac{Q}{\frac{4}{3}\pi R^3}$

Example : 44

Two concentric spherical shells of radius R_1 and R_2 ($R_2 > R_1$) are having uniformly distributed charges Q_1 and Q_2 respectively. Find out potential



(i) at point A
(ii) at surface of smaller shell (i.e. at point B)
(iii) at surface of larger shell (i.e. at point C)
(iv) *at $r \le R_1$*
(v) at $R_1 \le r \le R_2$
(vi) at $r \ge R_2$

Solution:

Using the results of hollow sphere as given in the table 7.4.

(i) $V_A = \frac{KQ_1}{R_1} + \frac{KQ_2}{R_2}$ (ii) $V_B = \frac{KQ_1}{R_1} + \frac{KQ_2}{R_2}$

(iii) $V_C = \frac{KQ_1}{R_2} + \frac{KQ_2}{R_2}$

(iv) for $r \le R_1$ $V = \frac{KQ_1}{R_1} + \frac{KQ_2}{R_2}$

(v) for $R_1 \le r \le R_2$ $V = \frac{KQ_1}{r} + \frac{KQ_2}{R_2}$

(vi) for $r \ge R_2$ $V = \frac{KQ_1}{r} + \frac{KQ_2}{r}$

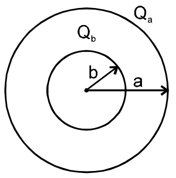
Example : 45

Two hollow concentric non-conducting spheres of radius a and b (a > b) contains charges Q_a and Q_b respectively. Prove that potential difference between two spheres is independent of charge on outer sphere. If outer sphere is given an extra charge, is there any change in potential difference?

Solution

$$V_{\text{inner sphere}} = \frac{KQ_b}{b} + \frac{KQ_a}{a}$$

$$V_{\text{outer sphere}} = \frac{KQ_b}{a} + \frac{KQ_a}{a}$$



$$V_{\text{inner sphere}} - V_{\text{outer sphere}} = \frac{KQ_b}{b} - \frac{KQ_b}{a}$$

$$\Delta V = KQ_b\left[\frac{1}{b} - \frac{1}{a}\right]$$

Which is independent of charge on outer sphere.

If outer sphere in given any extra charge then there will be no change in potential difference.

8. POTENTIAL DIFFERENCE

The potential difference between two points A and B is work done by external agent against electric field in taking a unit positive charge from A to B without acceleration (or keeping Kinetic Energy constant or $K_i = K_f$))

(1) Mathematical representation :

If $(W_{A \to B})_{ext}$ = work done by external agent against electric field in taking the unit charge from A to B

$$V_B - V_A = \left.\frac{(W_{A\to B})_{ext}}{q}\right)_{\Delta K=0} = \frac{-(W_{A\to B})_{electric}}{q}$$

$$= \frac{U_B - U_A}{q} = \frac{-\int_A^B \vec{F}_e.\vec{dr}}{q} = -\int_A^B \vec{E}.\vec{dr}$$

Note : Take W and q both with sign

(2) Properties:

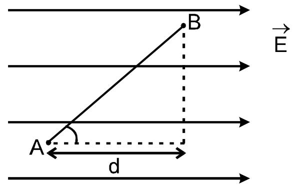
(i) The difference of potential between two points is called potential difference. It is also called voltage.

(ii) Potential difference is a scalar quantity. Its S.I. unit is also volt.

(iii) If V_A and V_B be the potential of two points A and B, then work done by an external agent in taking the charge q from A to B is $(W_{ext})_{AB} = q\,(V_B - V_A)$ or $(W_{el})_{AB} = q\,(V_A - V_B)$.

(iv) Potential difference between two points is independent of reference point.

8.1 Potential difference in a uniform electric field:



$\mathbf{V_B - V_A} = -\vec{E}\cdot\overrightarrow{AB} \Rightarrow V_B - V_A = -|E|\,|AB| \cos\theta$
$= -|E|\,d = -Ed$

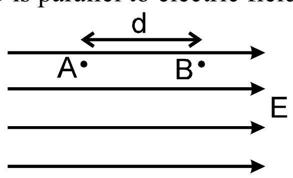
d = effective distance between A and B along electric field.

or we can also say that $E = \frac{\Delta V}{\Delta d}$

- **Special Cases:**

  Case 1

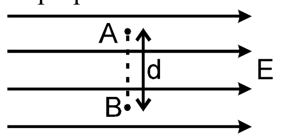
  Line AB is parallel to electric field.



$\therefore$ $V_A - V_B = Ed$

Case 2

Line AB is perpendicular to electric field.



$\therefore$ $V_A - V_B = 0$ $\Rightarrow$ $V_A = V_D$

Note :

In the direction of electric field potential always decreases.

Example : 46

1μC charge is shifted from A to B and it is found that work done by an external force is 40μJ in doing so against electrostatic forces then, find potential difference $V_A - V_B$

Solution

$(W_{AB})_{ext} = q(V_B - V_A) \Rightarrow 40\ \mu J = 1\mu C\ (V_B - V_A)$

$\Rightarrow\ V_A - V_B = -40$

Example : 47

A uniform electric field is present in the positive x-direction. If the intensity of the field is 5N/C then find the potential difference ($V_B - V_A$) between two points A (0m, 2 m) and B (5 m ,3 m)

Solution

$V_B - V_A = -\vec{E}.\vec{AB} = -(5\hat{i}).(5\hat{i}+\hat{j}) = -25V.$

The electric field intensity in uniform electric field,

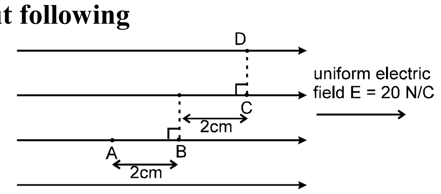
$$E = \frac{\Delta V}{\Delta d}$$

Where ΔV = potential difference between two points.

Δd = effective distance between the two points. (projection of the displacement along the direction of electric field.)

Example : 48

Find out following



(i) $V_A - V_B$ (ii) $V_B - V_C$

(iii) $V_C - V_A$ (iv) $V_D - V_C$

(v) $V_A - V_D$

(vi) Arrange the order of potential for points A, B, C and D.

Solution

(i) $|\Delta V_{AB}| = Ed = 20 \times 2 \times 10^{-2} = 0.4$

so, $V_A - V_B = 0.4$ V

because **In the direction of electric field potential always decreases.**

(ii) $|\Delta V_{BC}| = Ed = 20 \times 2 \times 10^{-2} = 0.4$

so, $V_B - V_C = 0.4$ V

(iii) $|\Delta V_{CA}| = Ed = 20 \times 4 \times 10^{-2} = 0.8$

so, $V_C - V_A = -0.8$ V

because **In the direction of electric field potential always decreases.**

(iv) $|\Delta V_{DC}| = Ed = 20 \times 0 = 0$ so, $V_D - V_C = 0$

because the effective distance between D and C is zero.

(v) $|\Delta V_{AD}| = Ed = 20 \times 4 \times 10^{-2} = 0.8$

so, $V_A - V_D = 0.8$ V

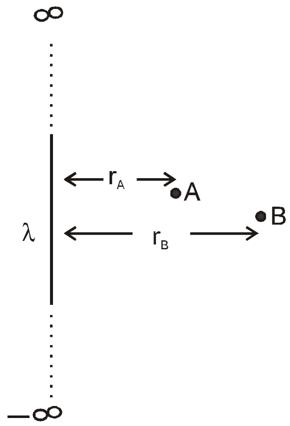
because **In the direction of electric field potential always decreases.**

(vi) The order of potential

$V_A > V_B > V_C = V_D$.

8.2 Potential difference due to infinitely long wire :

Derivation of expression for potential difference between two points, which have perpendicular distance r_A and r_B from infinitely long line charge of uniform linear charge density λ..



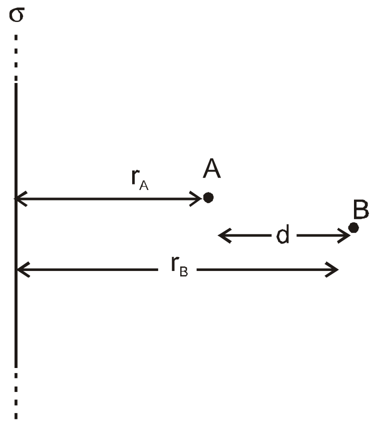
From definition of potential difference

$$V_{AB} = V_B - V_A = -\int_{r_A}^{r_B} \vec{E}\cdot\vec{dr} = -\int_{r_A}^{r_B} \frac{2K\lambda}{r}\hat{r}\cdot\vec{dr}$$

$$V_{AB} = -2K\lambda \ell n\left(\frac{r_B}{r_A}\right)$$

8.3 Potential difference due to infinitely long thin sheet:

Derivation of expression for potential difference between two points, having separation d in the direction perpendicularly to a very large uniformly charged thin sheet of uniform surface charge density σ.



Let the points A and B have perpendicular distance r_A and r_B respectively then from definition of potential difference.

$$V_{AB} = V_B - V_A = -\int_{r_A}^{r_B} \vec{E}\cdot\vec{dr} = -\int_{r_A}^{r_B} \frac{\sigma}{2\varepsilon_0}\hat{r}\cdot\vec{dr}$$

$$\Rightarrow V_{AB} = -\frac{\sigma}{2\varepsilon_o}(r_B - r_A) = -\frac{\sigma d}{2\varepsilon_o}$$

9. EQUIPOTENTIAL SURFACE :

9.1 Definition : If potential of a surface (imaginary or physically existing) is same throughout then such surface is known as a equipotential surface.

9.2 Properties of equipotential surfaces :

(i) When a charge is shifted from one point to another point on an equipotential surface then work done against electrostatic forces is zero.

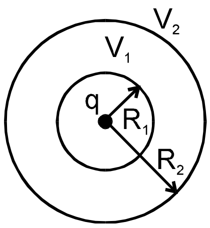
(ii) Electric field is always perpendicular to equipotential surfaces.

(iii) Two equipotential surfaces do not cross each other.

9.3 Examples of equipotential surfaces :

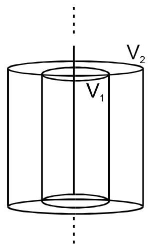
(i) Point charge :

Equipotential surfaces are concentric and spherical as shown in figure. In figure we can see that sphere of radius R_1 has potential V_1 throughout its surface and similarly for other concentric sphere potential is same.



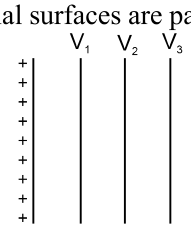
(ii) Line charge :

Equipotential surfaces have curved surfaces as that of coaxial cylinders of different radii.



(iii) Uniformly charged large conducting / non conducting sheets

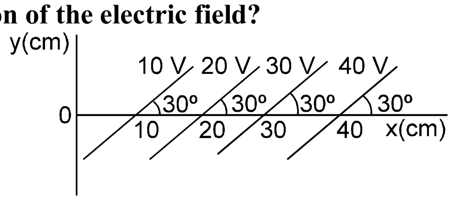
Equipotential surfaces are parallel planes.



Note : In uniform electric field equipotential surfaces are always parallel planes.

Example : 49

Some equipotential surfaces are shown in figure. What can you say about the magnitude and the direction of the electric field?



Solution:

Here we can say that the electric will be perpendicular to equipotential surfaces.

Also $|\vec{E}| = \dfrac{\Delta V}{\Delta d}$

where ΔV = potential difference between two equipotential surfaces.

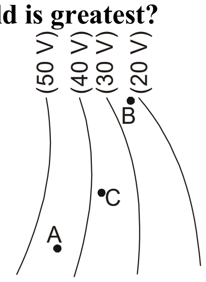
Δd = perpendicular distance between two equipotential surfaces.

So $|\vec{E}| = \dfrac{10}{(10\sin 30^\circ)\times 10^{-2}} = 200$ V/m

Now there are two perpendicular directions either direction 1 or direction 2 as shown in figure, but since we know that in the direction of electric field electric potential decreases so the correct direction is direction 2. Hence E = 200 V/m, making an angle 120° with the x-axis

Example : 50

Figure shows some equipotential surface produce by some charges. At which point the value of electric field is greatest?



Solution:

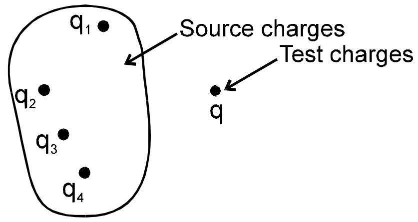
E is larger where equipotential surfaces are closer. ELOF are ⊥ to equipotential surfaces. In the figure we can see that for point B they are closer so E at point B is maximum

10. ELECTROSTATIC POTENTIAL ENERGY

10.1 Electrostatic potential energy of a point charge due to many charges:

The electrostatic potential energy of a point charge at a point in electric field is the work done in taking the charge from reference point (generally at infinity) to that point without acceleration (or keeping KE const. or $K_i = K_f$)).

Its Mathematical formula is



$U = W_{\infty P)ext}]_{acc\,=\,0} = qV = -W_{P\infty)el}$

Here q is the charge whose potential energy is being calculated and V is the potential at its position due to the source charges.

Note: Always put q and V with sign.

10.2 Properties:

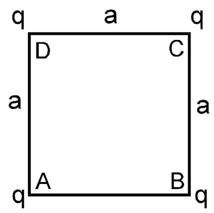
(i) Electric potential energy is a scalar quantity but may be positive, negative or zero.

(ii) Its unit is same as unit of work or energy that is joule (in S.I. system).
Some times energy is also given in electron-volts.
$1eV = 1.6 \times 10^{-19}$ J

(iii) Electric potential energy depends on reference point. (Generally Potential Energy at $r = \infty$ is taken zero)

Example : 51

The four identical charges q each are placed at the corners of a square of side a.
Find the potential energy of one of the charges due to the remaining charges.



Solution

The electric potential of point A due to the charges placed at B, C and D is

$$V = \frac{1}{4\pi\varepsilon_0}\frac{q}{a} + \frac{1}{4\pi\varepsilon_0}\frac{q}{\sqrt{2}a} + \frac{1}{4\pi\varepsilon_0}\frac{q}{a} = \frac{1}{4\pi\varepsilon_0}\left(2 + \frac{1}{\sqrt{2}}\right)\frac{q}{a}$$

$\therefore$ Potential energy of the charge at A is

$$= qV = \frac{1}{4\pi\varepsilon_0}\left(2 + \frac{1}{\sqrt{2}}\right)\frac{q^2}{a}.$$

Example : 52

A particle of mass 40 mg and carrying a charge 5×10^{-9} C is moving directly towards a fixed positive point charge of magnitude 10^{-8} C. When it is at a distance of 10 cm from the fixed point charge it has speed of 50 cm/s. At what distance from the fixed point charge will the particle come momentarily to rest? Is the acceleration constant during the motion?

Solution:

If the particle comes to rest momentarily at a distance r form the fixed charge, then from conservation of energy' we have

$$\frac{1}{2}mu^2 + \frac{1}{4\pi\varepsilon_0}\frac{Qq}{a} = \frac{1}{4\pi\varepsilon_0}\frac{Qq}{r}$$

Substituting the given data, we get

$$\frac{1}{2} \times 40 \times 10^{-6} \times \frac{1}{2} \times \frac{1}{2} = 9 \times 10^9 \times 5 \times 10^{-8} \times 10^{-9}\left[\frac{1}{r} - 10\right]$$

$$\text{or, } \frac{1}{r} - 10 = \frac{5 \times 10^{-6}}{9 \times 5 \times 10^{-8}} = \frac{100}{9} \Rightarrow \frac{1}{r} = \frac{190}{9} \Rightarrow r = \frac{9}{190} \text{ m}$$

or, i.e., $r = 4.7 \times 10^{-2}$ m

As here, $F = \frac{1}{4\pi\varepsilon_0}\frac{Qq}{r^2}$ so acc. $= \frac{F}{m} \propto \frac{1}{r^2}$

i.e., acceleration is not constant during the motion.

Example : 53

A proton moves from a large distance with a speed u m/s directly towards a free proton originally at rest. Find the distance of closet approach for the two protons in terms of mass of proton m and its charge e.

Solution

As here the particle at rest is free to move, when one particle approaches the other, due to electrostatic repulsion other will also start moving and so the velocity of first particle will decrease while of other will increase and at closest approach both will move with same velocity. So if v is the common velocity of each particle at closest approach, then by 'conservation of momentum' of the two protons system.

$$mu = mv + mv \quad \text{i.e.,} \quad v = \frac{1}{2}u$$

And by conservation of energy'

$$\frac{1}{2}mu^2 = \frac{1}{2}mv^2 + \frac{1}{2}mv^2 + \frac{1}{4\pi\varepsilon_0}\frac{e^2}{r}$$

$$\Rightarrow \frac{1}{2}mu^2 - m\left(\frac{u}{2}\right)^2 = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{r} \quad \left[\text{as } v = \frac{u}{2}\right]$$

$$\Rightarrow \frac{1}{4}mu^2 = \frac{e^2}{4\pi\varepsilon_0 r} \quad \Rightarrow \quad r = \frac{e^2}{\pi m\varepsilon_0 u^2}$$

11. ELECTROSTATIC POTENTIAL ENERGY OF A SYSTEM OF CHARGES

(This concept is useful when more than one charges move.)

It is the work done by an external agent against the internal electric field required to make a system of charges in a particular configuration from infinite separation without accelerating it.

11.1 Types of system of charge

(i) Point charge system

(ii) Continuous charge system.

11.2 Derivation for a system of point charges:

(i) Keep all the charges at infinity. Now bring the charges one by one to its corresponding position and find work required. PE of the system is algebraic sum of all the works.

Let W_1 = work done in bringing first charge

W_2 = work done in bringing second charge against force due to 1st charge.

W_3 = work done in bringing third charge against force due to 1st and 2nd charge.

PE = $W_1 + W_2 + W_3 + ...$. (This will contain $\frac{n(n-1)}{2} = {}^nC_2$ terms)

(ii) Method of calculation (to be used in problems)
U = sum of the interaction energies of the charges.
$= (U_{12} + U_{13} + ... + U_{1n}) + (U_{23} + U_{24} + ... + U_{2n}) + (U_{34} + U_{35} + ... + U_{3n}) ....$

(iii) Method of calculation useful for symmetrical point charge systems.
Find PE of each charge due to rest of the charges.
If U_1 = PE of first charge due to all other charges.
$= (U_{12} + U_{13} + ... + U_{1n})$
U_2 = PE of second charge due to all other charges.
$= (U_{21} + U_{23} + ... + U_{2n})$ then U = PE of the system $= \dfrac{U_1 + U_2 + ...U_n}{2}$

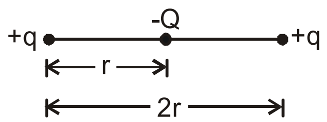
Example : 54

Find out potential energy of the two point charge system having q_1 and q_2 charges separated by distance r.

Solution:
Let both the charges be placed at a very large separation initially.
Let W_1 = work done in bringing charge q_1 in absence of $q_2 = q(V_f - V_i) = 0$
W_2 = work done in bringing charge q_2 in presence of $q_1 = q(V_f - V_i) = q_1(Kq_2/r - 0)$
$PE = W_1 + W_2 = 0 + Kq_1q_2 / r = Kq_1q_2 / r$

Example : 55

Figure shows an arrangement of three point charges. The total potential energy of this arrangement is zero. Calculate the ratio $\dfrac{q}{Q}$.



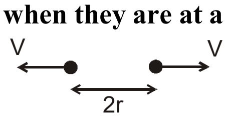
Solution

$$U_{sys} = \frac{1}{4\pi\varepsilon_0}\left[\frac{-qQ}{r} + \frac{(+q)(+q)}{2r} + \frac{Q(-q)}{r}\right] = 0$$

$$-Q + \frac{q}{2} - Q = 0 \quad \text{or} \quad 2Q = \frac{q}{2} \text{ or } \frac{q}{Q} = \frac{4}{1}.$$

Example : 56

Two point charges each of mass m and charge q are released when they are at a distance r from each other. What is the speed of each charge particle when they are at a distance 2r?



Solution
According to momentum conservation both the charge particles will move with same speed now applying energy conservation.

$$0 + 0 + \frac{Kq^2}{r} = 2\frac{1}{2}mv^2 + \frac{Kq^2}{2r} \Rightarrow v = \sqrt{\frac{Kq^2}{2rm}}$$

Example : 57

Two charged particles each having equal charges 2×10^{-5} C are brought from infinity to within a separation of 10 cm. Calculate the increase in potential energy during the process and the work required for this purpose.

Solution $\Delta U = U_f - U_i = U_f - 0 = U_f$
We have to simply calculate the electrostatic potential energy of the given system of charges

$$\Delta U = U_f = \frac{1}{4\pi\varepsilon_0}\frac{q_1q_2}{r}$$

$$= \frac{9 \times 10^9 \times 2 \times 10^{-5} \times 2 \times 10^{-5} \times 100}{10} \text{ J} = 36 \text{ J}$$

work required = 36 J.

Example : 58

A spherical shell of radius R with uniform charge q is expanded to a radius 2R. Find the work performed by the electric forces and external agent against electric forces in this process.

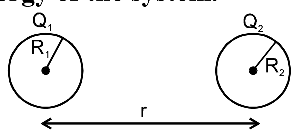
Solution

$$W_{ext} = U_f - U_i = \frac{q^2}{16\pi\varepsilon_0 R} - \frac{q^2}{8\pi\varepsilon_0 R} = -\frac{q^2}{16\pi\varepsilon_0 R}$$

$$W_{ext} = U_i - U_f = \frac{q^2}{8\pi\varepsilon_0 R} - \frac{q^2}{16\pi\varepsilon_0 R} = \frac{q^2}{16\pi\varepsilon_0 R}$$

Example : 59

Two nonconducting hollow uniformly charged spheres of radii R_1 and R_2 with charge Q_1 and Q_2 respectively are placed at a distance r. Find out total energy of the system.

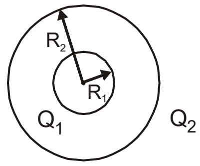


Solution:
$U_{total} = U_{self} + U_{Interaction}$

$$= \frac{Q_1^2}{8\pi\varepsilon_0 R_1} + \frac{Q_2^2}{8\pi\varepsilon_0 R_2} + \frac{Q_1Q_2}{4\pi\varepsilon_0 r}$$

Example : 60

Two concentric spherical shells of radius R_1 and R_2 ($R_2 > R_1$) are having uniformly distributed charges Q_1 and Q_2 respectively. Find out total energy of the system.



Solution:
$U_{total} = U_{self\,1} + U_{self\,2} + U_{Interaction}$

$$= \frac{Q_1^2}{8\pi\varepsilon_0 R_1} + \frac{Q_2^2}{8\pi\varepsilon_0 R_2} + \frac{Q_1Q_2}{4\pi\varepsilon_0 R_2}$$

11.4 Energy density:

Def: Energy density is defined as energy stored in unit volume in any electric field. Its mathematical formula is given as following

Energy density = $\frac{1}{2}\varepsilon E^2$

where E = electric field intensity at that point

$\varepsilon = \varepsilon_0\varepsilon_r$ electric permittivity of medium

Example : 61

Find out energy stored in an imaginary cubical volume of side a in front of a infinitely large non-conducting sheet of uniform charge density σ.

Solution:

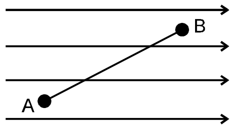
Energy stored

$U = \int \frac{1}{2}\varepsilon_0 E^2\, dV$ where dV is small volume$= \frac{1}{2}\varepsilon_0 E^2 \int dV$

$\because$ E is constant $= \frac{1}{2}\varepsilon_0 \frac{\sigma^2}{4\varepsilon_0^2}\,.\, a^3 . = \frac{\sigma^2 a^3}{8\varepsilon_0}$

12. RELATION BETWEEN ELECTRIC FIELD INTENSITY AND ELECTRIC POTENTIAL

12.1 For uniform electric field:



(i) Potential difference between two points A and B

$V_B - V_A = -\vec{E}.\,\vec{AB}$

12.2 Non uniform electric field

(i) $E_x = \frac{\partial V}{\partial x}-,\ E_y = -\frac{\partial V}{\partial y},\ E_z = -\frac{\partial V}{\partial z}$

$\Rightarrow \vec{E} = E_x\hat{i} + E_y\hat{j} + E_z\hat{k}$

$= -\left[\hat{i}\frac{\partial}{\partial x}V + \hat{j}\frac{\partial}{\partial y}V + \hat{k}\frac{\partial}{\partial z}V\right]$

$= -\left[\hat{i}\frac{\partial}{\partial x} + \hat{j}\frac{\partial}{\partial y} + \hat{k}\frac{\partial}{\partial z}\right]V = -\nabla V = -\text{grad } V$

Where $\frac{\partial V}{\partial x}$ = derivative of V with respect to x (keeping y and z constant)

$\frac{\partial V}{\partial y}$ = derivative of V with respect to y (keeping z and x constant)

$\frac{\partial V}{\partial z}$ = derivative of V with respect to z (keeping x and y constant)

12.3 If electric potential and electric field depends only on one coordinate, say r :

(i) $\vec{E} = -\frac{\partial V}{\partial r}\hat{r}$

where is a unit vector along increasing r.

(ii) $\int dV = -\int \vec{E}\cdot\vec{dr} \Rightarrow V_B - V_A = -\int_{r_A}^{r_B} \vec{E}.\,\vec{dr}$

$\vec{dr}$ is along the increasing direction of r.

(iii) The potential of a point $V = -\int_{\infty}^{r} \vec{E}.\,\vec{dr}$

Example : 62

A uniform electric field is along x – axis . The potential difference $V_A - V_B = 10$ V between two points A (2m , 3m) and B (4m, 8m). Find the electric field intensity.

Solution:

$E = \frac{\Delta V}{\Delta d} = \frac{10}{2} = 5$ V / m. It is along + ve x-axis.

Example : 63

$V = x^2 + y$, Find $\vec{E}$.

Solution:

$\frac{\partial V}{\partial x} = 2x,\quad \frac{\partial V}{\partial y} = 1 \quad$ and $\quad \frac{\partial V}{\partial z} = 0$

$\vec{E} = -\left(\hat{i}\frac{\partial V}{\partial x} + \hat{j}\frac{\partial V}{\partial y} + \hat{k}\frac{\partial V}{\partial z}\right) = -(2x\,\hat{i} + \hat{j})$

Electric field is nonuniform.

Example : 64

For given $\vec{E} = 2x\hat{i} + 3y\hat{j}$ find the potential at (x, y) if V at origin is 5 volts.

Solution:

$\int_5^V dV = -\int \vec{E}\cdot\vec{dr} = -\int_0^x E_x dx - \int_0^y E_y dy$

$\Rightarrow V - 5 = -\frac{2x^2}{2} - \frac{3y^2}{2} \Rightarrow V = -\frac{2x^2}{2} - \frac{3y^2}{2} + 5.$

13. ELECTRIC DIPOLE

13.1 Electric Dipole

If two point charges equal in magnitude q and opposite in sign separated by a distance a such that the distance of field point r>>a, the system is called a dipole. The electric dipole moment is defined as a vector quantity having magnitude p = (q × a) and direction from negative charge to positive charge.

Note:

[In chemistry, the direction of dipole moment is assumed to be from positive to negative charge.] The C.G.S unit of electric dipole moment is **debye** which is defined as the dipole moment of two equal and opposite point charges each having charge 10^{-10} frankline and separation of 1 Å, i.e.,

1 debye (4) = $10^{-10} \times 10^{-8} = 10^{-18}$ Fr × cm

1 D= $10^{-18} \times \frac{C}{3\times10^9} \times 10^{-2}$ m = 3.3× 10^{-30} C× m.

S.I. Unit is coulomb × metre = C.

Example : 65

A system has two charges $q_A = 2.5 \times 10^{-7}$ C and $q_B = -2.5 \times 10^{-7}$ C located at points A : (0, 0, – 0.15 m) and B ; (0, 0, + 0.15 m) respectively. What is the net charge and electric dipole moment of the system?

Solution

Net charge $= 2.5 \times 10^{-7} - 2.5 \times 10^{-7} = 0$

Electric dipole moment,

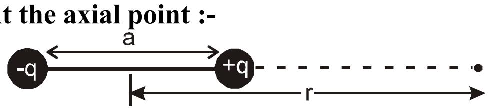
P = (Magnitude of charge) × (Separation between charges)

$= 2.5 \times 10^{-7}[0.15 + 0.15]$ C m $= 7.5 \times 10^{-8}$ C m

The direction of dipole moment is from B to A.

13.2 Electric Field Intensity Due to Dipole :

(i) At the axial point :-



$$\vec{E} = \frac{Kq}{\left(r - \frac{a}{2}\right)^2} - \frac{Kq}{\left(r + \frac{a}{2}\right)^2} \text{ along the } \hat{P}$$

$$= \frac{Kq(2ra)}{\left(r^2 - \frac{a^2}{4}\right)^2}\hat{P}$$

If r >> a then

$$\vec{E} = \frac{Kq\,2ra}{r^4}\hat{P} = \frac{2K\vec{P}}{r^3},$$

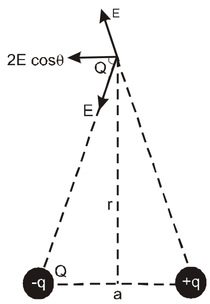
As the direction of electric field at axial position is along the dipole moment $(\vec{P})$ $\vec{E}_{axial} = \frac{2K\vec{P}}{r^3}$

(ii) Electric field at perpendicular Bisector (Equitorial Position)

$E_{net} = 2 E \cos\theta$ (along $-\hat{P}$)

$$\vec{E}_{net} = 2\left(\frac{Kq}{\left(\sqrt{r^2 + \left(\frac{a}{2}\right)^2}\right)^2}\right)\frac{\frac{a}{2}}{\sqrt{r^2 + \left(\frac{a}{2}\right)^2}}(-\hat{P}) = 2$$

$$\frac{Kqa}{\left(r^2 + \left(\frac{a}{2}\right)^2\right)^{3/2}}(-\hat{P})$$



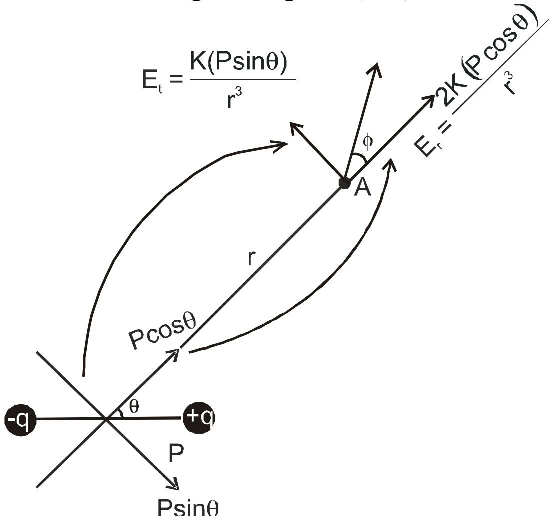
If r >> a then

$$\vec{E}_{net} = \frac{KP}{r^3}(-\hat{P})$$

As the direction of $\vec{E}$ at equatorial position is opposite of $\vec{P}$ so we can write in vector form:

$$\vec{E}_{eqt} = -\frac{K\vec{P}}{r^3}$$

(iii) Electric field at general point (r, θ) :



$$E_{net} = \frac{KP}{r^3}\sqrt{1 + 3\cos^2\theta} \quad ; \quad \tan\phi = \frac{\tan\theta}{2}$$

Example : 66

The electric field due to a short dipole at a distance r, on the axial line, from its mid point is the same as that of electric field at a distance r', on the equatorial line, from its mid-point. Determine the ratio.

Solution

$$\frac{1}{4\pi\varepsilon_0}\frac{2p}{r^3} = \frac{1}{4\pi\varepsilon_0}\frac{p}{r'^3} \text{ or } \frac{2}{r^3} = \frac{1}{r'^3} \text{ or } \frac{r^3}{r'^3}$$

$$= 2 \text{ or } \frac{r}{r'} = 2^{1/3}$$

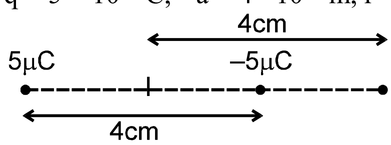
Example : 67

Two charges, each of 5 μC but opposite in sign, are placed 4 cm apart. Calculate the electric field intensity of a point that is at a distance 4 cm from the mid point on the axial line of the dipole.

Solution

We cannot use formula of short dipole here because distance of the point is comparable to the distance between the two point charges.

$q = 5 \times 10^{-6}$ C, $a = 4 \times 10^{-2}$ m, $r = 4 \times 10^{-2}$ m



$$E_{res} = E_+ + E_- = \frac{K(5\mu C)}{(2cm)^2} - \frac{K(5\mu C)}{(6cm)^2}$$

$$= \frac{144}{144 \times 10^{-8}} \text{ NC}^{-1} = 10^8 \text{ N C}^{-1}$$

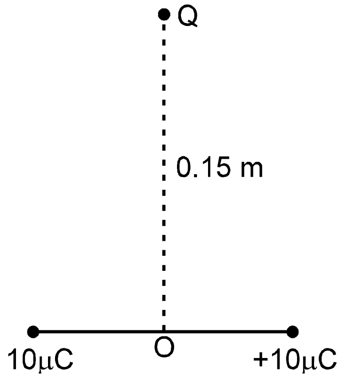
Example : 68

Two charges ± 10 μC are placed 5 × 10^{-3} m apart. Determine the electric field at a point Q which is 0.15 m away from O, on the equatorial line.

Solution

In the given problem, r >> a

$$\therefore \quad E = \frac{1}{4\pi\varepsilon_0}\frac{p}{r^3} = \frac{1}{4\pi\varepsilon_0}\frac{q(a)}{r^3}$$



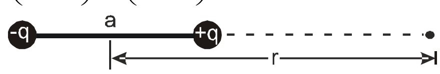
$$\text{or} \quad E = 9 \times 10^9 \frac{10\times10^{-6}\times5\times10^{-3}}{0.15\times0.15\times0.15}\ NC^{-1}$$

$$= 1.33 \times 10^5\ NC^{-1}$$

13.3 Electric Potential due to a small dipole:

(i) Potential at axial position:

$$V = \frac{Kq}{\left(r-\frac{a}{2}\right)} + \frac{K(-q)}{\left(r+\frac{a}{2}\right)}$$



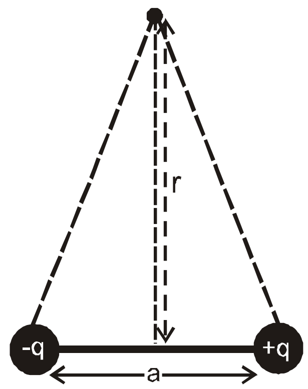
$$V = \frac{Kqa}{\left(r^2-\left(\frac{a}{2}\right)^2\right)}$$

If r >> a than

V = where qa = p $\qquad V_{axial} = \frac{KP}{r^2}$

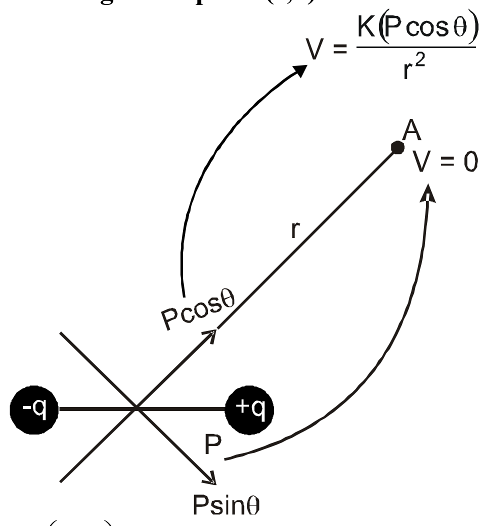
(ii) Potential at equatorial position :

$$V = \frac{Kq}{\sqrt{r^2+\left(\frac{a}{2}\right)^2}} + \frac{K(-q)}{\sqrt{r^2+\left(\frac{a}{2}\right)^2}} = 0$$



$V_{eqt} = 0$

(iii) Potential at general point (r,θ) :

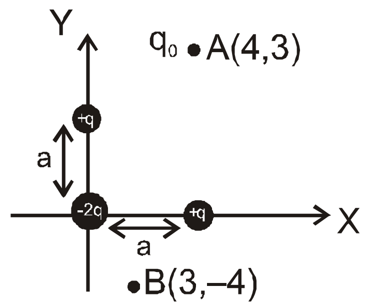


$$V = \frac{K\left(\vec{P}\cdot\vec{r}\right)}{r^3}$$

Example: 69

(i) Find potential at point A and B due to the small charge-system fixed near origin.(distance between the charges is negligible).

(ii) Find work done to bring a test charge q_0 from point A to point B, slowly. All parameters are in S.I. units.



Solution:

(i) Dipole moment of the system is

$\vec{P} = (qa)\ \hat{i}\ + (qa)\ \hat{j}$

Potential at point A due to the dipole

$$V_A = K\frac{(\vec{P}\cdot\vec{r})}{r^B} = \frac{K[(qa)\hat{i}+(qa)\hat{j}]\cdot(4\hat{i}+3\hat{j})}{5^3}$$

$$= \frac{k(qa)}{125}(7)$$

$$\Rightarrow \quad V_B = \frac{K\left[(qa)\hat{i}+(qa)\hat{j}\right]\cdot\left(3\hat{i}-4\hat{j}\right)}{(5)^3} = \frac{K(qa)}{125}$$

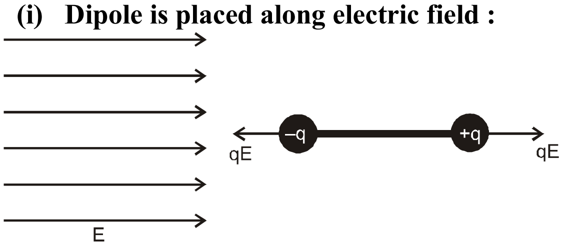
(ii) $W_{A\to B} = U_B - U_A = q_0\,(V_B - V_A)$

$$= \left[-\frac{K(qa)}{125} - \left(\frac{K(qa)(7)}{125}\right)\right]$$

$$\Rightarrow W_{A\to B} = \frac{K\ q\,q_0 a}{125}\ (8)$$

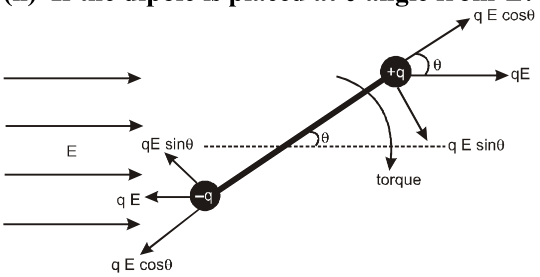
13.4 Dipole in uniform electric field

(i) Dipole is placed along electric field :



In this case $F_{net} = 0$, $\tau_{net} = 0$ so it is an equilibrium state. And it is a stable equilibrium position.

(ii) If the dipole is placed at θ angle from $\vec{E}$: -



In this case $F_{net} = 0$ but

Net torque $\tau = (qE\sin\theta)$ (1)

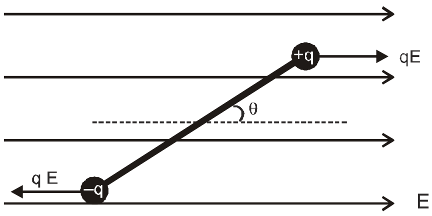
Here $qa = P \Rightarrow \tau = PE \sin\theta$

in vector form $\vec{\tau} = \vec{P} \times \vec{E}$

Example : 70

A dipole is formed by two point charge –q and +q, each of mass m, and both the point charges are connected by a rod of length ℓ and mass m_1. This dipole is placed in uniform electric field $\vec{E}$. If the dipole is disturbed by a small angle θ from stable equilibrium position, prove that its motion will be almost SHM. Also find its time period.

Solution



If the dipole is disturbed by θ angle,

$\tau_{net} = -PE\sin\theta$ (here – ve sign indicates that direction of torque is opposite of θ)

If θ is very small, $\sin\theta = \theta$

$\tau_{net} = -(PE)\theta$

$\tau_{net} \propto (-\theta)$ so motion will be almost SHM.

$$T = 2\pi\sqrt{\frac{I}{K}}$$

(iii) Potential energy of a dipole placed in uniform electric field :

$$U_B - U_A = -\int_A^B \vec{F} \cdot \overrightarrow{dr}$$

Here $$U_B - U_A = -\int_A^B \vec{\tau} \cdot \overrightarrow{d\theta}$$

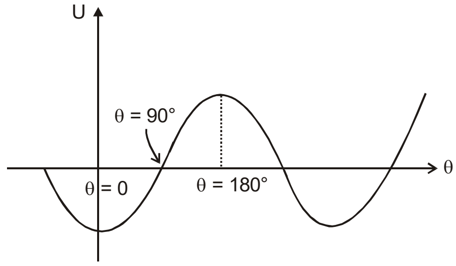
In the case of dipole, at θ = 90° , P.E. is assumed to be zero.

$$U_\theta - U_{90^\circ} = -\int_{\theta=90^\circ}^{\theta=\theta} (-PE\sin\theta)(d\theta)$$ (As the direction of torque is opposite of θ)

$U_\theta - 0 = -PE\cos\theta$

θ = 90° is chosen as reference,

so that the lower limit comes out to be zero.



$U_\theta = -\vec{P} \cdot \vec{E}$

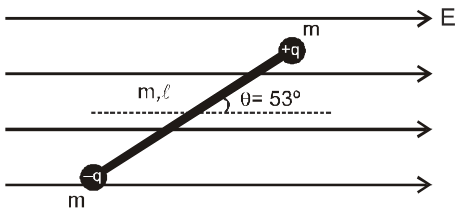
From the potential energy curve, we can conclude :

(i) at θ = 0, there is minimum of P.E. so it is a stable equilibrium position.

(ii) at θ = 180° , there is maxima of P.E. so it is a position of unstable equilibrium.

Example : 71

Two point masses of mass m and equal and opposite charge of magnitude q are attached on the corners of a non-conducting uniform rod of mass m and the system is released from rest in uniform electric field E as shown in figure from θ = 53°



(i) Find its angular acceleration of the rod just after releasing

(ii) What will be its angular velocity of the rod when it passes through stable equilibrium.

(iii) Find work required to rotate the system it by 180°.

Solution

(i) $t_{net} = PE\sin 53^\circ = I\alpha$

$$\alpha = \frac{(q\ell)E\left(\frac{4}{5}\right)}{\frac{m\ell^2}{12} + m\left(\frac{\ell}{2}\right)^2 + m\left(\frac{\ell}{2}\right)^2} = \frac{48qE}{35\,m\ell}$$

(ii) from energy conservation :

$K_i + U_i = K_f + U_f$

$$0 + (-PE\cos 53^\circ) = \frac{1}{2}I\omega^2 + (-PE\cos 0^\circ)$$

$$\text{where } I = \frac{m\ell^2}{12} + m\left(\frac{\ell}{2}\right)^2 + m\left(\frac{\ell}{2}\right)^2$$

$$\Rightarrow \omega = \sqrt{\frac{48qE}{35\,m\ell}}$$

(iii) $W_{ext} = U_f - U_i$

$W_{ext} = (-PE\cos(180° + 53°)) - (-PE\cos 53°)$

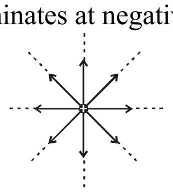
$W_{ext} = (q\ell)E + \left(\frac{4}{5}\right)(q\ell)E\left(\frac{4}{5}\right) \Rightarrow W_{ext} = \left(\frac{8}{5}\right)q\ell E$

14. ELECTRIC LINES OF FORCE (ELOF)

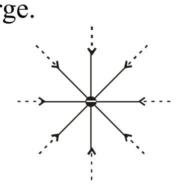
The line of force in an electric field is an imaginary line, the tangent to which at any point on it represents the direction of electric field at the given point.

14.1 Properties :

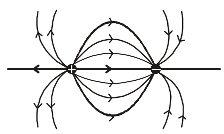
(i) Line of force originates out from a positive charge and terminates on a negative charge. If there is only one positive charge then lines start from positive charge and terminate at ∞. If there is only one negative charge then lines start from ∞ and terminates at negative charge.



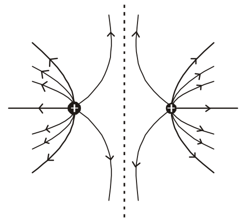
ELOF of Isolated positive charge



ELOF of Isolated negative charge

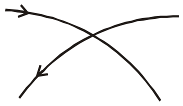


ELOF due to positive and negative charge



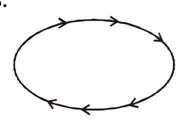
ELOF due to two positive charges

(ii) Two lines of force never intersect each other because there cannot be two directions of at a single Point



(iii) Electric lines of force produced by static charges do not form close loop.

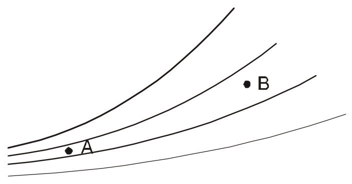
If lines of force make a closed loop, than work done to move a +q charge along the loop will be non-zero. So it will not be conservative field. So these type of lines of force are not possible in electrostatics.



(iv) The Number of lines per unit area (line density) represents the magnitude of electric field.

If lines are dense, ⇒ E will be more

If Lines are rare, ⇒ E will be less and if E = O, no line of force will be found there



$E_A > E_B$

(v) Number of lines originating (terminating) is proportional to the charge.

Example : 72

If number of electric lines of force from charge q are 10 then find out number of electric lines of force from 2q charge.

Solution

No. of ELOF ∝ charge

$10 \propto q \Rightarrow 20 \propto 2q$

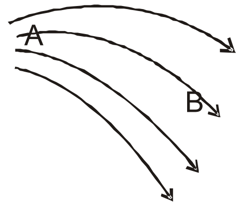
So number of ELOF will be 20.

(vi) Electric lines of force end or start perpendicularly on the surface of a conductor.

(vii) Electric lines of force never enter into conductors.

Example : 73

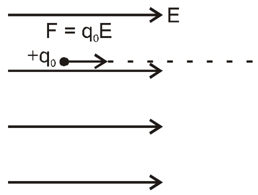
Some electric lines of force are shown in figure, for point A and B



(1) $E_A > E_B$	**(2) $E_B > E_A$**
(3) $V_A > V_B$	**(4) $V_B > B_A$**

Solution

lines are more dense at B so $E_A > E_B$ In the direction of Electric field, potential decreases so $V_A > V_B$



Example : 74

If a charge is released in electric field, will it follow lines of force?

Solution

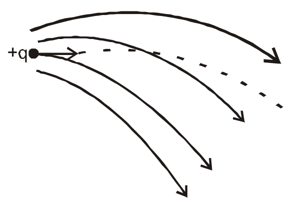
Case I :

If lines of force are parallel (in uniform electric field):-

In this type of field, if a charge is released, force on it will be q_oE and its direction will be along $\vec{E}$ .So the charge will move in a straight line , along the lines of force.

Case II : -

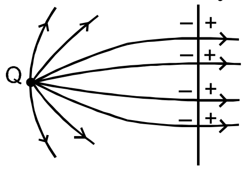
If lines of force are curved (in non-uniform electric field) :-



The charge will not follow lines of force

Example : 75

A charge + Q is fixed at a distance of d in front of an infinite metal plate. Draw the lines of force indicating the directions clearly.



Solution

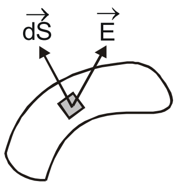
There will be induced charge on two surfaces of conducting plate, so ELOF will start from +Q charge and terminate at conductor and then will again start from other surface of conductor.

14.2 SOLID ANGLE:

Solid angle is a measure of a cone. Consider the intersection of the given cone with a sphere of radius R. The solid angle $\Delta\Omega$ of the cone is defined to be equal to $\Delta S/R^2$, where ΔS is the area on the sphere cut out by the cone.

15. ELECTRIC FLUX

Consider some surface in an electric field $\vec{E}$. Let us select a small area element $\overrightarrow{dS}$ on this surface. The electric flux of the field over the area element is given by $d\phi_E = \vec{E}.\overrightarrow{dS}$



Direction of $\overrightarrow{dS}$ is normal to the surface. It is along $\hat{n}$

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

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 $\overrightarrow{dS}$.

The electric flux over the whole area is given by

$\phi_E = \int_S \vec{E}.\overrightarrow{dS} = \int_S E_n dS$

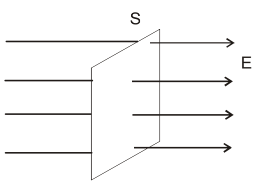
If the electric field is uniform over that area then

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

- **Special Cases :**
- **Case I :** If the electric field in normal to the surface, then angle of electric field $\vec{E}$ with normal will be zero

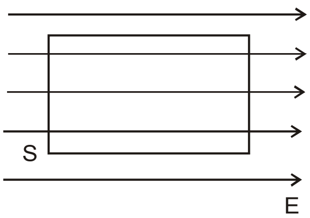
So $\phi = ES\cos 0$

$\phi = ES$



Case II : If electric field is parallel of the surface (glazing), then angle made by $\vec{E}$ with normal=90º

So $\phi = ES\cos 90^\circ = 0$



15.1 Physical Meaning :

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

15.2 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 : 76

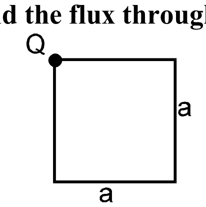
The electric field in a region is given by $\vec{E} = \left(\frac{3}{5}E_0\hat{i} + \frac{4}{5}E_0\hat{j}\right)$ with $E_0 = 2.0 \times 10^3$ N/C. Find the flux of this field through a rectangular surface of area $0.2m^2$ parallel to the Y–Z plane.

Solution:

$$\phi_E = \vec{E}\cdot\vec{S} = \left(\frac{3}{5}E_0\hat{i} + \frac{4}{5}E_0\hat{j}\right).\left(0.2\hat{i}\right) = 240\frac{N-m^2}{C}$$

Example : 77

A point charge Q is placed at the corner of a square of side a, then find the flux through the square.



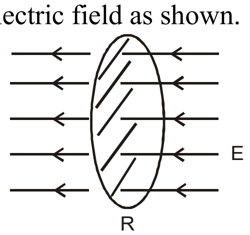
Solution:

The electric field due to Q at any point of the square will be along the plane of square and the electric field line are perpendicular to square ; so $\phi = 0$.

In other words we can say that no line is crossing the square so flux = 0.

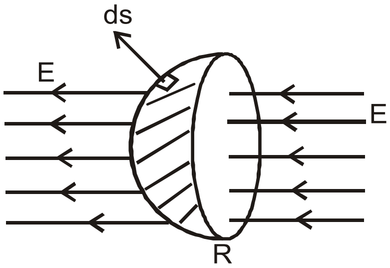
- **Case-III:** Curved surface in uniform electric field :-

Suppose a circular surface of radius R is placed in a uniform electric field as shown.



Flux passing through the surface $\phi = E(\pi R^2)$

(ii) Now suppose, a hemispherical surface is placed in the electric field flux through hemispherical surface



$\phi = \int E ds \cos\theta$

$\phi = E \int ds \cos\theta$

where $\int ds \cos\theta$ is

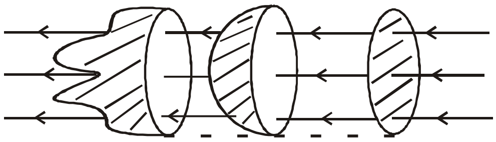
projection of the spherical surface Area on base.

$\int ds \cos\theta = \pi R^2$

so $\phi = E(\pi R^2)$ = same Ans. as in previous case

so we can conclude that

If the number of electric field lines passing through two surfaces are same, then flux passing through these surfaces will also be same, irrespective of the shape of surface



$\phi_1 = \phi_2 = \phi_3 = E(\pi R^2)$

- **Case IV:**
- **Flux through a closed surface :**

Suppose there is a spherical surface and a charge 'q' is placed at centre.

flux through the spherical surface

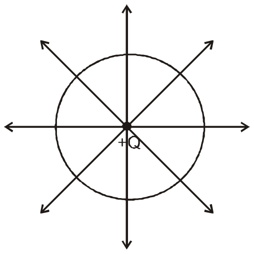
$\phi = \int \vec{E} \cdot \vec{ds} = \int E\, ds$ as $\vec{E}$ is along $\vec{ds}$ (normal)

$$\phi = \frac{1}{4\pi\varepsilon_o} \frac{Q}{R^2} \int ds \quad \text{where} \int ds = 4\pi R^2$$

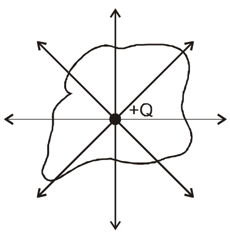
$$\phi = \left(\frac{1}{4\pi\varepsilon_o} \times \frac{Q}{R^2}\right)\left(4\pi R^2\right) \Rightarrow \phi = \frac{Q}{\varepsilon_o}$$

Now if the charge Q is enclosed by any other closed surface, still same lines of force will pass through the surface.

So here also flux will be $\phi = \frac{Q}{\varepsilon_o}$, that's what Gauss Theorem is.



$\phi = \frac{Q}{\varepsilon_o}$



$\phi = \frac{Q}{\varepsilon_o}$

16. GAUSS'S LAW IN ELECTROSTATICS OR GAUSS'S THEOREM

This law was stated by a mathematician Karl 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.

16.1 Statement and Details :

Gauss's law is stated as given below.

The surface integral of the electric field intensity over any closed hypothetical surface (called Gaussian surface) in free space is equal to $\frac{1}{\varepsilon_0}$ times the total charge enclosed within the 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,

$$\phi_E = \oint \vec{E} \cdot \vec{dS} = \frac{1}{\varepsilon_0} \sum_{i=1}^{n} q_i .$$

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.

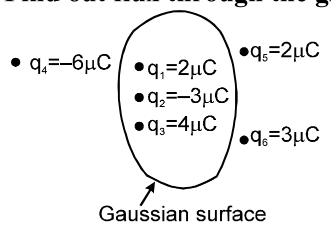
(iv) Electric field intensity at the gaussian surface is due to all the charges present inside as well as outside the gaussian surface.

(v) In a close surface incoming flux is taken negative while outgoing flux is taken positive, because $\hat{n}$ is taken positive in outward direction.

(vi) In a gaussian surface $\phi = 0$ does not imply E = 0 at every point of the surface but E = 0 at every point implies $\phi = 0$.

Example : 78

Find out flux through the given gaussian surface.



Sol. $\phi = \frac{Q_{in}}{\varepsilon_0} = \frac{2\mu C - 3\mu C + 4\mu C}{\varepsilon_0} = \frac{3 \times 10^{-6}}{\varepsilon_0}$ Nm²/C

Example : 79

If a point charge q is placed at the centre of a cube then find out flux through any one surface of cube.

Solution

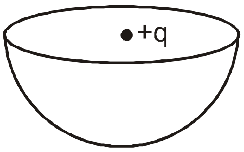
Flux through 6 surfaces = $\frac{q}{\varepsilon_0}$. Since all the surfaces are symmetrical

so, flux through one surfaces = $\frac{1}{6}\frac{q}{\varepsilon_0}$

16.2 Flux through open surfaces using Gauss's Theorem :

Example : 80

A point charge +q is placed at the centre of curvature of a hemisphere. Find flux through the hemispherical surface.

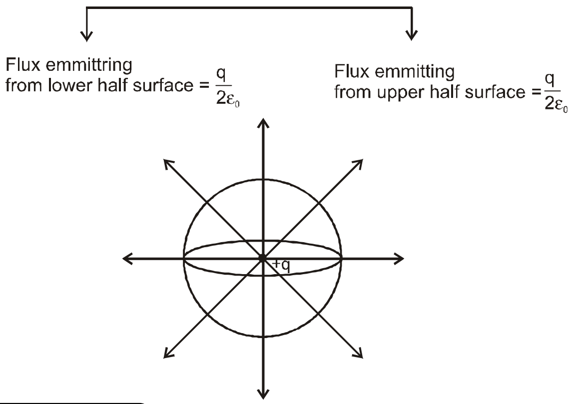


Solution

Lets put an upper half hemisphere.

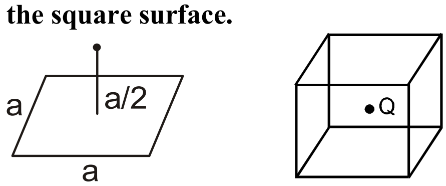
Now flux passing through the entire sphere = $\frac{q}{\varepsilon_0}$

As the charge q is symmetrical to the upper half and lower half hemispheres , so half-half flux will emit from both the surfaces.



Example : 81

A charge Q is placed at a distance a/2 above the centre of a horizontal, square surface of edge a as shown in figure. Find the flux of the electric field through the square surface.

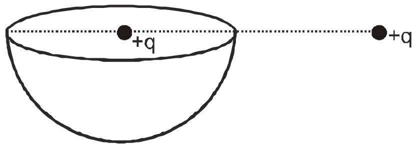


Solution

We can consider imaginary faces of cube such that the charge lies at the centre of the cube. Due to symmetry we can say that flux through the given area (which is one face of cube) $\phi = \frac{Q}{6\varepsilon_0}$

Example : 82

Find flux through the hemispherical surface

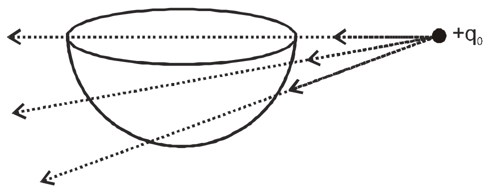


Solution

(i) Flux through the hemispherical surface due to +q

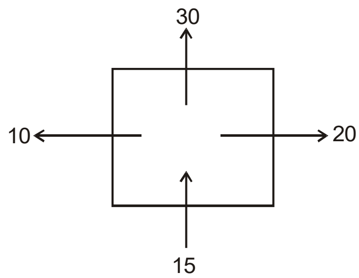
$= \frac{q}{2\varepsilon_0}$ (we have seen in previous examples)

(ii) Flux through the hemispherical surface due to $+q_0$ charge = 0, because due to $+q_0$ charge field lines entering the surface = field lines coming out of the surface.



16.3 Finding q_{in} from flux :

Example : 83



Flux (in S.I.units) coming out and entering a closed surface is shown in the figure. Find charge enclosed by the closed surface.

Solution:

Net flux through the closed surface = + 20 + 30 + 10 - 15 = 45 N.m^2/c

from Gauss`s theorem

$\phi_{net} = \frac{q_{in}}{\varepsilon_0} \Rightarrow 45 = \frac{q_{in}}{\varepsilon_0} \Rightarrow q_{in} = (45)\varepsilon_0$

16.4 Finding electric field from Gauss`s Theorem:

From gauss`s theorem, we can say

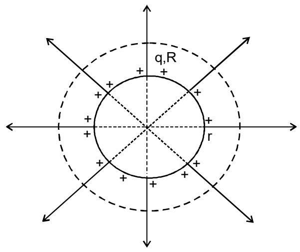
$$\int \vec{E}.\vec{ds} = \phi_{net} = \frac{q_{in}}{\varepsilon_0}$$

16.4.1 Finding E due to a spherical shell :-

- **Electric field outside the Sphere :**

  Since, electric field due to a shell will be radially outwards.

  So lets choose a spherical Gaussian surface Applying Gauss`s theorem for this spherical Gauss`s surface,



$$\int \vec{E}\,\vec{ds} = \phi_{net} = \frac{q_{in}}{\varepsilon_o} = \frac{q}{\varepsilon_o}$$

$\downarrow$

$\int |\vec{E}||\vec{ds}|\cos 0$ (because the $\vec{E}$ is normal to the surface)

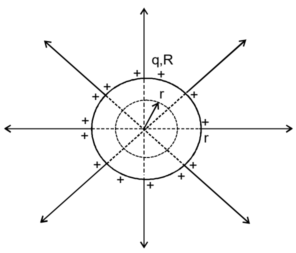
$\downarrow$

$E\int ds$ (because value of E is constant at the surface)

$E(4\pi r^2)$($\int ds$ total area of the spherical surface = $4\pi r^2$)

$$\Rightarrow E(4\pi r^2) = \frac{q_{in}}{\varepsilon_0} \quad \Rightarrow E_{out} = \frac{q}{4\pi\varepsilon_o r^2}$$

- **Electric field inside a spherical shell:**
  Lets choose a spherical gaussian surface inside the shell. Applying Gauss`s theorem for this surface



$$\int \vec{E}\,\vec{ds} = \phi_{net} = \frac{q_{in}}{\varepsilon_0} = 0$$

$\downarrow$

$\int \vec{E}.\vec{ds}$

$\downarrow$

$E\int ds$

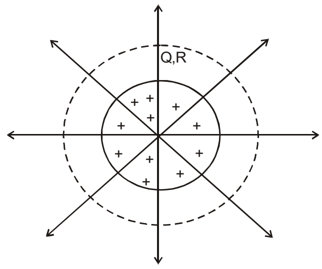
$\downarrow$

$E\ (4\pi r^2)$

$\Rightarrow E(4\pi r^2) = 0 \quad \Rightarrow \quad E_{in} = 0$

16.4.2 Electric field due to solid sphere (having uniformly distributed charge Q and radius R):

- **Electric field outside the sphere :**
  Direction of electric field is radially outwards, so we will choose
  a spherical gaussian surface Applying Gauss`s theorem



$$\int \vec{E}\,\vec{ds} = \phi_{net} = \frac{q_{in}}{\varepsilon_o} = \frac{Q}{\varepsilon_o}$$

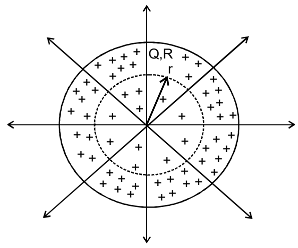
$\downarrow$

$E(4\pi r^2)$

$$\Rightarrow E(4\pi r^2) = \frac{Q}{\varepsilon_o}$$

$$\Rightarrow E_{out} = \frac{Q}{4\pi\varepsilon_o r^2}$$

- **Electric field inside a solid sphere :**



For this choose a spherical gaussian surface inside the solid sphere Applying gauss`s theorem for this surface

$$\int \vec{E}\,\vec{ds} = \phi_{net} = \frac{\rho\frac{4}{3}\pi r^3}{\varepsilon_o \frac{4}{3}\pi R^3} = \frac{qr^3}{\varepsilon_o R^3}$$

$\downarrow$

$\int E\,ds$

$\downarrow$

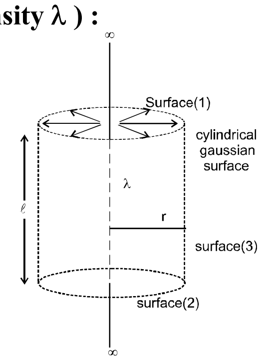
$E(4\pi r^2)$

$$\Rightarrow E(4\pi r^2) = \frac{qr^3}{\varepsilon_o R^3}$$

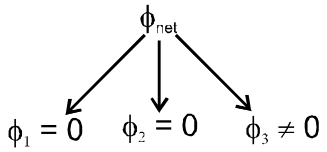
$$E = \frac{q\ r}{4\pi\varepsilon_o R^3}$$

$$\Rightarrow E_{in} = \frac{kQ}{R^3}\ r$$

16.4.3 Electric field due to infinite line charge (having uniformly distributed charged of charge density λ) :



Electric field due to infinite wire is radial so we will choose cylindrical Gaussian surface as shown is figure. $= \frac{q_{in}}{\varepsilon_o} = \frac{\lambda\ell}{\varepsilon_o}$ … (i)



$\phi_3 = \int \vec{E}.\vec{ds} = \int E\, ds = E\int ds$

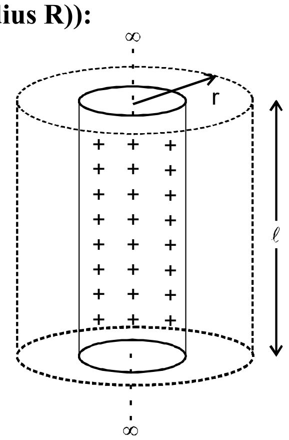
$\Rightarrow \phi_3 = E\,(2\pi r\ell)$ … (ii)

From Eq. (i) & (ii)

$\Rightarrow E\,(2\pi r\ell) = \frac{\lambda\ell}{\varepsilon_o}$

$\Rightarrow E = \frac{\lambda}{2\pi\varepsilon_o r} = \frac{2k\lambda}{r}$

16.4.4 Electric field due to infinity long charged tube (having uniform surface charge density σ and radius R)):



(i) E out side the tube :- lets choose a cylindrical gaussian surface

$\phi_{net} = \frac{q_{in}}{\varepsilon_o} = \frac{\sigma 2\pi R\ell}{\varepsilon_o}$

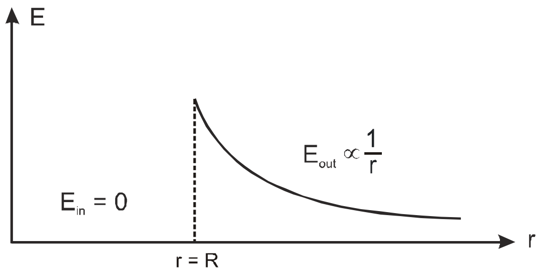
$\Rightarrow E_{out} \times 2\pi r\ell = \frac{\sigma 2\pi R\ell}{\varepsilon_o}$

$\Rightarrow E = \frac{\sigma R}{r\,\varepsilon_0}$

(ii) E inside the tube :

lets choose a cylindrical gaussian surface in side the tube.

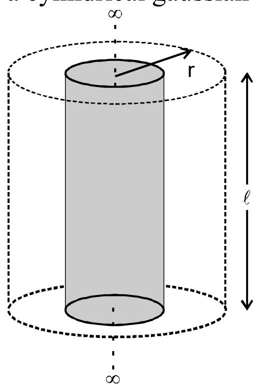
$\phi_{net} = \frac{q_{in}}{\varepsilon_o} = 0$ So $E_{in} = 0$



16.4.5 E due to infinitely long solid cylinder of radius R (having uniformly distributed charge in volume(charge density ρ)) :

(i) E at outside point :-

Lets choose a cylindrical gaussian surface.



Applying gauss`s theorem

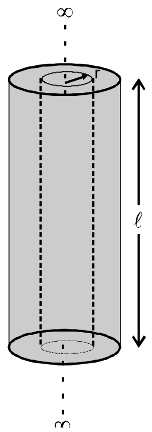
$E \times 2\pi r\ell = \frac{q_{in}}{\varepsilon_o} = \frac{\rho \times \pi R^2\ell}{\varepsilon_o}$

$\Rightarrow E_{out} = \frac{\rho R^2}{2r\,\varepsilon_0}$

(ii) E at inside point :

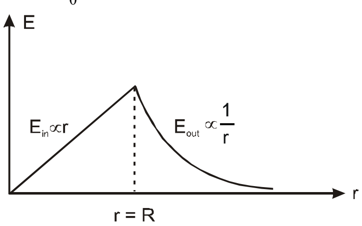
lets choose a cylindrical gaussian surface inside the solid cylinder.

Applying gauss`s theorem



$E \times 2\pi r\ell = \frac{q_{in}}{\varepsilon_o} = \frac{\rho \times \pi r^2\ell}{\varepsilon_o}$

$E_{in} = \frac{\rho r}{2\varepsilon_0}$



17. CONDUCTOR

17.1 Conductor and it's properties [For electrostatic condition]

(i) Conductors are materials which contains large number of free electrons which can move freely inside the conductor.

(ii) In electrostatics conductors are always equipotential surfaces.

(iii) Charge always resides on outer surface of conductor.

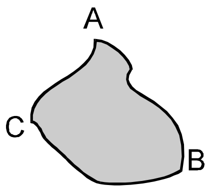
(iv) If there is a cavity inside the conductor having no charge then charge will always reside only on outer surface of conductor.

(v) Electric field is always perpendicular to conducting surface.

(vi) Electric lines of force never enter into conductors.

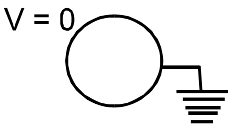
(vii) Electric field intensity near the conducting surface is given by formula

$$\vec{E} = \frac{\sigma}{\varepsilon_0}\hat{n}$$



$$\vec{E_A} = \frac{\sigma_A}{\varepsilon_0}\hat{n}\ ;\ \vec{E_B} = \frac{\sigma_B}{\varepsilon_0}\hat{n} \text{ and } \vec{E_C} = \frac{\sigma_C}{\varepsilon_0}\hat{n}$$

(viii) When a conductor is grounded its potential becomes zero.



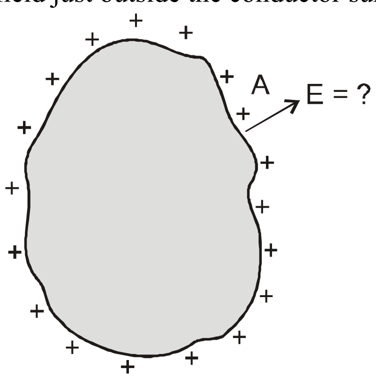
(ix) When an isolated conductor is grounded then its charge becomes zero.

(x) When two conductors are connected there will be charge flow till their potential becomes equal.

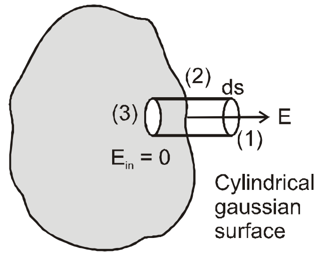
(xi) Electric pressure : Electric pressure at the surface of a conductor is given by formula $P = \frac{\sigma^2}{2\varepsilon_0}$ where σ is the local surface charge density.

17.2 Finding field due to a conductor

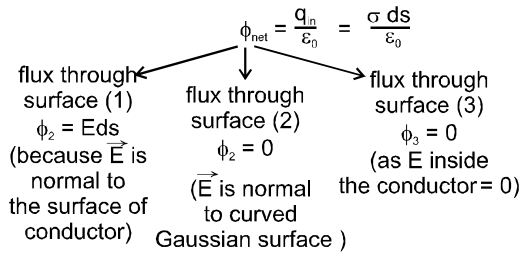
Suppose we have a conductor, and at any 'A', local surface charge density = σ. We have to find electric field just outside the conductor surface.



For this lets consider a small cylindrical gaussian surface, which is partly inside and partly outside the conductor surface, as shown in figure. It has a small cross section area ds and negligible height.



Applying gauss's theorem for this surface



So, $Eds = \frac{\sigma ds}{\varepsilon_0}$ $\qquad E = \frac{\sigma}{\varepsilon_0}$

Electric field just outside the surface of conductor

$E = \frac{\sigma}{\varepsilon_0}$ direction will be normal to the surface

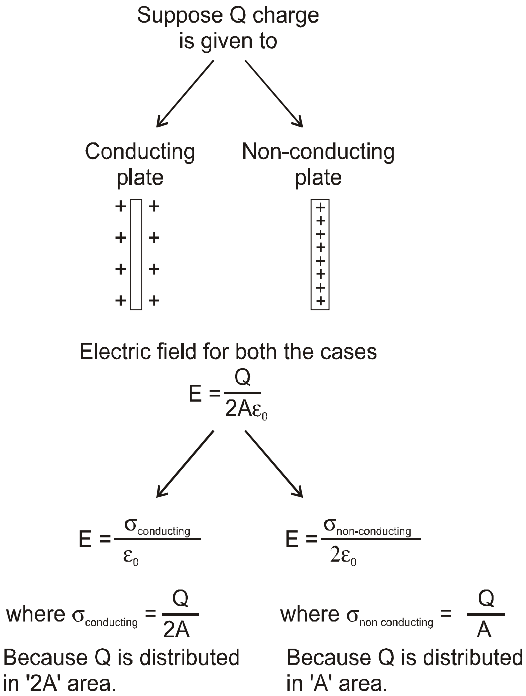
in vector form $\vec{E} = \frac{\sigma}{\varepsilon_0}\hat{n}$ (here $\hat{n}$ = unit vector normal to the conductor surface)

17.3 Electrostatic pressure at the surface of the conductor

Electrostatic pressure at the surface of the conductor $P = \frac{\sigma^2}{2\varepsilon_o}$

where σ = local surface charge density.

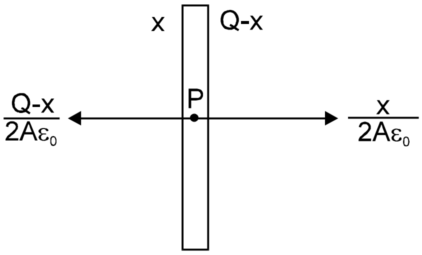
17.4 Electric field due to a conducting and non-conducting uniformly charge infinite sheets



Example : 84

Prove that if an isolated (isolated means no charges are near the sheet) large conducting sheet is given a charge then the charge distributes equally on its two surfaces.

Solution



Let there is x charge on left side of sheet and Q–x charge on right side of sheet.
Since point P lies inside the conductor so

$E_P = O$

$$\frac{x}{2A\varepsilon_O} - \frac{Q-x}{2A\varepsilon_O} = 0 \Rightarrow \frac{2x}{2A\varepsilon_O} = \frac{Q}{2A\varepsilon_O} \Rightarrow x = \frac{Q}{2}$$

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

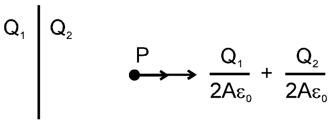
So charge in equally distributed on both sides

Example : 85

If an isolated infinite sheet contains charge Q_1 on its one surface and charge Q_2 on its other surface then prove that electric field intensity at a point in front of sheet will be $\frac{Q}{2A\varepsilon_O}$, where $Q = Q_1 + Q_2$

Solution

Electric field at point P : $\vec{E} = \vec{E}_{Q_1} + \vec{E}_{Q_2}$

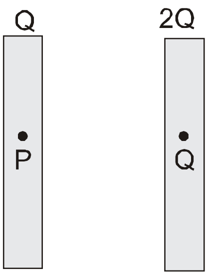


$$= \frac{Q_1}{2A\varepsilon_0}\hat{n} + \frac{Q_2}{2A\varepsilon_0}\hat{n} = \frac{Q_1 + Q_2}{2A\varepsilon_0}\hat{n} = \frac{Q}{2A\varepsilon_0}\hat{n}$$

[This shows that the resultant field due to a sheet depends only on the total charge of the sheet and not on the distribution of charge on individual surfaces].

Example : 86

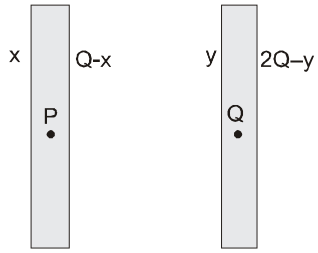
Two large parallel conducting sheets (placed at finite distance) are given charges Q and 2Q respectively. Find out charges appearing on all the surfaces.



Solution

Let there is x amount of charge on left side of first plate, so on its right side charge will be Q–x, similarly for second plate there is y charge on left side and 2Q – y charge is on right side of second plate

$E_p = 0$ (By property of conductor)

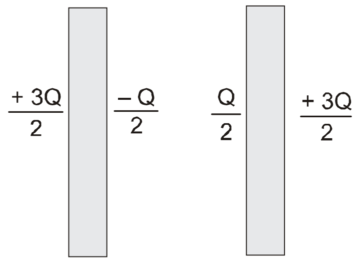


$$\Rightarrow \frac{x}{2A\varepsilon_o} - \left\{\frac{Q-x}{2A\varepsilon_o} + \frac{y}{2A\varepsilon_o} + \frac{2Q-y}{2A\varepsilon_o}\right\} = 0$$

we can also say that charge on left side of P = charge on right side of P

$x = Q - x + y + 2Q - y$

$$\Rightarrow x = \frac{3Q}{2}, \; Q - x = \frac{-Q}{2}$$



Similarly for point Q:

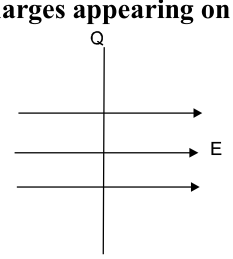
$x + Q - x + y = 2Q - y$

$\Rightarrow y = Q/2$, $2Q - y = 3Q/2$

So final charge distribution of plates is :-

Example : 87

An isolated conducting sheet of area A and carrying a charge Q is placed in a uniform electric field E, such that electric field is perpendicular to sheet and covers all the sheet. Find out charges appearing on its two surfaces.

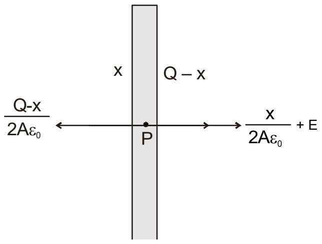


Solution

Let there is x charge on left side of plate and Q – x charge on right side of plate

$E_P = 0$

$$\frac{x}{2A\varepsilon_0} + E = \frac{Q-x}{2A\varepsilon_0} \qquad \Rightarrow \frac{x}{A\varepsilon_0} = \frac{Q}{2A\varepsilon_0} - E$$



$$\Rightarrow x = \frac{Q}{2} - EA\varepsilon_0 \text{ and } Q - x = \frac{Q}{2} + EA\varepsilon_0$$

So charge on one side is $\frac{Q}{2} - EA\varepsilon_o$ and other side

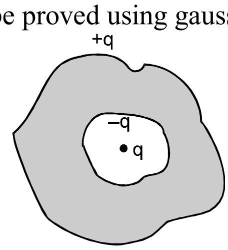
$\frac{Q}{2} + EA\varepsilon_o$

Note :

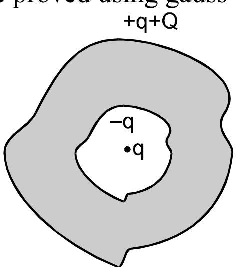
Solve this question for Q = 0 without using the above answer and match that answers with the answers that you will get by putting Q = 0 in the above answer.

17.5 Some other important results for a closed conductor.

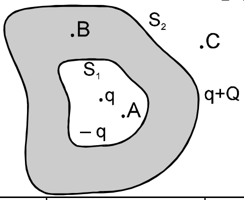
(i) If a charge q is kept in the cavity then –q will be induced on the inner surface and +q will be induced on the outer surface of the conductor (it can be proved using gauss theorem)



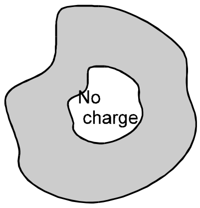
(ii) If a charge q is kept inside the cavity of a conductor and conductor is given a charge Q then –q charge will be induced on inner surface and total charge on the outer surface will be q + Q. (it can be proved using gauss theorem)



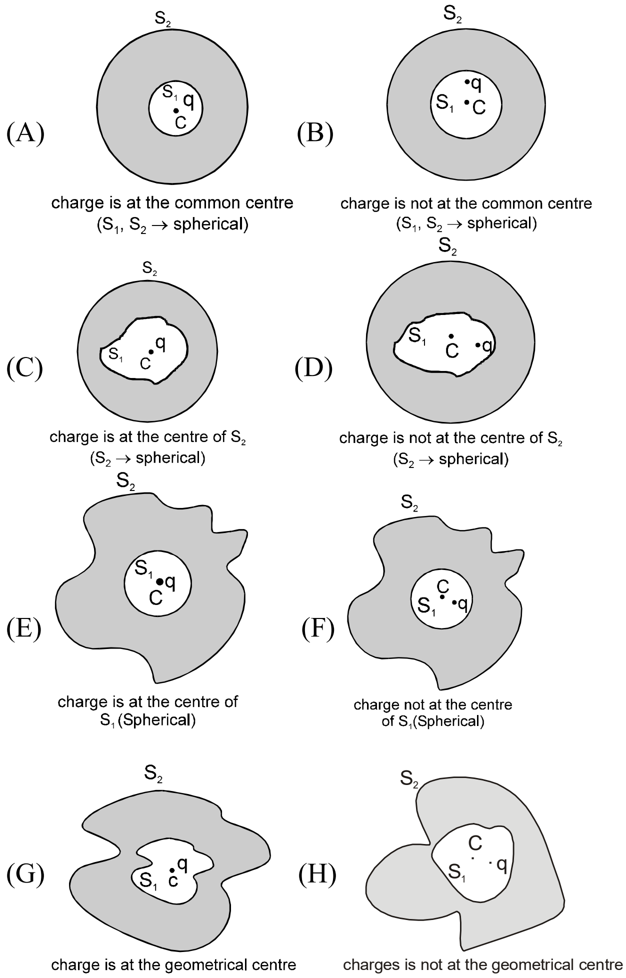
(iii) Resultant field, due to q (which is inside the cavity) and induced charge on S_1, at any point outside S_1 (like B,C) is zero. Resultant field due to **q + Q on S_2 and any other charge outside S_2**, at any point inside of surface S_2 (like A, B) is zero



(iv) Resultant field in a charge free cavity in a closed conductor is zero. There can be charges outside the conductor and on the surface also. Then also this result is true. No charge will be induced on the inner most surface of the conductor.



(v) Charge distribution for different types of cavities in conductors



Using the result that $\vec{E}_{res}$ in the conducting material should be zero and using result

(iii) We can show that

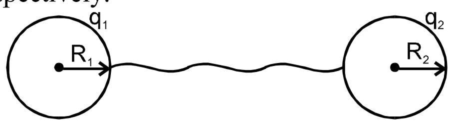
Case	A	B	C	D	E	F	G	H
S_1	Uniform	Nonuniform	Nonuniform	Nonuniform	Uniform	Nonuniform	Nonuniform	Nonuniform
S_2	Uniform	Uniform	Uniform	Uniform	Nonuniform	Nonuniform	Nonuniform	NonUniform

Note : In all cases charge on inner surface $S_1 = -q$ and on outer surface $S_2 = q$. The distribution of charge on 'S_1' will not change even if some charges are kept outside the conductor (i.e. outside the surface S_2). But the charge distribution on 'S_2' may change if some charges(s) is/are kept outside the conductor.

(vi) Sharing of charges :

Two conducting hollow spherical shells of radii R_1 and R_2 having charges Q_1 and Q_2 respectively and seperated by large distance, are joined by a conducting wire

Let final charges on spheres are q_1 and q_2 respectively.



Potential on both spherical shell become equal after joining, therefore

$$\frac{Kq_1}{R_1} = \frac{Kq_2}{R_2} \Rightarrow \frac{q_1}{q_2} = \frac{R_1}{R_2} \quad \text{......(i)}$$

and, $\quad q_1 + q_2 = Q_1 + Q_2 \quad$ ......(ii)

from (i) and (ii) $\quad q_1 = \frac{(Q_1+Q_2)R_1}{R_1+R_2}$

$$q_2 = \frac{(Q_1+Q_2)R_2}{R_1+R_2}$$

ratio of charges $\frac{q_1}{q_2} = \frac{R_1}{R_2} \Rightarrow \frac{\sigma_1 4\pi R_1^2}{\sigma_2 4\pi R_2^2} = \frac{R_1}{R_2}$

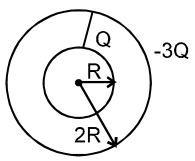
ratio of surface charge densities $\frac{\sigma_1}{\sigma_2} = \frac{R_2}{R_1}$

Ratio of final charges $\frac{q_1}{q_2} = \frac{R_1}{R_2}$

Ratio of final surface charge densities. $\frac{\sigma_1}{\sigma_2} = \frac{R_2}{R_1}$

Example : 88

The two conducting spherical shells are joined by a conducting wire and cut after some time when charge stops flowing. Find out the charge on each sphere after that.



Solution

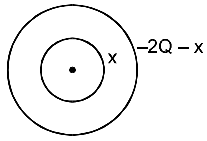
After cutting the wire, the potential of both the shells is equal

Thus, potential of inner shell

$$V_{in} = \frac{Kx}{R} + \frac{K(-2Q-x)}{2R} = \frac{k(x-2Q)}{2R}$$

and potential of outer shell

$$V_{out} = \frac{Kx}{2R} + \frac{K(-2Q-x)}{2R} = \frac{-KQ}{R}$$



As $V_{out} = V_{in}$

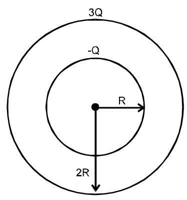
$$\Rightarrow \frac{-KQ}{R} = \frac{K(x-2Q)}{2R} \Rightarrow -2Q = x - 2Q \Rightarrow x = 0$$

So charge on inner spherical shell = 0

and outer spherical shell = – 2Q.

Example : 89

Two conducting hollow spherical shells of radii R and 2R carry charges – Q and 3Q respectively. How much charge will flow into the earth if inner shell is grounded ?



Solution

When inner shell is grounded to the Earth then the potential of inner shell will become zero because potential of the Earth is taken to be zero.

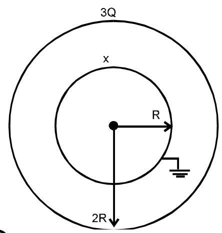
$$\frac{Kx}{R} + \frac{K3Q}{2R} = 0$$

$x = \frac{-3Q}{2}$, the charge that has increased

$$= \frac{-3Q}{2} - (-Q) = \frac{-Q}{2}$$

hence charge flows into the Earth

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



Example : 90

An isolated conducting sphere of charge Q and radius R is connected to a similar uncharged sphere (kept at a large distance) by using a high resistance wire. After a long time what is the amount of heat loss ?

Solution

When two conducting spheres of equal radius are connected charge is equally distributed on them (Result VI). So we can say that heat loss of system

$$\Delta H = U_i - U_f = \left(\frac{Q^2}{8\pi\varepsilon_0 R} - 0\right) - \left(\frac{Q^2/4}{8\pi\varepsilon_0 R} + \frac{Q^2/4}{8\pi\varepsilon_0 R}\right)$$

$$= \frac{Q^2}{16\pi\varepsilon_0 R}$$

EXERCISE # 1

Based On PROPERTIES OF CHARGE AND COULOMB'S LAW

1. Relative permittivity of mica is :
(1) One (2) Less than one
(3) More then one (4) Infinite

2. Two identical metallic sphere are charged with 10 and -20 units of charge. If both the spheres are first brought into contact with each other and then are placed to their previous positions, then the ratio of the force in the two situations will be :-
(1) –8 : 1 (2) 1 : 8 (3) –2 : 1 (4) 1 : 2

3. Two equal and like charges when placed 5 cm apart experience a repulsive force of 0.144 newton. The magnitude of the charge in microcoloumb will be :
(1) 0.2 (2) 2 (3) 20 (4) 12

4. Two charges of +1 μC & + 5 μC are placed 4 cm apart, the ratio of the force exerted by both charges on each other will be -
(1) 1 : 1 (2) 1 : 5 (3) 5 : 1 (4) 25 : 1

5. A negative charge is placed at some point on the line joining the two +Q charges at rest. The direction of motion of negative charge will depend upon the :
(1) position of negative charge alone
(2) magnitude of negative charge alone
(3) both on the magnitude and position of negative charge
(4) magnitude of positive charge.

6. A body has 80 micro coulomb of charge. Number of additional electrons on it will be :
(1) 8×10^{-5} (2) 80×10^{15}
(3) 5×10^{14} (4) 1.28×10^{-17}

7. Coulomb's law for the force between electric charges most closely resembles with :
(1) Law of conservation of energy
(2) Newton's law of gravitation
(3) Newton's 2nd law of motion
(4) The law of conservation of charge

8. A charge Q_1 exerts force on a second charge Q_2. If a 3rd charge Q_3 is brought near, the force of Q_1 exerted on Q_2.
(1) Will increase
(2) Will decrease
(3) Will remain unchanged
(4) Will increase if Q_3 is of the same sign as Q_1 and will decrease if Q_3 is of opposite sign

9. A charge particle q_1 is at position (2, - 1, 3). The electrostatic force on another charged particle q_2 at (0, 0, 0) is :
(1) $\frac{q_1 q_2}{56\pi \epsilon_0}(2\hat{i} - \hat{j} + 3\hat{k})$
(2) $\frac{q_1 q_2}{56\sqrt{14}\,\pi \epsilon_0}(2\hat{i} - \hat{j} + 3\hat{k})$
(3) $\frac{q_1 q_2}{56\pi \epsilon_0}(\hat{j} - 2\hat{i} - 3\hat{k})$
(4) $\frac{q_1 q_2}{56\sqrt{14}\,\pi \epsilon_0}(\hat{j} - 2\hat{i} - 3\hat{k})$

10. Three charge +4q, Q and q are placed in a straight line of length ℓ at points distance 0, $\ell/2$ and ℓ respectively. What should be the value of Q in order to make the net force on q to be zero?
(1) –q (2) –2q (3) –q/2 (4) 4q

11. Two point charges placed at a distance r in air exert a force F on each other. The value of distance R at which they experience force 4F when placed in a medium of dielectric constant K = 16 is :
(1) r (2) r/4 (3) r/8 (4) 2r

Based On ELECTRIC FIELD

12. If an electron is placed in a uniform electric field, then the electron will :
(1) experience no force.
(2) moving with constant velocity in the direction of the field.
(3) move with constant velocity in the direction opposite to the field.
(4) accelerate in direction opposite to field.

13. If Q = 2 coulomb and force on it is F = 100 newton, then the value of field intensity will be :
(1) 100 N/C (2) 50 N/C
(3) 200 N/C (4) 10 N/C

14. Two infinite linear charges are placed parallel at 0.1 m apart. If each has charge density of 5μ C/m, then the force per unit length of one of linear charges in N/m is :
(1) 2.5 (2) 3.25 (3) 4.5 (4) 7.5

15. Two spheres of radii 2 cm and 4 cm are charged equally, then the ratio of charge density on the surfaces of the spheres will be -
(1) 1 : 2 (2) 4 : 1 (3) 8 : 1 (4) 1 : 4

16. Total charge on a sphere of radii 10 cm is 1 μC. The maximum electric field due to the sphere in N/C will be -
(1) 9×10^{-5} (2) 9×10^{3}
(3) 9×10^{5} (4) 9×10^{15}

17. A charged water drop of radius 0.1 μm is under equilibrium in some electric field. The charge on the drop is equivalent to electronic charge. The intensity of electric field is ($g = 10\ m/s^2$)-
(1) $1.61\ NC^{-1}$ (2) $26.2\ NC^{-1}$
(3) $262\ NC^{-1}$ (4) $1610\ NC^{-1}$

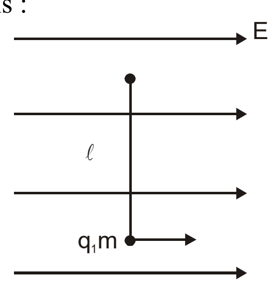
18. Two large sized charged plates have a charge density of $+\sigma$ and $-\sigma$. The resultant force on the proton located midway between them will be -
(1) $\sigma e/\epsilon_0$ (2) $\sigma e/2\epsilon_0$
(3) $2\sigma e/\epsilon_0$ (4) zero

19. Two parallel charged plates have a charge density $+\sigma$ and $-\sigma$. The resultant force on the proton located outside the plates at some distance will be-
(1) $2\sigma e/\epsilon_0$ (2) $\sigma e/\epsilon_0$
(3) $\sigma e/2\epsilon_0$ (4) zero

20. The charge density of an insulating infinite surface is $(e/\pi)\ C/m^2$ then the field intensity at a nearby point in volt/meter will be -
(1) 2.88×10^{-12} (2) 2.88×10^{-10}
(3) 2.88×10^{-9} (4) 2.88×10^{-19}

21. There is a uniform electric field in x-direction. If the work done by external agent in moving a charge of 0.2 C through a distance of 2 metre slowly along the line making an angle of 60º with x-direction is 4 joule, then the magnitude of E is:
(1) $\sqrt{3}$ N/C (2) 4 N/C (3) 5 N/C (4) 20 N/C

22. A simple pendulum has a length ℓ, mass of bob m. The bob is given a charge q coulomb. The pendulum is suspended in a uniform horizontal electric field of strength E as shown in figure, then calculate the time period of oscillation when the bob is slightly displace from its mean position is :



(1) $2\pi\sqrt{\frac{\ell}{g}}$ (2) $2\pi\sqrt{\left\{\frac{\ell}{g+\frac{qE}{m}}\right\}}$

(3) $2\pi\sqrt{\left\{\frac{\ell}{g-\frac{qE}{m}}\right\}}$ (4) $2\pi\sqrt{\frac{\ell}{\sqrt{g^2+\left(\frac{qE}{m}\right)^2}}}$

23. The maximum electric field intensity on the axis of a uniformly charged ring of charge q and radius R will be :
(1) $\frac{1}{4\pi\varepsilon_0}\frac{q}{3\sqrt{3}R^2}$ (2) $\frac{1}{4\pi\varepsilon_0}\frac{2q}{3R^2}$
(3) $\frac{1}{4\pi\varepsilon_0}\frac{2q}{3\sqrt{3}R^2}$ (4) $\frac{1}{4\pi\varepsilon_0}\frac{3q}{2\sqrt{3}R^2}$

24. A charged particle of charge q and mass m is released from rest in an uniform electric field E. Neglecting the effect of gravity, the kinetic energy of the charged particle after time 't' seconds is
(1) $\frac{Eqm}{t}$ (2) $\frac{E^2q^2t^2}{2m}$
(3) $\frac{2E^2t^2}{mq}$ (4) $\frac{Eq^2m}{2t^2}$

Based On	ELECTRIC POTENTIAL AND POTENTIAL DIFFERENCE

25. The distance between two plates is 2 cm, when an electric potential of 10 volt is applied to both the plates, then the value of electric field will be -
(1) 20 N/C (2) 500 N/C
(3) 5 N/C (4) 250 N/C

26. Two points (0, a) and (0, -a) have charges q and -q respectively then the electrical potential at origin will be-
(1) zero (2) kq/a (3) kq/2a (4) $kq/4a^2$

27. The charges of same magnitude q are placed at four corners of a square of side a. The value of potential at the centre of square will be -
(1) 4kq/a (2) $4\sqrt{2}kq/a$
(3) $4kq\sqrt{2a}$ (4) $kq/a\sqrt{2}$

28. A wire of 5 m length carries a steady current. If it has an electric field of 0.2 V/m, the potential difference across the wire in volt will be -
(1) 25 (2) 0.04
(3) 1.0 (4) none of the above

29. Two metallic spheres which have equal charges, but their radii are different, are made to touch each other and then separated apart. The potential the spheres will be -
(1) same as before (2) more for bigger
(3) more for smaller (4) equal

30. Two spheres of radii R and 2R are given source equally positive charged and then connected by a long conducting wire, then the positive charge will
(1) flow from smaller sphere to the bigger sphere.
(2) flow from bigger sphere to the smaller sphere
(3) not flow.
(4) oscillate between the spheres.

31. The potential difference between two isolated spheres of radii r_1 and r_2 is zero. The ratio of their charges Q_1/Q_2 will be-

(1) r_1/r_2 (2) r_2/r_1 (3) r_1^2/r_2^2 (4) r_1^3/r_2^3

32. The potential on the conducting spheres of radii r_1 and r_2 is same, the ratio of their charge densities will be-

(1) r_1/r_2 (2) r_2/r_1 (3) r_1^2/r_2^2 (4) r_2^2/r_1^2

33. A conducting shell of radius 10 cm is charged with 3.2×10^{-19} C. The electric potential at a distance 4cm from its centre in volt be -

(1) 9×10^{-9} (2) 288

(3) 2.88×10^{-8} (4) zero

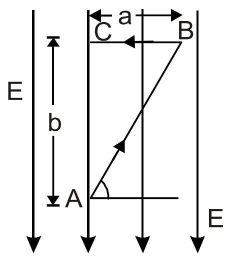
34. At a certain distance from a point charge the electric field is 500 V/m and the potential is 3000 V. What is the distance ?

(1) 6 m (2) 12 m (3) 36 m (4) 144 m

35. A semicircular ring of radius 0.5 m is uniformly charged with a total charge of 1.5×10^{-9} coul. The electric potential at the centre of this ring is :

(1) 27 V (2) 13.5 V (3) 54 V (4)45.5 V

36. The potential difference between points A and B in the given uniform electric field is :



(1) Ea (2) $E\sqrt{(a^2 + b^2)}$

(3) Eb (4) $(Eb/\sqrt{2})$

37. A particle of charge Q and mass m travels through a potential difference V from rest. The final momentum of the particle is :

(1) $\frac{mV}{Q}$ (2) $2Q\sqrt{mV}$

(3) $\sqrt{2m\ QV}$ (4) $\sqrt{\frac{2QV}{m}}$

38. If a uniformly charged spherical shell of radius 10 cm has a potential V at a point distant 5 cm from its centre, then the potential at a point distant 15 cm from the centre will be :

(1) $\frac{V}{3}$ (2) $\frac{2V}{3}$ (3) $\frac{3}{2}V$ (4) 3V

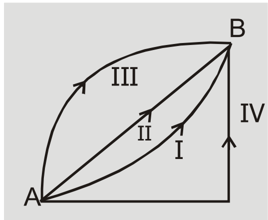
Based On	ELECTRIC POTENTIAL ENERGY OF A PARTICLE

39. A nucleus has a charge of + 50e. A proton is located at a distance of 10^{-12} m. The potential at this point in volt will be -

(1) 14.4×10^4 (2) 7.2×10^4

(3) 7.2×10^{-12} (4) 14.4×10^8

40. Under the influence of charge, a point charge q is carried along different paths from a point A to point B, then work done will be -



(1) Maximum for path four.

(2) Maximum for path one.

(3) Equal for all paths

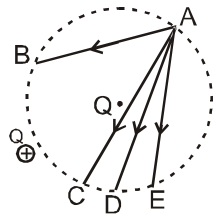
(4) Minimum for path three.

41. An electron moving in a electric potential field V_1 enters a higher electric potential field V_2, then the change in kinetic energy of the electron is proportional to -

(1) $(V_2 — V_1)^{1/2}$ (2) $V_2 — V_1$

(3) $(V_2 — V_1)^2$ (4) $\frac{(V_2 - V_1)}{V_2}$

42. In the electric field of charge Q, another charge is carried from A to B. A to C, A to D and A to E, then work done will be –



(1) Minimum along path AB.

(2) Minimum along path AD.

(3) Minimum along path AE.

(4) Zero along all the paths.

43. The work done to take an electron from rest where potential is – 60 volt to another point where potential is – 20 volt is given by -

(1) 40 eV (2) –40 eV

(3) 60 eV (4) –60 eV

44. If a charge is shifted from a low potential region to high potential region. the electrical potential energy:

(1) Increases

(2) Decreases

(3) Remains constant

(4) May increase or decrease.

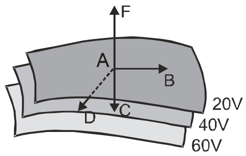
Based On	POTENTIAL ENERGY OF A SYSTEM OF POINT CHARGE

45. In H atom, an electron is rotating around the proton in an orbit of radius r. Work done by an electron in moving once around the proton along the orbit will be -

(1) ke/r (2) ke^2/r^2 (3) $2\pi re$ (4) zero

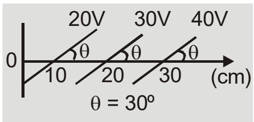
Based On | **QUESTIONS BASED ON RELATION BETWEEN $\vec{E}$ AND V :**

46. A family of equipotential surfaces are shown. The direction of the electric field at point A is along -



(1) AB (2) AC (3) AD (4) AF

47. Some equipotential surfaces are shown in the figure. The magnitude and direction of the electric field is-



(1) 100 V/m making angle 120^0 with the x-axis
(2) 100 V/m making angle 60^0 with the x-axis
(3) 200 V/m making angle 120^0 with the x-axis
(4) none of the above

48. The electric field in a region is directed outward and is proportional to the distance r from the origin. Taking the electric potential at the origin to be zero, the electric potential at a distance r :
(1) is uniform in the region
(2) is proportional to r
(3) is proportional to r^2
(4) increases as one goes away from the origin.

Based On | **DIPOLE**

49. The force on a charge situated on the axis of a dipole is F. If the charge is shifted to double the distance, the acting force will be -
(1) 4F (2) F/2 (3) F/4 (4) F/8

50. The ratio of electric fields due to an electric dipole on the axis and on the equatorial line at equal distance will be -
(1) 4 : 1 (2) 1 : 2 (3) 2 : 1 (4) 1 : 1

51. An electric dipole is made up of two equal and opposite charges of 2 x 10^{-6} coulomb at a distance of 3 cm. This is kept in an electric field of 2 x 10^5 N/C, then the maximum torque acting on the dipole -
(1) 12 x 10^{-1} Nm (2) 12 x 10^{-3} Nm
(3) 24 x 10^{-3} Nm (4) 24 x 10^{-1} Nm

52. The distance between two singly ionized atoms is 1Å. If the charge on both ions is equal and opposite then the dipole moment in coulomb-metre is -
(1) 1.6×10^{-29} (2) 0.16×10^{-29}
(3) 16×10^{-29} (4) $1.6 \times 10^{-29}/ 4\pi\varepsilon_0$

53. The electric potential in volt at a distance of 0.01 m on the equatorial line of an electric dipole of dipole moment p is -
(1) $p / 4\pi \in_0 x 10^{-4}$ (2) zero
(3) $4\pi \in_0$ p x 10^{-4} (4) $4\pi \in_0$ /p x 10^{-4}

54. The electric potential in volt due to an electric dipole of dipole moment 2 x 10^{-8} C-m at a distance of 3m on a line making an angle of 60^0 with the axis of the dipole is -
(1) 0 (2) 10 (3) 20 (4) 40

55. A dipole of electric dipole moment P is placed in a uniform electric field of strength E. If is the angle between positive directions of P and E, then the potential energy of the electric dipole is largest when is :
(1) zero (2) π/2
(3) π (4) π /4

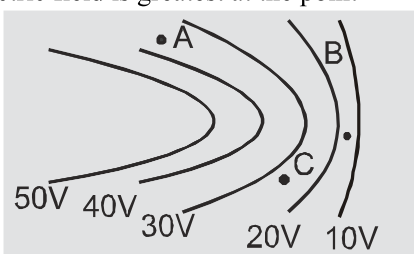
Based On | **FLUX CALCULATION AND GAUSS'S LAW**

56. Eight charges, 1μC,. -7μC, -4μC, 10μC, 2μC, -5μC, -3μC and 6μC are situated at the eight corners of a cube of side 20 cm. A spherical surface of radius 80 cm encloses this cube. The centre of the sphere coincides with the centre of the cube. Then the total outgoing flux from the spherical surface (in unit of volt meter) is-
(1) 36π x 10^3 (2) 684π x 10^3
(3) zero (4) none of the above

57. A closed cylinder of radius R and length L is placed in a uniform electric field E, parallel to the axis of the cylinder. Then the electric flux through the cylinder must be -
(1) $2\pi R^2E$ (2) $(2\pi R^2 + 2\pi RL)E$
(3) $2\pi RLE$ (4) zero

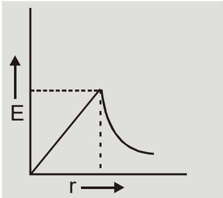
Based On | **CONDUCTOR, IT'S PROPERTIES & ELECTRIC PRESSURE**

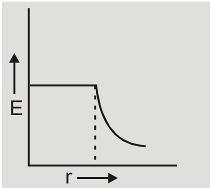
58. The fig. shows lines of constant potential in a region in which an electric field is present. The value of the potential are written in brackets of the points A, B and C, the magnitude of the electric field is greatest at the point –

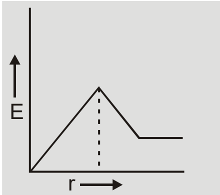


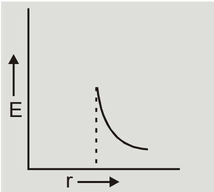
(1) A (2) B
(3) C (4) A & C

59. Which of the following represents the correct graph for electric field intensity and the distance r from the centre of a hollow charged metal sphere or solid metallic conductor of radius R :

(1) 

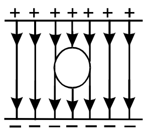
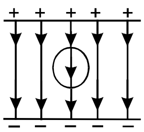
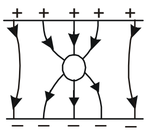
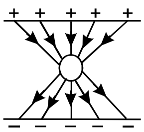
(2) 

(3) 

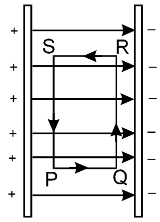
(4) 

60. A neutral metallic object is placed near a finite metal plate carrying a positive charge. The electric force on the object will be :
(1) towards the plate
(2) away from the plate
(3) parallel to the plate
(4) zero

61. An uncharged sphere of metal is placed in a uniform electric field produced by two large conducting parallel plates having equal and opposite charges, then lines of force look like

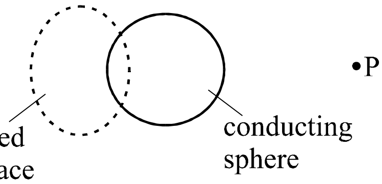
(1) 
(2) 
(3) 
(4) 

62. The amount of work done in Joules in carrying a charge +q along the closed path PQRSP between the oppositely charged metal plates is (where E is electric field between the plates)



(1) zero
(2) q
(3) qE (PQ + QR + SR + SP)
(4) q/ε_0

63. Figure shows a closed surface which intersects a conducting sphere. If a positive charge is placed at the point P, the flux of the electric field through the closed surface



(1) will remain zero
(2) will become positive
(3) will become negative
(4) will become undefined

EXERCISE # 2

1. Two point charges $100\ \mu C$ and $5\ \mu C$ are placed at points A and B respectively with $AB = 40\ cm$. The work done by external force in displacing the charge $5\ \mu C$ from B to C, where $BC = 30 cm$, angle $ABC = \frac{\pi}{2}$ and $[1/(4\pi\epsilon 0)] = 9 \times 10^9 Nm^2/c^2$.

(1) $9\,J$ (2) $\frac{81}{20}J$ (3) $\frac{9}{25}J$ (4) $-\frac{9}{4}J$

2. An electric dipole is placed at an angle of 60^0 with an electric field of intensity $10^5\ NC^{-1}$. It experiences a torque equal to $8\sqrt{3}$ Nm. Calculate the charge on the dipole, if the dipole length is 2 cm.

(1) -8×10^3 C (2) 8.54×10^{-4} C
(3) 8×10^{-3} C (4) 0.85×10^{-6} C

3. The electrostatic potential inside a charged spherical ball is given by $\phi = ar^2 + b$ where r is the distance from the centre a, b are constants. Then the charge density inside the ball is

(1) $-6a\varepsilon_0 r$ (2) $-24\pi a\varepsilon_0$
(3) $-6a\varepsilon_0$ (4) $-24\pi a\varepsilon_0 r$

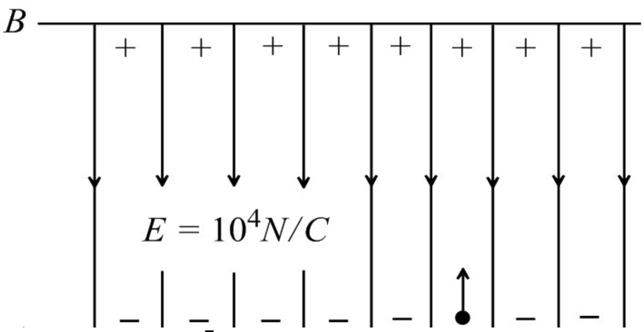
4. The electric potential V is given as a function of distance x(metre) by $V = (5x^2 + 10x - 9) volt$. Value of electric field at $x = 1$ is

(1) $-20V/m$ (2) $6V/m$
(3) $11V/m$ (4) $-23V/m$

5. A hollow conducting sphere of radius R has a charge $(+Q)$ on its surface. What is the electric potential within the sphere at a distance $r = R/3$ from its centre

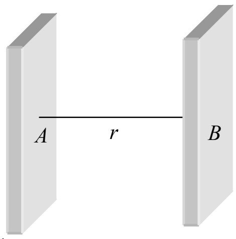
(1) Zero (2) $\frac{1}{4\pi\varepsilon_0}\frac{Q}{r}$
(3) $\frac{1}{4\pi\varepsilon_0}\frac{Q}{R}$ (4) $\frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2}$

6. An electron is released from the bottom plate A as shown in the figure $(E = 10^4 N/C)$. The velocity of the electron when it reaches plate B will be nearly equal to



(1) $0.85 \times 10^7\ m/s$
(2) $1.0 \times 10^7\ m/s$
(3) $1.25 \times 10^7\ m/s$
(4) $1.65 \times 10^7\ m/s$

7. There are two equipotential surfaces as shown in figure. The distance between them is r. The charge of $-q$ coulomb taken from the surface A to B, the resultant work done will be



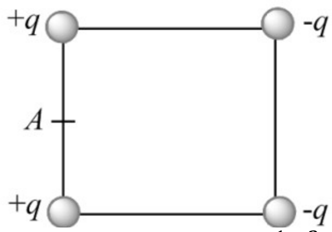
(1) $W = \frac{1}{4\pi\varepsilon_0}\frac{q}{r}$ (2) $W = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}$
(3) $W = -\frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}$ (4) $W =$ zero

8. An infinite number of electric charges each equal to $5\ nano - coulomb$ (magnitude) are placed along X-axis at $x = 1\ cm, x = 2\ cm, x = 4\ cm\ x = 8\ cm$ ……… and so on. In the setup if the consecutive charges have opposite sign, then the electric field in $Newton/Coulomb$ at $X = 0$ is

$$\left[\frac{1}{4\pi\varepsilon_0} = 9 \times 10^9 N - m^2/c^2\right]$$

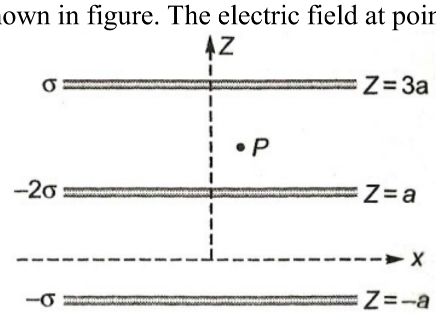
(1) 12×10^4 (2) 24×10^4
(3) 36×10^4 (4) 48×10^4

9. Four electric charges $+q, +q, -q$ and $-q$ are placed at the corners of a square of side $2L$ (see figure). The electric potential at point A, midway between the two charges $+q$



(1) Zero (2) $\frac{1}{4\pi\varepsilon_0}\frac{2q}{L}(1 + \sqrt{5})$
(3) $\frac{1}{4\pi\varepsilon_0}\frac{2q}{L}\left(1 + \frac{1}{\sqrt{5}}\right)$ (4) $\frac{1}{4\pi\varepsilon_0}\frac{2q}{L}\left(1 - \frac{1}{\sqrt{5}}\right)$

10. Three infinitely long charge sheets are placed as shown in figure. The electric field at point P is



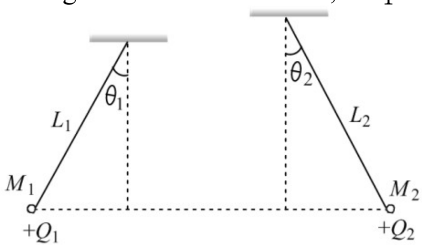
(1) $\frac{2\sigma}{\varepsilon_0}\hat{\boldsymbol{k}}$ (2) $-\frac{2\sigma}{\varepsilon_0}\hat{\boldsymbol{k}}$
(3) $\frac{4\sigma}{\varepsilon_0}\hat{\boldsymbol{k}}$ (4) $-\frac{4\sigma}{\varepsilon_0}\hat{\boldsymbol{k}}$

11. If 3 charges are placed at the vertices of equilateral triangle of charge $'q'$ each. What is the net potential energy, if the side of equilateral Δ is $l\ cm$

(1) $\frac{1}{4\pi\varepsilon_0}\frac{q^2}{l}$ (2) $\frac{1}{4\pi\varepsilon_0}\frac{2q^2}{l}$

(3) $\frac{1}{4\pi\varepsilon_0}\frac{3q^2}{l}$ (4) $\frac{1}{4\pi\varepsilon_0}\frac{4q^2}{l}$

12. Two small spheres of masses M_1 and M_2 are suspended by weightless insulating threads of lengths L_1 and L_2. The spheres carry charges Q_1 and Q_2 respectively. The spheres are suspended such that they are in level with one another and the threads are inclined to the vertical at angles of θ_1 andθ_2 as shown. Which one of the following conditions is essential, if $\theta_1 = \theta_2$

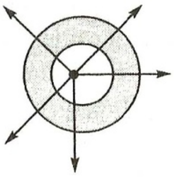


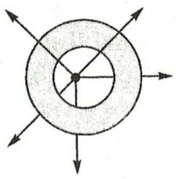
(1) $M_1 \neq M_2$ but $Q_1 = Q_2$

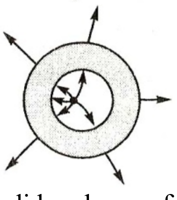
(2) $M_1 = M_2$

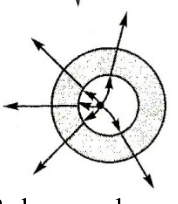
(3) $Q_1 = Q_2$ (4) $L_1 = L_2$

13. A metallic shell has a point charge q kept inside its cavity. Which one of the following diagrams correctly represents the electric lines or forces?

(1) 

(2) 

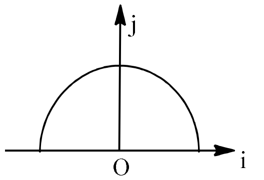
(3) 

(4) 

14. A solid sphere of radius R has a charge Q distributed in its volume with a charge density$\rho = kr^a$, where k and a are constants and $r$is the distance from its centre. If the electric field at $r = \frac{R}{2}$ is$\frac{1}{8}$times that at $r = R$, find the value of a.

(1) 2 (2) 3 (3) 2.5 (4) 0.2

15. A thin semi-circular ring of radius r has a positive charge$q$ distributed uniformly over it. The net field **E** at the centre O is



(1) $\frac{q}{4\pi^2\varepsilon_0 r^2}\hat{\mathbf{i}}$ (2) $-\frac{q}{4\pi^2\varepsilon_0 r^2}\hat{\mathbf{j}}$

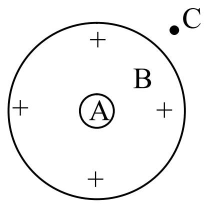
(3) $-\frac{q}{2\pi^2\varepsilon_0 r^2}\hat{\mathbf{i}}$ (4) $\frac{q}{2\pi^2\varepsilon_0 r^2}\hat{\mathbf{j}}$

16. Charge Q is placed on each of $(n-1)$ corners of a polygon of n sides. The distance of centre of the polygon from each corners is $'r'$, then electric field at centre is

(1) $\frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2}$ (2) $\frac{(n-1)}{4\pi\varepsilon_0}\frac{Q}{r^2}$

(3) $\frac{n}{(n-1)}\frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2}$ (4) Zero

17. Two equal metal balls are charged to 10 and -20 units of electricity. Then they are brought in contact with each other and then again separated to the original distance. The ratio of magnitudes of the force between the two balls before and after contact is



(1) 8:1 (2) 1:8

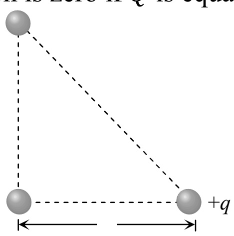
(3) 2:1 (4) 1:2

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

(1) $\frac{4\pi\rho_0 r}{3\varepsilon_0}\left(\frac{5}{3} - \frac{r}{R}\right)$ (2) $\frac{\rho_0 r}{4\varepsilon_0}\left(\frac{5}{3} - \frac{r}{R}\right)$

(3) $\frac{4\rho_0 r}{3\varepsilon_0}\left(\frac{5}{4} - \frac{r}{R}\right)$ (4) $\frac{\rho_0 r}{3\varepsilon_0}\left(\frac{5}{4} - \frac{r}{R}\right)$

19. The charges $Q, +q$ and $+q$ are placed at the vertices of a right-angled isosceles triangle as shown. The net electrostatic energy of the configuration is zero if Q is equal to



(1) $\frac{-q}{1+\sqrt{2}}$ (2) $\frac{-2q}{2+\sqrt{2}}$

(3) $-2q$ (4) $+q$

20. Two small spheres each having the charge $+Q$ are suspended by insulating threads of length L from a hook. This arrangement is taken in space where there is no gravitational effect, then the angle between the two suspensions and the tension in each will be

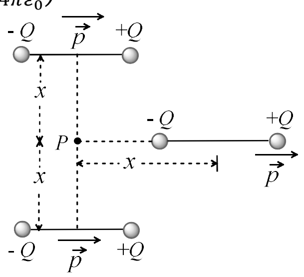
(1) $180^0, \frac{1}{4\pi\varepsilon_0}\frac{Q^2}{(2L)^2}$ (2) $90^0, \frac{1}{4\pi\varepsilon_0}\frac{Q^2}{L^2}$

(3) $180^0. \frac{1}{4\pi\varepsilon_0}\frac{Q^2}{2L^2}$ (4) $180^0, \frac{1}{4\pi\varepsilon_0}\frac{Q^2}{L^2}$

21. A small conducting sphere of radius r is lying concentrically inside a bigger hollow conducting sphere of radius R. The bigger and smaller spheres are charged with Q and $q(Q > q)$ and are insulated from each other. The potential difference between the spheres will be

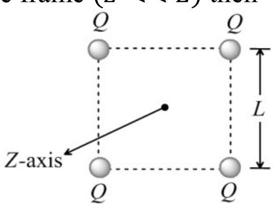
(1) $\frac{1}{4\pi\varepsilon_0}\left(\frac{q}{r} - \frac{Q}{R}\right)$ (2) $\frac{1}{4\pi\varepsilon_0}\left(\frac{Q}{R} + \frac{q}{r}\right)$
(3) $\frac{1}{4\pi\varepsilon_0}\left(\frac{q}{r} - \frac{q}{R}\right)$ (4) $\frac{1}{4\pi\varepsilon r_0}\left(\frac{q}{R} - \frac{Q}{r}\right)$

22. Three identical dipoles are arranged as shown below. What will be the net electric field at $P\left(k = \frac{1}{4\pi\varepsilon_0}\right)$



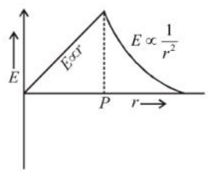
(1) $\frac{k.p}{x^3}$ (2) $\frac{2kp}{x^3}$ (3) Zero (4) $\frac{\sqrt{2}kp}{x^3}$

23. Four point $+ve$ charges of same magnitude (Q) are placed at four corners of a rigid square frame as shown in figure. The plane of the frame is perpendicular to Z −axis. If a $-ve$ point charge is placed at a distance z away from the above frame $(z << L)$ then



(1) $-ve$ charge oscillates along the $Z -$ axis
(2) It moves away from the frame
(3) It moves slowly towards the frame and stays in the plane of the frame
(4) It passes through the frame only once

24. The figure shows electric field E at a distance r in any direction from the origin O. The electric field E is due to

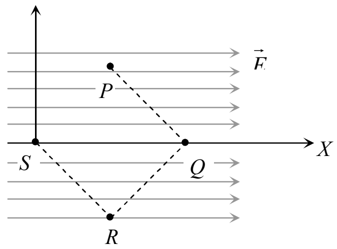


(1) A charged hollow metallic sphere of radius OP with centre at O
(2) A charged solid metallic sphere of radius OP with centre at O
(3) A uniformly charged non-conducting sphere of radius OP with centre at O
(4) A uniformly charged non-conducting hollow sphere of radius OP with centre at O

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

(1) $\frac{\rho_0 r}{4\varepsilon_0}\left(\frac{5}{4} - \frac{r}{R}\right)$ (2) $\frac{4\pi\rho_0 r}{3\varepsilon_0}\left(\frac{5}{3} - \frac{r}{R}\right)$
(3) $\frac{\rho_0 r}{4\varepsilon_0}\left(\frac{5}{3} - \frac{r}{R}\right)$ (4) $\frac{4\rho_0 r}{3\varepsilon_0}\left(\frac{5}{4} - \frac{r}{R}\right)$

26. Point charge q moves from point P to point S along the path $PQRS$ (figure shown) in a uniform electric field E pointing coparallel to the positive direction of the X-axis. The coordinates of the points P, Q, R and S are $(a, b, 0)(2a, 0, 0)(a, -b, 0)$ and $(0,0,0)$ respectively. The work done by the field in the above process is given by the expression

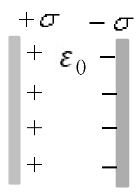


(1) qEa (2) $-qEa$
(3) $qEa\sqrt{2}$ (4) $qE\sqrt{[(2a)^2 + b^2]}$

27. The electric potential at a point (x, y, z) is given by $V = -x^2y - xz^3 + 4$ The electric field $\vec{E}$ at that point is

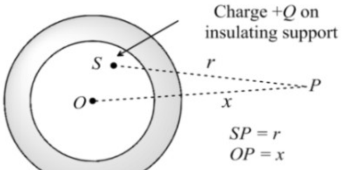
(1) $\vec{E} = \hat{\imath}(2xy + z^3) + \hat{\jmath}x^2 + \hat{k}3xz^2$
(2) $\vec{E} = \hat{\imath}\,2xy + \hat{\jmath}(x^2 + y^2) + \hat{k}(3xz - y^2)$
(3) $\vec{E} = \hat{\imath}z^3 + \hat{\jmath}\,xyz + \hat{k}z^2$
(4) $\vec{E} = \hat{\imath}(2xy - z^3) + \hat{\jmath}\,xy^2 + \hat{k}3z^2x$

28. Two large metal plates are placed parallel to each other. The inner surfaces of plates are charged by $+\sigma$ and $-\sigma$ (Coulomb/m^2). The outer surfaces are neutral. The electric field is …… in the region between the plates and …… outside the plates



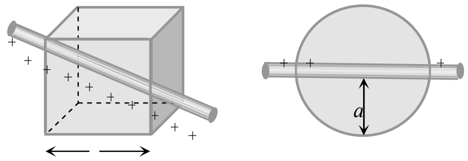
(1) $\frac{2\sigma}{\epsilon_0}, \frac{\sigma}{\epsilon_0}$ (2) $\frac{\sigma}{\epsilon_0}$, zero
(3) $\frac{2\sigma}{\epsilon_0}$, zero (4) zero, $\frac{2\sigma}{\epsilon_0}$

29. The adjacent diagram shows a charge $+Q$ held on an insulating support S and enclosed by a hollow spherical conductor. O represents the centre of the spherical conductor and P is a point such that $OP = x$ and $SP = r$
The electric field at point P will be



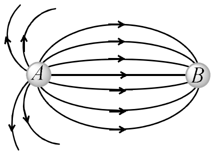
(1) $\frac{Q}{4\pi\varepsilon_0 x^2}$ (2) $\frac{Q}{4\pi\varepsilon_0 r^2}$
(3) 0 (4) None of the above

30. A linear charge having linear charge density λ, penetrates a cube diagonally and then it penetrate a sphere diametrically as shown. What will be the ratio of flux coming cut of cube and sphere



(1) $\frac{1}{2}$ (2) $\frac{2}{\sqrt{3}}$ (3) $\frac{\sqrt{3}}{2}$ (4) $\frac{1}{1}$

31. The spatial distribution of the electric field due to charges (A, B) is shown in figure. Which one of the following statements is correct



(1) A is $+ve$ and $B - ve$ and $|A| > |B|$
(2) A is $-ve$ and $B + ve$; $|A| = |B|$
(3) Both are $+ve$ but $A > B$
(4) Both are $-ve$ but $A > B$

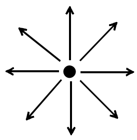
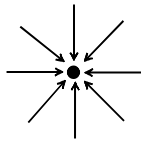
32. Tow positive charges of magnitude q are placed at the ends of a side1 of a square of side $2a$. Two negative charges of the same magnitude are kept at the other corners. Starting from rest, if a charge Q moves from the middle of side 1 to the centre of square, its kinetic energy at the centre of square is

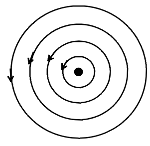
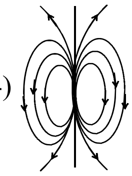
(1) $\frac{1}{4\pi\varepsilon_0}\frac{2qQ}{a}\left(1 - \frac{1}{\sqrt{5}}\right)$ (2) Zero
(3) $\frac{1}{4\pi\varepsilon_0}\frac{2qQ}{a}\left(1 + \frac{1}{\sqrt{5}}\right)$ (4) $\frac{1}{4\pi\varepsilon_0}\frac{2qQ}{a}\left(1 - \frac{2}{\sqrt{5}}\right)$

33. Two equal negative charges $-q$ are fixed at points $(0, a)$ and $(0, -a)$ on the Y-axis. A positive charge $'q'$ is released from rest at the point $(x << a)$ on the x-axis. What is the frequency of motion

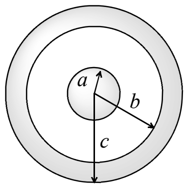
(1) $\sqrt{\frac{2q^2}{4\pi\epsilon_0 ma^3}}$ (2) $\sqrt{\frac{4q^2}{2\pi\epsilon_0 ma^3}}$
(3) $\sqrt{\frac{q^2}{2\pi\epsilon_0 ma^3}}$ (4) $\sqrt{\frac{q^2}{\pi\epsilon_0 ma^3}}$

34. Which of the field patterns given below is valid for electric field as well as for magnetic field

(1)  (2) 

(3)  (4) 

35. A solid conducting sphere of radius a has a net positive charge$2Q$. A conducting spherical shell of inner radius b and outer radius c is concentric with the solid sphere and has a net charge $-Q$. The surface charge density on the inner and outer surfaces of the spherical shell will be

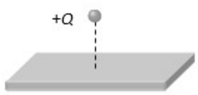


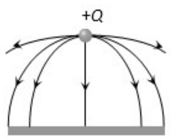
(1) $-\frac{2Q}{4\pi b^2}, \frac{Q}{4\pi c^2}$ (2) $-\frac{Q}{4\pi b^2}, \frac{Q}{4\pi c^2}$
(3) $0, \frac{Q}{4\pi c^2}$ (4) None of the above

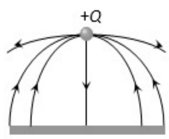
36. Two identical thin rings each of radius R meters are coaxially placed at a diatance R meters apart. If Q_1 coulomb and Q_2 coulomb are respectively the charges uniformly spread on the two rings, the work done in moving a charge q from the centre of one ring to that of other is

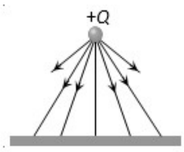
(1) Zero (2) $\frac{q(Q_1 - Q_2)(\sqrt{2}-1)}{\sqrt{2}.4\pi\varepsilon_0 R}$
(3) $\frac{q\sqrt{2}(Q_1 + Q_2)}{4\pi\varepsilon_0 R}$ (4) $\frac{q(Q_1 + Q_2)(\sqrt{2}+1)}{\sqrt{2}.4\pi\varepsilon_0 R}$

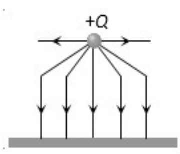
37. A charge Q is fixed at a distance d in front of an infinite metal plate. The lines of force are represented by



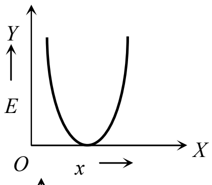
(1) 

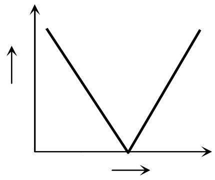
(2) 

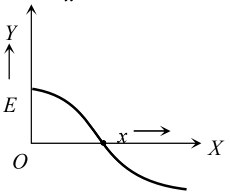
(3) 

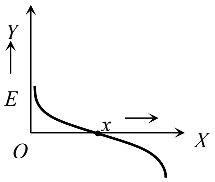
(4) 

38. Two identical point charges are placed at a separation of $d. P$ is a point on the line joining the charges, at a distance x from any one charge. The field at P is E, E is plotted against x for values of x from close to zero to slightly less than d. Which of the following represents the resulting curve

(1) 

(2) 

(3) 

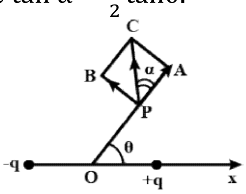
(4) 

39. An electric dipole is placed along the x −axis at the origin O. A point P is at a distance of $20cm$ from this origin such that OP makes an angle $\frac{\pi}{3}$ with the x −axis. If the electric field at P makes an angle θ with the x −axis, the value of θ would be

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

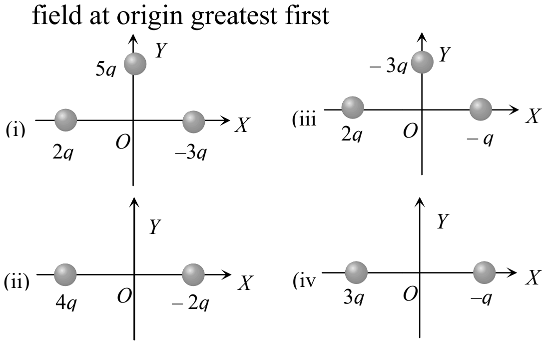
(3) $\frac{2\pi}{3}$ (4) $\tan^{-1}\left(\frac{\sqrt{3}}{2}\right)$

40. An electric dipole of moment **p** is placed at the origin along the x-axis. The electric field at a point P, whose position vector makes an angle θ with the x-axis, will make an angle With the x-axis, where $\tan\alpha = \frac{1}{2}\tan\theta$.



(1) α (2) θ (3) $\theta + \alpha$ (4) $2\theta + \alpha$

41. In the following four situations charged particles are at equal distance from the origin. Arrange them the magnitude of the net electric field at origin greatest first



(1) (i) > (ii) > (iii) > (iv)

(2) (ii) > (i) > (iii) > (iv)

(3) (i) > (iii) > (ii) > (iv)

(4) (iv) > (iii) > (ii) > (i)

42. Two identical conducting spheres carrying different charges attract each other with a force F when placed in air medium at a distance d apart. The spheres are brought into contact and then taken to their original positions. Now the two spheres repel each other with a force whose magnitude is equal to that of the initial attractive force. The ratio between initial charges on the spheres is

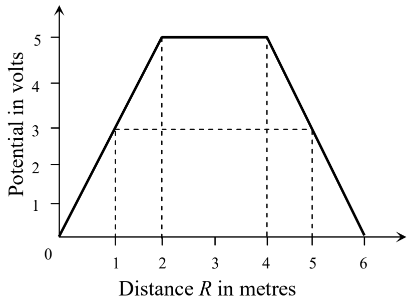
(1) $-(3+\sqrt{8})$ only

(2) $-3+\sqrt{8}$ only

(3) $-3(3+\sqrt{8})$ or $(-3+\sqrt{8})$

(4) $+\sqrt{3}$

43. The variation of potential with distance R from a fixed point is as shown below. The electric field at $R = 5m$ is



(1) 2.5 $volt/m$ (2) −2.5 $volt/m$

(3) 2/5 $volt/m$ (4) −2/5 $volt/m$

44. An electric dipole coincides on Z-axis and its mid point is on origin of the co-ordinate system. The electric field at an axial point at a distance z from origin is $\vec{E}_{(z)}$ and electric field at an equatorial point at a distance y from origin is $\vec{E}_{(y)}$ Here $z = y \gg a$, so $\left|\frac{\vec{E}_{(z)}}{\vec{E}_{(y)}}\right| = \cdots$

(1) 1 (2) 4 (3) 3 (4) 2

45. A square of side $a$has charge Qat its centre and charge q at one of the corners. The work required to be done in moving the charge q from the corner to the diagonally opposite corner is

(1) Zero (2) $\frac{Qq}{4\pi\varepsilon_0 a}$ (3) $\frac{Qq\sqrt{2}}{4\pi\varepsilon_0 a}$ (4) $\frac{Qq}{2\pi\varepsilon_0 a}$

46. An electric charge $10^{-3}\mu C$ is placed at the origin (0, 0) of X-Y coordinate system. Two points A and B are situated at $(\sqrt{2}, \sqrt{2})$and(2,0)respectively.The potential difference between the points A and B will be

(1) 9V (2) Zero (3) 2V (4) 4.5V

47. The displacement of a charge Qin the electric field $\boldsymbol{E} = e_1\hat{\boldsymbol{i}} + e_2\hat{\boldsymbol{j}} + e_3\hat{\boldsymbol{k}}$ is $\boldsymbol{r} = a\hat{\boldsymbol{i}} + b\hat{\boldsymbol{j}}$. The work done is

(1) $Q(ae_1 + be_2)$

(2) $Q\sqrt{(ae_1)^2 + (be_2)^2}$

(3) $Q(e_1 + e_2)\sqrt{a^2 + b^2}$

(4) $Q\left(\sqrt{e_1^2 - e_2^2}\right)(a + b)$

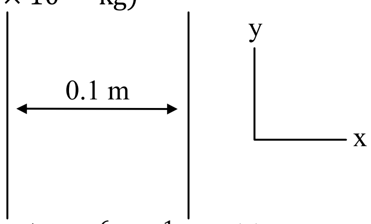
48. Small drops of the same size are charged to V volt each. If n such drops coalesce to form a single large drop, its potential will be

(1) Vn (2) $\frac{V}{n}$ (3) $Vn^{\frac{1}{3}}$ (4) $Vn^{\frac{2}{3}}$

49. Along the x-axis, three charges $\frac{q}{2}, -q$ and $\frac{q}{2}$ are placed at $x = 0, x = a$ and $x = 2a$ respectively. The resultant electric potential at a point P located at a distance r from the charge $-q(a < < r)$ is (ε_0 is the permittivity of free space)

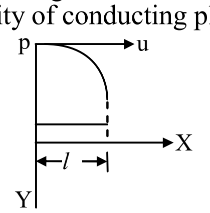
(1) $\frac{qa}{4\pi\varepsilon_0 r^2}$ (2) $\frac{qa^2}{4\pi\varepsilon_0 r^3}$ (3) $\frac{q\left(\frac{a^2}{4}\right)}{4\pi\varepsilon_0 r^3}$ (4) $\frac{q}{4\pi\varepsilon_0 r}$

50. Two insulating plates are both uniformly charged in such a way that the potential difference between them is $V_2 - V_1 = 20\text{V}$. (ie, plate 2 is at a higher potential). The plates are separated by $d = 0.1\text{m}$ and can be treated as infinitely large. An electron is released from rest on the inner surface of plate 1. What is its speed when it hits plate 2? (e=1.6×10^{-1} C, $m_0 = 9.11 \times 10^{-31}$kg)



(1) $2.65 \times 10^6 \text{ms}^{-1}$ (2) $7.02 \times 10^{12} \text{ms}^{-1}$
(3) $1.87 \times 10^6 \text{ms}^{-1}$ (4) $32 \times 10^{-19} \text{ms}^{-1}$

51. The electron is projected from a distance d and with initial velocity u parallel to a uniformly charged flat conducting plate as shown in figure. It strikes the plate after travelling a distance l along the direction. The surface charge density of conducting plate is equal to



(1) $\frac{2d\varepsilon_0 mu^2}{el^2}$ (2) $\frac{2d\varepsilon_0 mu}{el}$
(3) $\frac{d\varepsilon_0 mu^2}{el}$ (4) $\frac{d\varepsilon_0 mu}{el}$

52. An electric field is given by $\vec{E} = (y\hat{i} + x\hat{j})$m NC^{-1}. The work done in moving a 1 C charge from $\vec{r}_A = (2\hat{i} + 2\hat{j})$m to $\vec{r}_B = (4\hat{i} + 2\hat{j})$m is

(1) +8 J (2) +4 J (3) Zero (4) −4 J

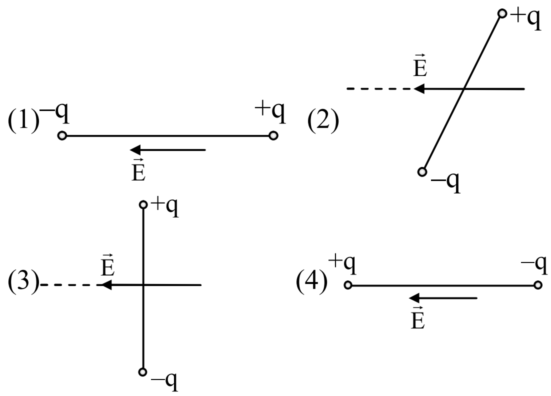
53. 27 identical drops of mercury are charged simultaneously to the same potential of 10 V each. Assuming drops to be spherical, if all the charged drops are made to combine to form one large drop, then the potential of larger drop would be

(1) 45 V (2) 135 (3) 270 V (4) 90 V

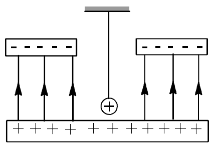
54. A soap bubble is charged to a potential of 16V. Its radius is, then doubled. The potential of the bubble now will be

(1) 16V (2) 8V (3) 4V (4) 2V

55. In which of the states shown in figure is the potential energy of a electric dipole maximum?

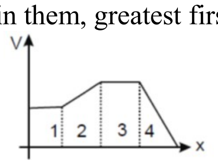


56. If a positively charged pendulum is oscillating in a uniform electric field as shown in figure. Its time period as compared to that when it was uncharged will



(1) Increase (2) Decrease
(3) Not change
(4) First increase and then decrease

57. The figure shows electric potential V as a function of x. Rank the four regions according to the magnitude of x-component of the electric field E within them, greatest first



(1) $E_4 > E_2 > E_3 > E_1$
(2) $E_2 > E_4 > E_1 = E_3$
(3) $E_1 > E_2 > E_3 > E_4$
(4) $E_1 > E_3 > E_2 > E_4$

58. A hollow charged metal sphere has radius r. If the potential difference between its surface and a point at a distance $3r$ from the centre is V, then electric field intensity at a distance $3r$ is

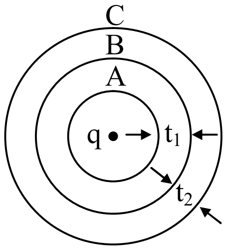
(1) $\frac{V}{2r}$ (2) $\frac{V}{3r}$ (3) $\frac{V}{6r}$ (4) $\frac{V}{4r}$

59. A charge $(-q)$ and another charge $(+Q)$ are kept at two points A and B respectively. Keeping the charge $(+Q)$ fixed at B, the charge $(-q)$ at A is moved to another point C such that ABC forms an equilateral triangle of side l. The net work done in moving the charge $(-q)$ is

(1) $\frac{1}{4\pi\varepsilon_0}\frac{Qq}{l}$ (2) $\frac{1}{4\pi\varepsilon_0}\frac{Qq}{l^2}$
(3) $\frac{1}{4\pi\varepsilon_0} Qql$ (4) Zero

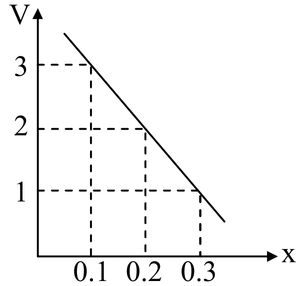
60. The electric potential at a point (x, y) in the x-y plane is given by $V = -Kxy$
The electric field intensity at a distance r from the origin varies as
(1) r^2 (2) r (3) $2r$ (4) $2r^2$

61. Figure shows three spherical and equipotential surfaces *A, B* and *C* round a point charge q. The potential difference $V_A - V_B = V_B - V_C$. If $t_1$and $t_2$be the distance between them. Then



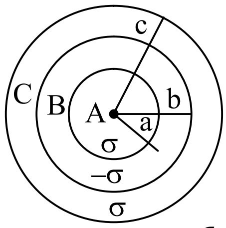
(1) $t_1 = t_2$ (2) $t_1 > t_2$
(3) $t_1 < t_2$ (4) $t_1 \leq t_2$

62. The variation of potential V with distance x from a fixed point charge is shown in figure. The electric field strength between $x = 0.1$ m and 0.3 m is



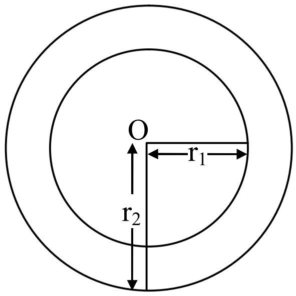
(1) $+0.4\ \text{Vm}^{-1}$ (2) $-0.4\ \text{Vm}^{-1}$
(3) $+10\ \text{Vm}^{-1}$ (4) $-10\ \text{Vm}^{-1}$

63. Consider three concentric shells of metal *A, B* and *C* are having radii *a, b* and *c* respectively as shown in the figure $(a < b < c)$. Their surface charge densities are $\sigma, -\sigma$ and σ respectively. Calculate the electric potential on the surface of shell *A*



(1) $\frac{\sigma}{\varepsilon_0}(a - b + c)$ (2) $\frac{\sigma}{\varepsilon_0}(a - b - c)$
(3) $\frac{\sigma}{\varepsilon_0}(a^2 + b^2 + c^2)$ (4) $\frac{\sigma}{\varepsilon_0}(a + b - c)$

64. In the given figure, a hollow spherical capacitor is shown. The electric field will not be zero at



(1) $r < r_1$ (2) $r_1 < r_2$
(3) $r < r_2$ (4) $r_1 < r < r_2$

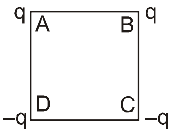
EXERCISE # 3

Question **Previous Year (JEE Main)**

1. An electric charge $10^{-3}\mu C$ is placed at the origin (0,0) of X–Y co-ordinate system. Two points A and B are situated at $\left(\sqrt{2},\sqrt{2}\right)$ and (2, 0) respectively. The potential difference between the points A and B will be **[AIEEE-2007]**

(1) 9 volt (2) zero (3) 2 volt (4) 4.5 volt

2. Charges are placed on the vertices of a square as shown. Let $\vec{E}$ be the electric field and V the potential at the centre. If the charges on A and B are interchanged with those on D and C respectively, then **[AIEEE-2007]**



(1) $\vec{E}$ remains unchanged, V changes

(2) Both $\vec{E}$ and V change

(3) $\vec{E}$ and V remain unchanged

(4) $\vec{E}$ changes, V remains unchanged

3. The potential at a point x (measured in μm) due to some charges situated on the x-axis is given by $V(x) = 20/(x^2 - 4)$ volts. The electric field E at x = 4 μm is given by : **[AIEEE-2007]**

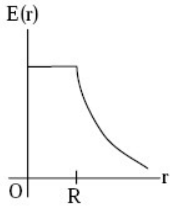
(1) 5/3 volt/μm and in the –ve x direction

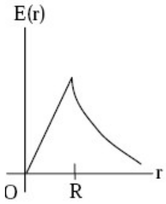
(2) 5/3 volt/μm and in the +ve x direction

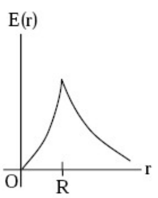
(3) 10/9 volt/μm and in the –ve x direction

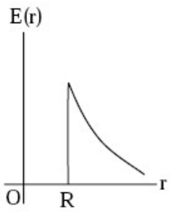
(4) 10/9 volt/μm and in the +ve x direction

4. A thin spherical shell of radius R has charge Q spread uniformly over its surface. Which of the following graphs most closely represents the electric field E (r) produced by the shell in the range $0 \le r < \infty$, where r is the distance from the centre of the shell? **[AIEEE-2008]**

(1)


(2)


(3)


(4)


5. Two points P and Q are maintained at the potentials of 10 V and –4 V respectively. The work done in moving 100 electrons from P to Q is: **[AIEEE-2009]**

(1) 9.60×10^{-17} J (2) -2.24×10^{-16} J

(3) 2.24×10^{-16} J (4) -9.60×10^{-17} J

6. A charge Q is placed at each of the opposite corners of a square. A charge q is placed at each of the other two corners. If the net electrical force on Q is zero, then Q/q equals: **[AIEEE-2009]**

(1) –1 (2) 1 (3) $-\frac{1}{\sqrt{2}}$ (4) $-2\sqrt{2}$

7. **Statement 1 :** For a charged particle moving from point P to point Q, the net work done by an electrostatic field on the particle is independent of the path connecting point P to point Q. **[AIEEE-2009]**

Statement 2 : The net work done by a conservative force on an object moving along a closed loop is zero.

(1) Statement-1 is true, Statement-2 is true; Statement-2 is the correct explanation of Statement-1.

(2) Statement-1 is true, Statement-2 is true; Statement-2 is not the correct explanation of Statement-1.

(3) Statement-1 is false, Statement-2 is true.

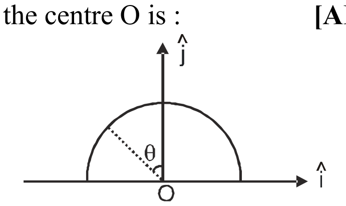
(4) Statement-1 is true, Statement-2 is false

8. Let $\rho(r) = \frac{Q}{\pi R^4} r$ be the charge density distribution for a solid sphere of radius R and total charge Q. For a point 'P' inside the sphere at distance r_1 from the centre of sphere, the magnitude of electric field is : **[AIEEE-2009]**

(1) $\frac{Q}{4\pi\varepsilon_0 r_1^2}$ (2) $\frac{Qr_1^2}{4\pi\varepsilon_0 R^4}$

(3) $\frac{Qr_1^2}{3\pi\varepsilon_0 R^4}$ (4) 0

9. A thin semi-circular ring of radius r has a positive charge q distributed uniformly over it. The net field at the centre O is : **[AIEEE-2010]**



(1) $\frac{q}{4\pi^2\varepsilon_0 r^2}\hat{j}$ (2) $-\frac{q}{4\pi^2\varepsilon_0 r^2}\hat{j}$

(3) $-\frac{q}{2\pi^2\varepsilon_0 r^2}\hat{j}$ (4) $\frac{q}{2\pi^2\varepsilon_0 r^2}\hat{j}$

10. Let there be a spherically symmetric charge distribution with charge density varying as $\rho(r) = \rho_0\left(\frac{5}{4} - \frac{r}{R}\right)$ upto r = R, and ρ(r) = 0 for r > R, where r is the distance from the origin. The electric field at a distance r (r < R) from the origin is given by **[AIEEE-2010]**

(1) $\frac{4\pi\rho_0 r}{3\varepsilon_0}\left(\frac{5}{3} - \frac{r}{R}\right)$ (2) $\frac{\rho_0 r}{4\varepsilon_0}\left(\frac{5}{3} - \frac{r}{R}\right)$

(3) $\frac{4\rho_0 r}{3\varepsilon_0}\left(\frac{5}{4} - \frac{r}{R}\right)$ (4) $\frac{\rho_0 r}{3\varepsilon_0}\left(\frac{5}{4} - \frac{r}{R}\right)$

11. Two identical charged spheres are suspended by strings of equal lengths. The strings make an angle of 30º with each other. When suspended in a liquid of density 0.8 g cm^{-3}, the angle remains the same. If density of the material of the sphere is 1.6 g cm^{-3}, the dielectric constant of the liquid is **[AIEEE-2010]**

(1) 4 (2) 3 (3) 2 (4) 1

12. The electrostatic potential inside a charged spherical ball is given by $\phi = ar^2 + b$ where r is the distance from the centre; a,b are constants. Then the charge density inside the ball is : **[AIEEE - 2011]**

(1) $-24\pi a\varepsilon_0 r$ (2) $-6\pi a\varepsilon_0 r$

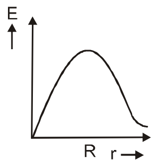
(3) $-24\pi a\varepsilon_0$ (4) $-6 a\varepsilon_0$

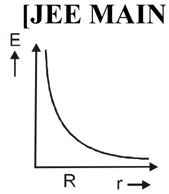
13. Two positive charges of magnitude 'q' are placed at the ends of a side (side 1) of a square of side '2a'. Two negative charges of the same magnitude are kept at the other corners. Starting from rest, if a charge Q moves from the middle of side 1 to the centre of square, its kinetic energy at the centre of square is : **[AIEEE-2011]**

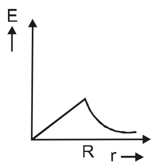
(1) Zero (2) $\frac{1}{4\pi\varepsilon_0}\frac{2qQ}{a}\left(1+\frac{1}{\sqrt{5}}\right)$

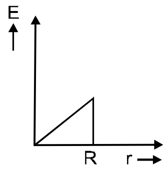
(3) $\frac{1}{4\pi\varepsilon_0}\frac{2qQ}{a}\left(1-\frac{2}{\sqrt{5}}\right)$ (4) $\frac{1}{4\pi\varepsilon_0}\frac{2qQ}{a}\left(1-\frac{1}{\sqrt{5}}\right)$

14. In a uniformly charged sphere of total charge Q and radius R, the electric field E is plotted as function of distance from the centre. The graph which would correspond to the above will be : **[JEE MAIN 2012]**

(1)


(2)


(3)


(4)


15. This question has statement-1 and statement-2. Of the four choices given after the statements, choose the one that best describes the two statements. **[JEE MAIN 2012]**

An insulating solid sphere of radius R has a uniformly positive charge density ρ. As a result of this uniform charge distribution there is a finite value of electric potential at the centre of the sphere, at the surface of the sphere and also at a point out side the sphere. The electric potential at infinite is zero.

Statement-1 : When a charge 'q' is taken from the centre to the surface of the sphere its potential energy changes by $\frac{q\rho}{3\varepsilon_0}$.

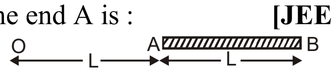
Statement-2 : The electric field at a distance r (r < R) from the centre of the sphere is $\frac{\rho r}{3\varepsilon_0}$

(1) Statement-1 is true, Statement-2 is true; Statement-2 is not the correct explanation of statement-1.
(2) Statement-1 is true Statement-2 is false.
(3) Statement-1 is false Statement-2 is true.
(4) Statement-1 is true, Statement-2 is true, Statement-2 is the correct explanation of Statement-1.

16. Two charges, each equal to q, are kept at x = – a and x = a on the x-axis. A particle of mass m and charge $q_0 = \frac{q}{2}$ is placed at the origin. If charge q_0 is given a small displacement (y <<a) along the y-axis, the net force acting on the particle is proportional to: **[JEE MAIN 2013]**

(1) y (2) –y (3) $\frac{1}{y}$ (4) $-\frac{1}{y}$

17. A charge Q is uniformly distributed over a long rod AB of length L as shown in the figure. The electric potential at the point O lying at distance L from the end A is : **[JEE MAIN 2013]**



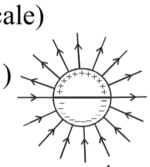
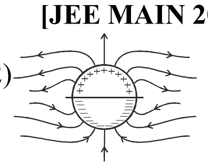
(1) $\frac{Q}{8\pi\epsilon_0 L}$ (2) $\frac{3Q}{4\pi\epsilon_0 L}$

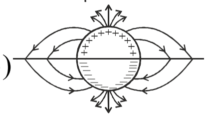
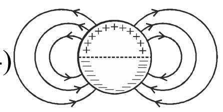
(3) $\frac{Q}{4\pi\epsilon_0 L\ln 2}$ (4) $\frac{Q\ln 2}{4\pi\epsilon_0 L}$

18. Assume that an electric field $\vec{E} = 30x^2\hat{i}$ exists in space. Then the potential difference $V_A - V_O$, where V_O is the potential at the origin and V_A the potential at x = 2 m is: **[JEE MAIN 2014]**

(1) 120 V (2) –120 V
(3) – 80 V (4) 80 V

19. A long cylindrical shell carries positive surface charge σ in the upper half and negative surface charge –σ 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]**

(1) 
(2) 

(3) 
(4) 

20. 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]**

(1) $R_1 \neq 1$ and $(R_2 - R_1) > (R_4 - R_3)$
(2) $R_1 = 0$ and $R_2 < (R_4 - R_3)$
(3) $2R < R_4$
(4) $R_1 = 0$ and $R_2 > (R_4 - R_3)$

21. 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]**

(1) $\frac{Q}{2\pi(b^2 - a^2)}$ (2) $\frac{2Q}{\pi(a^2 - b^2)}$

(3) $\frac{2Q}{\pi a^2}$ (4) $\frac{Q}{2\pi a^2}$

22. 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 $\vec{E}_1 = E\hat{i}$, 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]**

(1) 30° (2) 45° (3) 60° (4) 90°

23. Three concentric metal shells A, B and C of respective radii a, b and c (a < b < c) have surface charge densities +σ, –σ and +σ respectively. The potential of shell B is: **[JEE MAIN 2018]**

(1) $\frac{\sigma}{\varepsilon_0}\left[\frac{b^2 - c^2}{b} + a\right]$ (2) $\frac{\sigma}{\varepsilon_0}\left[\frac{b^2 - c^2}{c} + a\right]$

(3) $\frac{\sigma}{\varepsilon_0}\left[\frac{a^2 - b^2}{a} + c\right]$ (4) $\frac{\sigma}{\varepsilon_0}\left[\frac{a^2 - b^2}{b} + c\right]$

24. 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]**

(1) +Q/2 (2) –Q/2 (3) –Q/4 (4) +Q/4

25. 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]**

(1) $R/\sqrt{5}$ (2) R (3) $R/\sqrt{2}$ (4) $R\sqrt{2}$

26. Two point charges $q_1(\sqrt{10}\ \mu C)$ and q_2 (–25 μC) 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 $\frac{1}{4\pi\varepsilon_0} = 9 \times 10^9\ Nm^2C^{-2}$]

(1) $(-63\hat{i} + 27\hat{j}) \times 10^2$ (2) $(81\hat{i} - 81\hat{j}) \times 10^2$

(3) $(63\hat{i} - 27\hat{j}) \times 10^2$ (4) $(-81\hat{i} + 81\hat{j}) \times 10^2$

27. 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]**

(1) $\frac{a}{2}\log\left(1 - \frac{Q}{2\pi aA}\right)$ (2) $a\log\left(1 - \frac{Q}{2\pi aA}\right)$

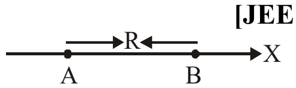
(3) $a\log\left(\frac{1}{1 - \frac{Q}{2\pi aA}}\right)$ (4) $\frac{a}{2}\log\left(\frac{1}{1 - \frac{Q}{2\pi aA}}\right)$

28. 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]**

(1) $\frac{Q}{4\pi\varepsilon_0(a + b + c)}$ (2) $\frac{Q(a + b + c)}{4\pi\varepsilon_0(a^2 + b^2 + c^2)}$

(3) $\frac{Q}{12\pi\varepsilon_0}\frac{ab + bc + ca}{abc}$ (4) $\frac{Q}{4\pi\varepsilon_0}\frac{(a^2 + b^2 + c^2)}{(a^3 + b^3 + c^3)}$

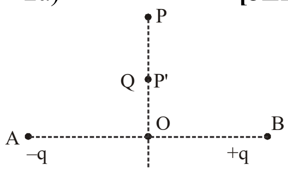
29. Two electric dipoles, A, B with respective dipole moments $\vec{d}_A = -4qa\hat{i}$ and $\vec{d}_B = -2qa\hat{i}$ placed on the x-axis with a separation R, as shown in the figure. The distance from A at which both of them produce the same potential is : **[JEE MAIN 2019]**



(1) $\frac{\sqrt{2}R}{\sqrt{2} + 1}$ (2) $\frac{R}{\sqrt{2} + 1}$

(3) $\frac{\sqrt{2}R}{\sqrt{2} - 1}$ (4) $\frac{R}{\sqrt{2} - 1}$

30. 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 >> 2a. The charge Q experiences and 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 >> 2a) **[JEE MAIN 2019]**



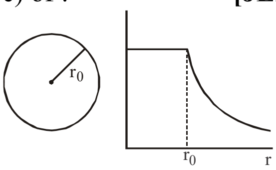
(1) F/3 (2) 3F (3) 9F (4) 27F

31. 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]**

(1) $\frac{Q^2}{2\sqrt{2}\pi\varepsilon_0}$ (2) $\frac{Q^2}{4\pi\varepsilon_0}\left(1+\frac{1}{\sqrt{5}}\right)$

(4) $\frac{Q^2}{4\pi\varepsilon_0}\left(1+\frac{1}{\sqrt{3}}\right)$ (3) $\frac{Q^2}{4\pi\varepsilon_0}$

32. The given graph shows variation (with distance r from centre) of : **[JEE MAIN 2019]**

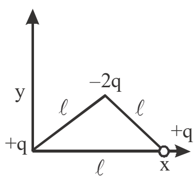


(1) Potential of a uniformly charged sphere.
(2) Potential of a uniformly charged spherical shell.
(3) Electric field of uniformly charged spherical shell.
(4) Electric field of uniformly charged sphere.

33. 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]**

(1) -9×10^{-20} J (2) -7×10^{-27} J
(3) -10×10^{-29} J (4) -20×10^{-18} J

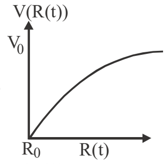
34. Determine the electric dipole moment of the system of three charges, placed on the vertices of an equilateral triangle, as shown in the figure: **[JEE MAIN 2019]**

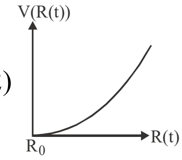


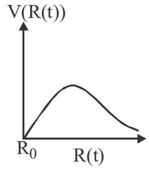
(1) $(q\ell)\frac{\hat{i}+\hat{j}}{\sqrt{2}}$ (2) $\sqrt{3}q\ell\,\frac{\hat{j}-\hat{i}}{\sqrt{2}}$

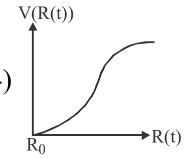
(3) $-\sqrt{3}q\ell\,\hat{j}$ (4) $2q\ell\,\hat{j}$

35. 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]**

(1) 

(2) 

(3) 

(4) 

36. The bob of a simple pendulum has mass 2g and a charge of 5.0 μC. 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 m/s^2) **[JEE MAIN 2019]**

(1) $\tan^{-1}$ (5.0) (2) $\tan^{-1}$ (2.0)
(3) $\tan^{-1}$ (0.5) (4) $\tan^{-1}$ (0.2)

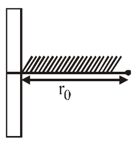
37. A solid conducting sphere, having a charge Q, is surrounded by an uncharged conducting hollow spherical shell. Let the potential difference between the surface of the solid sphere and that of the outer surface of the hollow shell be V. If the shell is now given a charge of – 4Q, the new potential difference between the same two surfaces is : **[JEE MAIN 2019]**

(1) V (2) 2V (3) –2V (4) 4V

38. 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]**

(1) $\sqrt{\frac{qE}{2md}}$ (2) $2\sqrt{\frac{qE}{md}}$ (3) $\sqrt{\frac{2qE}{md}}$ (4) $\sqrt{\frac{qE}{md}}$

39. 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]**



(1) $v \propto e^{+r/r_0}$ (2) $v \propto \ln\left(\frac{r}{r_0}\right)$

(3) $v \propto \left(\frac{r}{r_0}\right)$ (4) $v \propto \sqrt{\ln\left(\frac{r}{r_0}\right)}$

40. 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 SI unit and B = 10 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]**

(1) – 48 V (2) –520 V (3) 180 V (4) 320 V

41. 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 >> d, will behave as : **[JEE MAIN 2019]**

(1) $E \propto 1/D$ (2) $E \propto 1/D^3$
(3) $E \propto 1/D^2$ (4) $E \propto 1/D^4$

42. 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]**

(1) $\sqrt{\frac{2}{m}}\left(\frac{1}{15}\frac{q^2}{4\pi\varepsilon_0 a}\right)^{1/2}$ (2) $\sqrt{\frac{2}{m}}\left(\frac{2}{15}\frac{q^2}{4\pi\varepsilon_0 a}\right)^{1/2}$

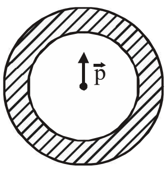
(3) $\sqrt{\frac{2}{m}}\left(\frac{4}{15}\frac{q^2}{4\pi\varepsilon_0 a}\right)^{1/2}$ (4) $\sqrt{\frac{2}{m}}\left(\frac{1}{5}\frac{q^2}{4\pi\varepsilon_0 a}\right)^{1/2}$

43. In free space, a particle A of charge 1 μC is held fixed at a point P. Another particle B of the same charge and mass 4 μg is kept at a distance of 1mm from P. If B is released, then its velocity at a distance of 9 mm from P is : **[JEE MAIN 2019]**

[Take $\frac{1}{4\pi\varepsilon_0} = 9 \times 10^9\ Nm^2\ C^{-2}$]

(1) 2.0×10^3 m/s (2) 3.0×10^4 m/s
(3) 1.5×10^2 m/s (4) 1.0 m/s

44. 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]**



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

45. 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) :

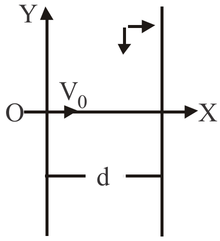
(1) $\frac{|\vec{p}|}{4\pi\varepsilon_0 d^2}, \frac{-\vec{p}}{4\pi\varepsilon_0 d^3}$ (2) $0, \frac{\vec{p}}{4\pi\varepsilon_0 d^3}$

(3) $\frac{|\vec{p}|}{4\pi\varepsilon_0 d^2}, \frac{\vec{p}}{4\pi\varepsilon_0 d^3}$ (4) $0, \frac{-\vec{p}}{4\pi\varepsilon_0 d^3}$

46. 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]**

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

47. 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]**



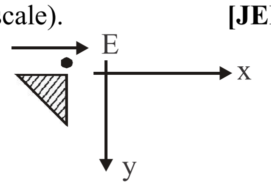
(1) $y = \frac{qEd}{mV_0^2}\left(\frac{d}{2}-x\right)$

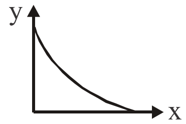
(2) $y = \frac{qEd}{mV_0^2}(x-d)$

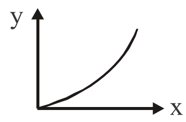
(3) $y = \frac{qEd}{mV_0^2}x$

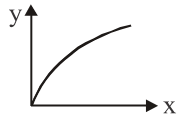
(4) $y = \frac{qEd^2}{mV_0^2}x$

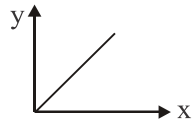
48. A small point mass carrying some positive charge on it, is released from the edge of a table. There is a uniform electric field in this region in the horizontal direction. Which of the following options then correctly describe the trajectory of the mass ? (Curves are drawn schematically and are not to scale). **[JEE MAIN 2020]**



(1) 

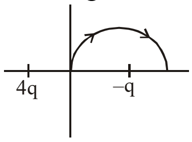
(2) 

(3) 

(4) 

49. A wire of density 9×10^{-3} 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 $Y = 9 \times 10^{10}$ Nm^{-2}),
(to the nearest integer),___.**[JEE MAIN 2020]**

50. 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]**



(1) Increase by $\frac{2q^2}{3\pi\varepsilon_0 d}$ (2) Increase by $\frac{3q^2}{4\pi\varepsilon_0 d}$

(3) Decrease by $\frac{4q^2}{3\pi\varepsilon_0 d}$ (4) decrease by $\frac{q^2}{4\pi\varepsilon_0 d}$

51. Concentric metallic hollow spheres of radii R and 4R hold charges Q_1 and Q_2respectively.Given that surface charge densities of the concentric spheres are equal, the potential difference V(R) – V(4R) is: **[JEE MAIN 2020]**

(1) $\frac{3Q_1}{16\pi\varepsilon_0 R}$ (2) $\frac{Q_2}{4\pi\varepsilon_0 R}$

(3) $\frac{3Q_1}{4\pi\varepsilon_0 R}$ (4) $\frac{3Q_2}{4\pi\varepsilon_0 R}$

52. 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]**

(1) $\sqrt{2/a}$ (2) $\sqrt{1/a}$ (3) a (4) $\sqrt{3/a}$

53. 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]**

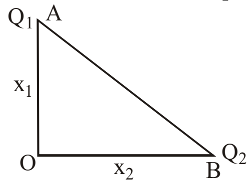
(1) $V = \frac{10q}{4\pi\varepsilon_0 R}, E = \frac{10q}{4\pi\varepsilon_0 R^2}$

(2) V = 0, $E = \frac{10q}{4\pi\varepsilon_0 R^2}$

(3) V = 0, E = 0

(4) $V = \frac{10q}{4\pi\varepsilon_0 R}, E = 0$

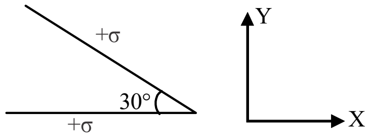
54. Charges Q_1 and Q_2 arc at points A and B of a right angle triangle OAB (see figure). The resultant electric field at point O is perpendicular to the hypotenuse, then Q_1/Q_2 is proportional to : **[JEE MAIN 2020]**



(1) $\frac{x_2^2}{x_1^2}$ (2) $\frac{x_1^3}{x_2^3}$

(3) $\frac{x_1}{x_2}$ (4) $\frac{x_2}{x_1}$

55. There are two infinite plane sheets each having uniform surface charge density $+\sigma$ C/m^2. 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]**



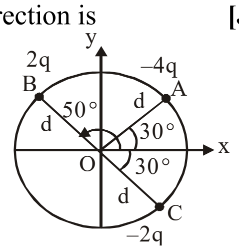
(1) $\frac{\sigma}{2\varepsilon_0}\left[\left(1-\frac{\sqrt{3}}{2}\right)\hat{y}-\frac{1}{2}\hat{x}\right]$

(2) $\frac{\sigma}{2\varepsilon_0}\left[\left(1+\frac{\sqrt{3}}{2}\right)\hat{y}-\frac{1}{2}\hat{x}\right]$

(3) $\frac{\sigma}{2\varepsilon_0}\left[\left(1-\frac{\sqrt{3}}{2}\right)\hat{y}+\frac{1}{2}\hat{x}\right]$

(4) $\frac{\sigma}{2\varepsilon_0}\left[\left(1+\frac{\sqrt{3}}{2}\right)\hat{y}+\frac{1}{2}\hat{x}\right]$

56. Three charged particle 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]**



(1) $\frac{2\sqrt{3}q}{\pi\varepsilon_0 d^2}$ (2) $\frac{\sqrt{3}q}{4\pi\varepsilon_0 d^2}$

(3) $\frac{3\sqrt{3}q}{4\pi\varepsilon_0 d^2}$ (4) $\frac{\sqrt{3}q}{\pi\varepsilon_0 d^2}$

57. 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 Nm^2/C) ______. **[JEE MAIN 2020]**

58. 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 = $4.8 \times 10^7\ Nm^{-2}$ and area of cross-section of the wire = $10^{-2}\ cm^2$) is: **[JEE MAIN 2020]**

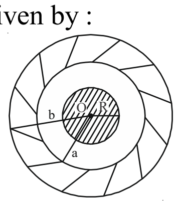
59. The two thin coaxial rings, each of radius 'a' and having charges +Q and –Q respectively are separated by a distance of 's'. The potential difference between the centres of the two rings is: **[JEE MAIN 2021]**

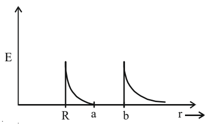
(1) $\frac{Q}{2\pi\varepsilon_0}\left[\frac{1}{a} - \frac{1}{\sqrt{s^2 + a^2}}\right]$ (2) $\frac{Q}{2\pi\varepsilon_0}\left[\frac{1}{a} + \frac{1}{\sqrt{s^2 + a^2}}\right]$

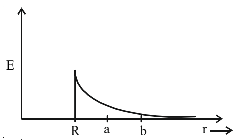
(3) $\frac{Q}{4\pi\varepsilon_0}\left[\frac{1}{a} + \frac{1}{\sqrt{s^2 + a^2}}\right]$ (4) $\frac{Q}{4\pi\varepsilon_0}\left[\frac{1}{a} - \frac{1}{\sqrt{s^2 + a^2}}\right]$

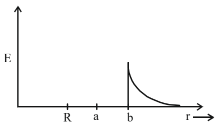
60. If the maximum value of accelerating potential provided by a radio frequency oscillator is 12 kV. The number of revolution made by a proton in a cyclotron to achieve one sixth of the speed of light is _____.
[$m_p = 1.67 \times 10^{-27}$ kg, $e = 1.6 \times 10^{-19}$ C, Speed of light = 3×10^8 m/s] **[JEE MAIN 2021]**

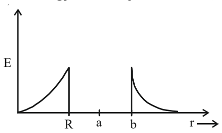
61. A solid metal sphere of radius R having charge q is enclosed inside the concentric spherical shell of inner radius a and outer radius b as shown in figure. The approximate variation electric field $\vec{E}$ as a function of distance r from centre O is given by : **[JEE MAIN 2021]**



(1)


(2)


(3)


(4)


62. 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]**

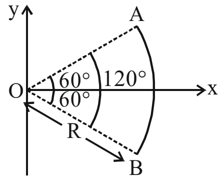
(1) $E = \frac{\sigma}{2\varepsilon_0}\left(1 - \frac{Z}{(Z^2 + R^2)^{1/2}}\right)$

(2) $E = \frac{2\varepsilon_0}{\sigma}\left(\frac{1}{(Z^2 + R^2)^{1/2}} + Z\right)$

(3) $E = \frac{\sigma}{2\varepsilon_0}\left(\frac{1}{(Z^2 + R^2)} + \frac{1}{Z^2}\right)$

(4) $E = \frac{\sigma}{2\varepsilon_0}\left(1 + \frac{Z}{(Z^2 + R^2)^{1/2}}\right)$

63 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]

(1) $\frac{3\sqrt{3}Q}{8\pi^2\varepsilon_0 R^2}(\hat{i})$ (2) $\frac{3\sqrt{3}Q}{8\pi^2\varepsilon_0 R^2}(-\hat{i})$

(3) $\frac{3\sqrt{3}Q}{8\pi\varepsilon_0 R^2}(\hat{i})$ (4) $\frac{3\sqrt{3}Q}{16\pi^2\varepsilon_0 R^2}(\hat{i})$

64. 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.

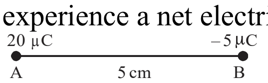
(c) In a uniform electric field net flux through a closed Gaussian surface containing no net charge, is zero.

(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]**

(1) (d) Only (2) (c) and (d) Only
(3) (a) and (c) Only (4) (b) and (d) Only

65. 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]

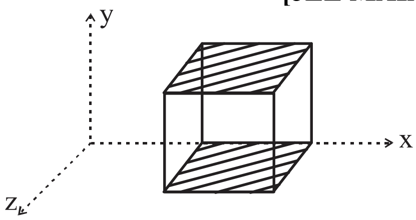
(1) At 5 cm from –5 μC on the right side

(2) At 1.25 cm from a –5 μC between two charges

(3) At 5 cm from 20 μC on the left side of system

(4) At midpoint between two charges

66. 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]



(1) 8.3×10^{-11} C (2) 3.8×10^{-11} C
(3) 8.3×10^{-12} C (4) 3.8×10^{-12} C

67. A charge of 4 μC 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]**
(1) 1 μC and 3 μC (2) 2 μC and 2 μC
(3) 0 and 4 μC (4) 1.5μC and 2.5μC

68. 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]**

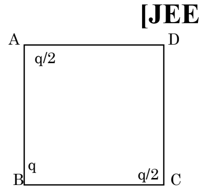
(1) $\sqrt{\dfrac{4\pi^3\varepsilon_0 ma^3}{q_0Q}}$ (2) $\sqrt{\dfrac{q_0Q}{4\pi^3\varepsilon_0 ma^3}}$

(3) $\sqrt{\dfrac{2\pi^2\varepsilon_0 ma^3}{q_0Q}}$ (4) $\sqrt{\dfrac{8\pi^3\varepsilon_0 ma^3}{q_0Q}}$

69. Two point charges A and B of magnitude $+ 8 \times 10^{-6}$ C and -8×10^{-6} C respectively are placed at a distance d apart. The electric field at the middle point O between the charges is 6.4×10^4 NC^{-1}. The distance 'd' between the point charges A and B is : **[JEE MAIN 2022]**
(1) 2.0 m (2) 3.0 m (3) 1.0 m (4) 4.0 m

70. 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]**
(1) Both statement-I and statement-II are true
(2) Both statement-I and statement-II are false
(3) Statement-I is true but statement-II is false
(4) Statement-I is false but statement-II is true

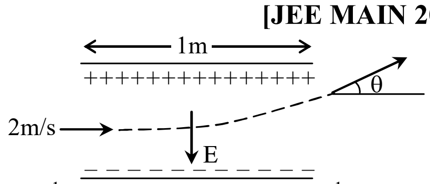
71. The three charges $\frac{q}{2}$, q and $\frac{q}{2}$ are placed at the corners *A*, *B* and *C* of a square of side '*a*' as shown in figure. The magnitude of electric field (*E*) at the corner *D* of the square is
[JEE MAIN 2022]



(1) $\dfrac{q}{4\pi\epsilon_0 a^2}\left(\dfrac{1}{\sqrt{2}}+\dfrac{1}{2}\right)$ (2) $\dfrac{q}{4\pi\epsilon_0 a^2}\left(1+\dfrac{1}{\sqrt{2}}\right)$

(3) $\dfrac{q}{4\pi\epsilon_0 a^2}\left(1-\dfrac{1}{\sqrt{2}}\right)$ (4) $\dfrac{q}{4\pi\epsilon_0 a^2}\left(\dfrac{1}{\sqrt{2}}-\dfrac{1}{2}\right)$

72. A uniform electric field E = (8m/e) 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]



(1) $\tan^{-1}(4)$ (2) $\tan^{-1}(2)$
(3) $\tan^{-1}\left(\dfrac{1}{3}\right)$ (4) $\tan^{-1}(3)$

73. Two electric dipoles of dipole moments 1.2×10^{-30} C-m and 2.4×10^{-30} C-m are placed in two different uniform electric fields of strength 5×10^4 NC^{-1} and 15×10^4 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]**

74. 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]**
(1) x = d (2) $x = \dfrac{d}{2}$ (3) $x = \dfrac{d}{\sqrt{2}}$ (4) $x = \dfrac{d}{2\sqrt{2}}$

75. The electric field at a point associated with a light wave is given by
$E = 200[\sin(6 \times 10^{15})t + \sin(9 \times 10^{15})t]\ Vm^{-1}$
Given : $h = 4.14 \times 10^{-15}$ 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]
(1) 1.90 eV (2) 3.27 eV
(3) 3.60 eV (4) 3.42 eV

76. 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]
(1) 3 Vm^{-1}, directed along positive x-axis
(2) 3 Vm^{-1}, directed along negative x-axis
(3) 6 Vm^{-1}, directed along positive x-axis
(4) 6 Vm^{-1}, directed along negative x-axis

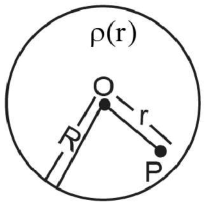
77. A positive charge particle of 100 mg is thrown in opposite direction to a uniform electric field of strength $1 \times 10^5\ NC^{-1}$. If the charge on the particle is 40 μC and the initial velocity is 200 ms^{-1}, how much distance it will travel before coming to the rest momentarily?
[JEE MAIN 2022]
(1) 1 m (2) 5 m
(3) 10 m (4) 0.5 m

78. 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]
(1) 3F/2 (2) 3F/4 (3) F (4) 2F

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

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

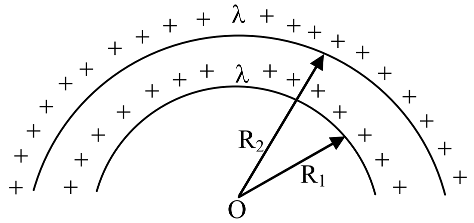
Where, r(r < R) is the distance from the centre O (as shown in figure). The electric field at point P will be : **[JEE MAIN 2022]**



(1) $\frac{\rho_0 r}{4\varepsilon_0}\left(\frac{3}{4} - \frac{r}{R}\right)$ (2) $\frac{\rho_0 r}{3\varepsilon_0}\left(\frac{3}{4} - \frac{r}{R}\right)$
(3) $\frac{\rho_0 r}{4\varepsilon_0}\left(1 - \frac{r}{R}\right)$ (4) $\frac{\rho_0 r}{5\varepsilon_0}\left(1 - \frac{r}{R}\right)$

80. Given below are two statements.
Statement I : Electric potential is constant within and at the surface of each conductor.
Statement II : Electric field just outside a charged conductor is perpendicular to the surface of the conductor at every point.
In the light of the above statements, choose the most appropriate answer from the options give below. **[JEE MAIN 2022]**
(1) Both statement I and statement II are correct
(2) Both statement I and statement II are incorrect
(3) Statement I is correct but statement II is incorrect
(4) Statement I is incorrect but and statement II is correct

81. 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]



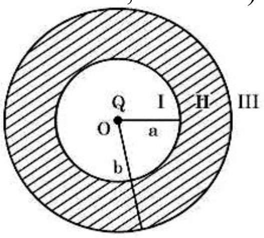
(1) $\frac{\lambda}{4\varepsilon_0}$ (2) $\frac{\lambda}{2\varepsilon_0}$ (3) $\frac{2\lambda}{\varepsilon_0}$ (4) $\frac{\lambda}{\varepsilon_0}$

82. 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:
(1) Both A and R are true but R is not the correct explanation of A
(2) A is false but R is true
(3) Both A and R are true but R is the correct explanation of A
(4) A is true but R is false

83. A cubical volume is bounded by the surfaces x = 0, 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 $E_0 = 4 \times 10^4\ NC^{-1}m^{-1}$. If a = 2 cm, the charge contained in the cubical volume is $Q \times 10^{-14}$C. The value of Q is _________. (Take $\epsilon_0 = 9 \times 10^{-12}\ C^2/Nm^2$)
[JEE MAIN 2023]

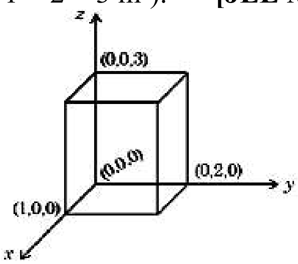
84. As shown in the figure, a point charge Q is placed at the centre of conducting spherical shell of inner radius a and outer radius b. The electric field due to charge Q in three different regions I, II and III is given: **[JEE MAIN 2023]**

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

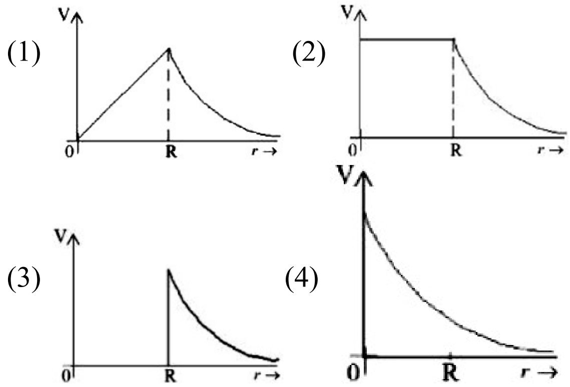


(1) $E_I \neq 0,\ E_{II} = 0,\ E_{III} \neq 0$
(2) $E_I = 0,\ E_{II} = 0,\ E_{III} = 0$
(3) $E_I \neq 0,\ E_{II} = 0,\ E_{III} = 0$
(4) $E_I = 0,\ E_{II} = 0,\ E_{III} \neq 0$

85. As shown in figure, a cuboid lies in a region with electric field $E = 2x^2\hat{i} - 4y\hat{j} + 6\hat{k}\,\frac{N}{C}$. The magnitude of charge within the cuboid is $n\in_0$C. The value of n is ______ (if dimension of cuboid is $1 \times 2 \times 3\ m^3$). **[JEE MAIN 2023]**

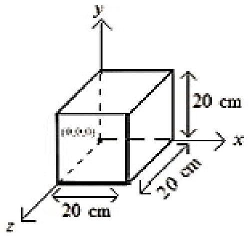


86. Which of the following correctly represents the variation of electric potential(V) of a charged spherical conductor of radius (R) with radial distance (r) from the center? **[JEE MAIN 2023]**



87. 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 = 3×10^8 ms^{-1} and for the given medium $\mu_1 = 1$)

88. 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]**



89. 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]**

(1) $2d\sqrt{k}$ (2) $d\sqrt{k}$ (3) $1.5d\sqrt{k}$ (4) $k\sqrt{d}$

90. A stream of a positively charged particles having $\frac{q}{m} = 2\times10^{11}\frac{C}{kg}$ and velocity $\vec{v}_0 = 3\times10^7\hat{i}$ m/s is deflected by an electric field $1.8\hat{j}$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]**

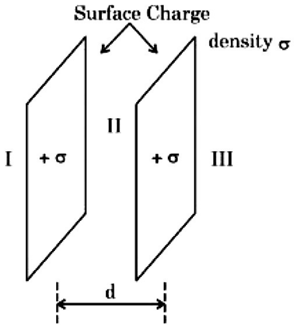
91. Two isolated metallic solid spheres of radii R and 2R are charged such that both have same charge density σ. The spheres are then connected by a thin conducting wire. If the new charge density of the bigger sphere is σ′. The ratio $\frac{\sigma'}{\sigma}$ is **[JEE MAIN2023]**

(1) $\frac{5}{6}$ (2) $\frac{4}{3}$ (3) $\frac{5}{3}$ (4) $\frac{9}{4}$

92. 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]**

(1) Nm^3C ; Nm^2C (2) Nm^2C ; Nm^3C
(3) Nm^2C^{-1} ; Nm^2C^{-1} (4) Nm^3C^{-1} ; Nm^2C^{-1}

93. 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]**



(1) $\vec{E}_I = 0,\ \vec{E}_{II} = \frac{\sigma}{\epsilon_0}\hat{n},\ E_{III} = 0$

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

(3) $\vec{E}_I = -\frac{2\sigma}{2\epsilon_0}\hat{n},\ \vec{E}_{II} = 0,\ \vec{E}_{III} = \frac{2\sigma}{\epsilon_0}\hat{n}$

(4) $\vec{E}_I = -\frac{\sigma}{2\epsilon_0}\hat{n},\ \vec{E}_{II} = 0,\ \vec{E}_{III} = \frac{\sigma}{\epsilon_0}\hat{n}$

94. 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]**

95. Considering a group of positive charges, which of the following statements is correct? **[JEE MAIN 2023]**

(1) Net potential of the system cannot be zero at a point but net electric field can be zero at that point.
(2) Both the net potential and the net field can be zero at a point.
(3) Net potential of the system at a point can be zero but net electric field can't be zero at that point.
(4) Both the net potential and the net electric field cannot be zero at a point.

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

(1) 180 (2) 60 (3) 150 (4) 90

97. Given below are two statements : one is labelled as **Assertion (1)** and the other is labelled as **Reason (R).**

Assertion (1) : Work done by electric field on moving a positive charge on an equipotential surface is always zero.

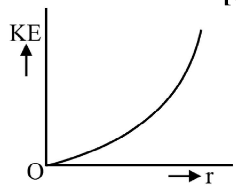
Reason (R) : Electric lines of forces are always perpendicular to equipotential surfaces.

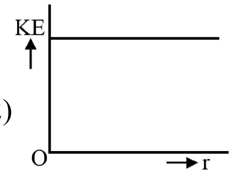
In the light of the above statements, choose the **most appropriate** answer from the options given below. **[JEE MAIN 2024]**

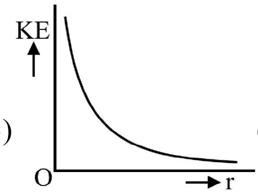
(1) (1) is correct but (R) not correct
(2) (1) is not correct but (R) is correct
(3) Both (1) and (R) are true and (R) is the correct explanation of (1)
(4) Both (1) and (R) are true and (R) is not the correct explanation of (1)

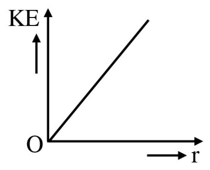
98. Two charges of –4μC and + 4μC are placed at the point A(1, 0, 4) m and B(2, –1, 5) m located in an electric field $\vec{E} = 0.20\ \hat{i}$ V/cm. The magnitude of the torque acting on the dipole is $8\sqrt{\alpha} \times 10^{-5}$ Nm, where α = ___. **[JEE MAIN 2024]**

99. An infinitely long positively charged straight thread has a linear charge density λ 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]**

(1)


(2)


(3)


(4)


100. An infinite plane sheet of charge having uniform surface charge density $+\sigma_s$ C/m^2 is placed on x-y plane. Another infinitely long line charge having uniform linear charge density $+\lambda_e$ C/m is placed at z = 4m 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]**

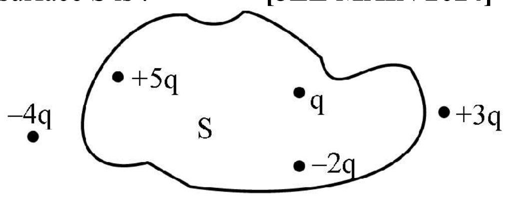
101. The magnetic field in a plane electromagnetic wave is

$B_y = (3.5 \times 10^{-7}) \sin (1.5 \times 10^3 x + 0.5 \times 10^{11} t)$T.

The corresponding electric field will be **[JEE MAIN 2024]**

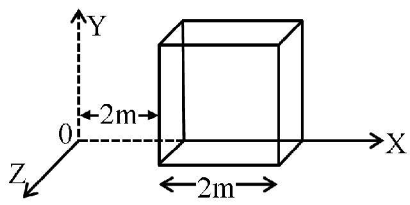
(1) $E_y = 1.17 \sin (1.5 \times 10^3 x + 0.5 \times 10^{11} t) Vm^{-1}$
(2) $E_z = 105 \sin (1.5 \times 10^3 x + 0.5 \times 10^{11} t) Vm^{-1}$
(3) $E_z = 1.17 \sin (1.5 \times 10^3 x + 0.5 \times 10^{11} t) Vm^{-1}$
(4) $E_y = 10.5 \sin (1.5 \times 10^3 x + 0.5 \times 10^{11} t) Vm^{-1}$

102. 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]**



(1) $\frac{5q}{\epsilon_0}$ (2) $\frac{4q}{\epsilon_0}$ (3) $\frac{3q}{\epsilon_0}$ (4) $\frac{q}{\epsilon_0}$

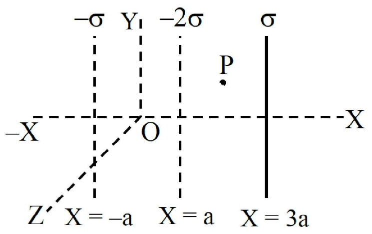
103 An electric field $\vec{E} = (2x\hat{i}) NC^{-1}$ exists in space. A cube of side 2m is placed in the space as per figure given below. The electric flux through the cube is ……………… Nm^2/C. **[JEE MAIN 2024]**



104. 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]**

(1) $\sigma/\varepsilon_0 R$ (2) $\sigma/2\varepsilon_0$ (3) σ/ε_0 (4) $\sigma/4\varepsilon_0$

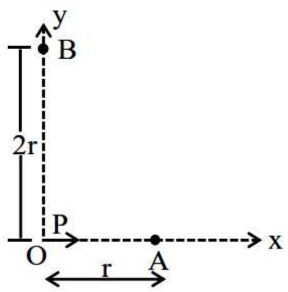
105. Three infinitely long charged thin sheets are placed as shown in figure. The magnitude of electric field at the point P is $\frac{x\sigma}{\varepsilon_0}$. The value of x is _____ (all quantities are measured in SI units). **[JEE MAIN 2024]**



106. An electron is made to enters 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 = 9.1×10^{-31} kg and charge of electron = 1.6×10^{-19} C) **[JEE Main 2025]**

(1) 1×10^6 m/s (2) 0
(3) 16×10^6 m/s (4) 16×10^4 m/s

107. 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]**



(1) $\frac{V_0}{2}$ and $\frac{E_0}{16}$ (2) zero and $\frac{E_0}{8}$
(3) zero and $\frac{E_0}{16}$ (4) V_0 and $\frac{E_0}{4}$

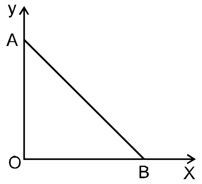
EXERCISE # 4

Questions **Previous Year (NEET)**

1. An electric dipole has the magnitude of its charge as q and its dipole moment is p. It is placed in a uniform electric field E. If its dipole moment is along the direction of the field, the force on it and its potential energy are respectively: **[AIPMT - 2004]**

(1) 2qE and minimum (2) qe and pE
(3) zero and minimum (4) qE and maximum

2. As per this diagram a point charge +q is placed at the origin O. Work done in taking another point charge –Q from the point A [co-ordinates (o,a)] to another point B [co-ordinates(a,o)] along the straight path AB is : **[AIPMT - 2005]**



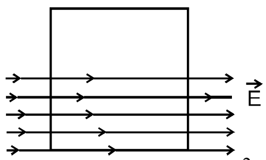
(1) Zero (2) $\left(\frac{-qQ}{4\pi\varepsilon_0}\frac{1}{a^2}\right)\sqrt{2}\ a$

(3) $\left(\frac{qQ}{4\pi\varepsilon_0}\frac{1}{a^2}\right)\cdot\frac{a}{\sqrt{2}}$ (4) $\left(\frac{qQ}{4\pi\varepsilon_0}\frac{1}{a^2}\right)\sqrt{2}\,a$

3. An electric dipole of moment $\vec{p}$ is lying along a uniform electric field $\vec{E}$.The work done in rotating the dipole by 90° is : **[AIPMT-2006]**

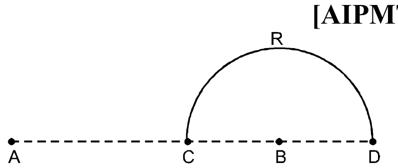
(1) $\sqrt{2}$ pE (2) $\frac{pE}{2}$ (3) 2pE (4) pE

4. A square surface of side L m is in the plane of the paper. A uniform electric field(V/m), also in the plane of the paper, is limited only to the lower half of the square surface, (see figure). The electric flux in SI units associated with the surface is : **[AIPMT-2006]**



(1) $EL^2/(2\varepsilon_0)$ (2) $EL^2/2$
(3) zero (4) EL^2

5. Charges +q and –q are placed at points A and B respectively which are a distance2 L apart, C is the midpoint between A and B. The work done in moving a charge +Q along the semicircle CRD is: **[AIPMT - 2007]**



(1) $\frac{qQ}{4\pi\varepsilon_0 L}$ (2) $\frac{qQ}{2\pi\varepsilon_0 L}$ (3) $\frac{qQ}{6\pi\varepsilon_0 L}$ (4) $-\frac{qQ}{6\pi\varepsilon_0 L}$

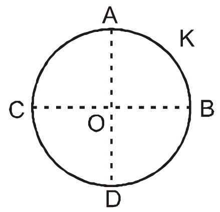
6. Three point charges +q, –2q and + q are placed at points (x = 0, y = a, z = 0), (x = 0, y = 0, z = 0) and (x = a, y = 0, z = 0), respectively. The magnitude and direction of the electric dipole moment vector of this charge assembly are : **[AIPMT_2007]**

(1) $\sqrt{2}$ qa along + y direction
(2) $\sqrt{2}$ qa along the line joining points (x = 0, y = 0, z = 0) and (x = a, y = a, z = 0)
(3) qa along the line joining points (x = 0, y = 0, z = 0) and (x = a, y = a, z = 0)
(4) $\sqrt{2}$ qa along + x direction

7. The electric potential at a point in free space due to a charge Q coulomb is $Q \times 10^{11}$ V. The electric field at that point is **[AIPMT - 2008]**

(1) $4\pi\,\varepsilon_0\, Q \times 10^{22}$ V/m
(2) $12\pi\,\varepsilon_0\, Q \times 10^{20}$ V/m
(3) $4\pi\,\varepsilon_0\, Q \times 10^{20}$ V/m
(4) $12\pi\,\varepsilon_0\, Q \times 10^{22}$ V/m

8. A thin conducting ring of radius R is given a charge +Q. The electric field at the centre O of the ring due to the charge on the part AKB of the ring is E. The electric field at the centre due to the charge on the part ACDB of the ring is **[AIPMT - 2008]**



(1) 3E along KO (2) E along OK
(3) E along KO (4) 3 E along OK

9. The electric potential at a point (x, y, z) is given by $V = -x^2y - xz^3 + 4$ **[AIPMT 2009]**

The electric field $\vec{E}$ at that point is

(1) $\vec{E} = \hat{i}\,(2xy + z^3) + \hat{j}\,x^2 + \hat{k}\ 3xz^2$
(2) $\vec{E} = \hat{i}\ 2xy + \hat{j}\,(x^2 + y^2) + \hat{k}\,(3xz - y^2)$
(3) $\vec{E} = \hat{i}\ z^3 + \hat{j}\ xyz + \hat{k}\,z^2$
(4) $\vec{E} = \hat{i}\,(2xy - z^3) + \hat{j}\,xy^2 + \hat{k}\ 3z^2x$

10. The electric field at a distance $\frac{3R}{2}$ from the centre of a charged conducting spherical shell of radius R is E. The electric field at a distance $\frac{R}{2}$ from the centre of the sphere is **[AIPMT - 2010]**

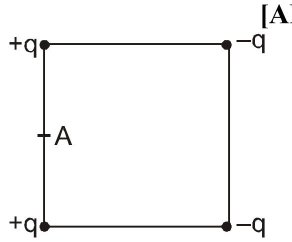
(1) Zero (2) E (3) $\frac{E}{2}$ (4) $\frac{E}{3}$

11. A charge Q is enclosed by a Gaussian spherical surface of radius R. If the radius is doubled, then the outward electric flux will : **[AIPMT- 2011,]**

(1) increase four times (2) be reduced to half

(3) remain the same (4) be doubled

12. Four electric charges +q, +q, –q and –q are placed at the corners of a square of side 2I (see figure). The electric potential at point A, midway between the two charges +q and +q, is : **[AIPMT- 2011]**



(1) $\frac{1}{4\pi \in_0}\frac{2q}{L}(1+\sqrt{5})$ (2) $\frac{1}{4\pi \in_0}\frac{2q}{L}\left(1+\frac{1}{\sqrt{5}}\right)$

(3) $\frac{1}{4\pi \in_0}\frac{2q}{L}\left(1-\frac{1}{\sqrt{5}}\right)$ (4) Zero

13. The electric potential V at any point (x, y, z), all in meters in space is given by $V = 4x^2$ volt. The electric field at the point (1, 0, 2) in volt/meter is: **[AIPMT-2011]**

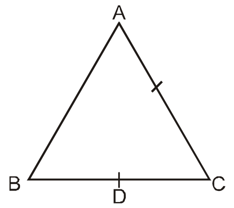
(1) 8 along positive X-axis

(2) 16 along negative X-axis

(3) 16 along positive X-axis

(4) 8 along negative X-axis

14. Three charges, each +q, are placed at the corners of an isosceles triangle ABC of sides BC and AC, 2a. D and E are the mid points of BC and CA. The work done in taking a charge Q from D to E is: **[AIPMT-2011]**



(1) $\frac{eqQ}{8\pi \in_0 a}$ (2) $\frac{qQ}{4\pi \in_0 a}$

(3) zero (4) $\frac{3qQ}{4\pi \in_0 a}$

15. A short electric dipole has a dipole moment of 16×10^{-9} C m. The electric potential due to the dipole at a point at a distance of 0.6 m from the centre of the dipole, situated on a line making an angle of 60° with the dipole axis is : **[NEET 2020]**

$\left(\frac{1}{4\pi\varepsilon_0} = 9\times10^9 \text{Nm}^2/\text{C}^2\right)$

(1) zero (2) 50 V (3) 200 V (4) 400 V

16. In a certain region of space with volume 0.2 m^3 the electric potential is found to be 5V throughout. The magnitude of electric field in this region is : **[NEET 2020]**

(1) 5 N/C (2) Zero (3) 0.5 N/C (4) 1 N/C

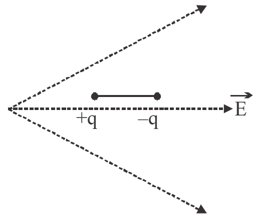
17. A spherical conductor of radius 10 cm has a charge of 3.2×10^{-7} C distributed uniformly. What is the magnitude of electric field at a point 15 cm from the centre of the sphere ?

$\left(\frac{1}{4\pi\varepsilon_0} = 9\times10^9 \text{Nm}^2/\text{C}^2\right)$ **[NEET 2020]**

(1) 1.28×10^7 N/C (2) 1.28×10^4 N/C

(3) 1.28×10^5 N/C (4) 1.28×10^6 N/C

18. A dipole is placed in an electric field as shown. In which direction will it move ? **[NEET 2021]**



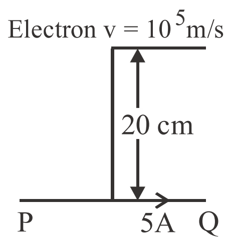
(1) towards the left as its potential energy will increase.

(2) towards the right as its potential energy will decrease.

(3) towards the left as its potential energy will decrease.

(4) towards the right as its potential energy will increase.

19. An infinitely long straight conductor carries a current of 5A as shown. An electron is moving with a speed of 10^5m/s parallel to the conductor. The perpendicular distance between the electron and the conductor is 20 cm at an instant. Calculate the magnitude of the force experienced by the electron at that instant. **[NEET 2021]**



(1) 4×10^{-20} N (2) $8\pi \times 10^{-20}$ N

(3) $4\pi \times 10^{-20}$ N (4) 8×10^{-20} N

20. Polar molecules are the molecules : **[NEET-2021]**

(1) having zero dipole moment.

(2) acquire a dipole moment only in the presence of electric field due to displacement of charges.

(3) acquire a dipole moment only when magnetic field is absent.

(4) having a permanent electric dipole moment.

21. Two charged spherical conductors of radius R_1 and R_2 are connected by a wire. Then the ratio of surface charge densities of the spheres (σ_1 / σ_2) is: **[NEET-2021]**

(1) R_1 / R_2 (2) R_2 / R_1

(3) $\sqrt{R_1 / R_2}$ (4) R_1^2 / R_2^2

22. Twenty seven drops of same size are charged at 220 V each. They combine to form a bigger drop. Calculate the potential of the bigger drop. **[NEET-2021]**

(1) 660 V (2) 1320 V (3) 1520 V (4) 1980 V

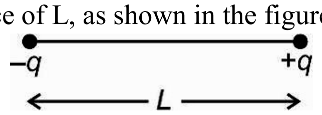
23. The angle between the electric lines of force and the equipotential surface is **[NEET-2022]**

(1) 45° (2) 90° (3) 180° (4) 0°

24. Two hollow conducting spheres of radii R_1 and R_2 ($R_1 >> R_2$) have equal charges. The potential would be **[NEET-2022]**

(1) More on smaller sphere
(2) Equal on both the spheres
(3) Dependent on the material property of the sphere
(4) More on bigger sphere

25. Two point charges –q and +q are placed at a distance of L, as shown in the figure.



The magnitude of electric field intensity at a distance R(R >>L) varies as: **[NEET-2022]**

(1) $\frac{1}{R^3}$ (2) $\frac{1}{R^4}$ (3) $\frac{1}{R^6}$ (4) $\frac{1}{R^2}$

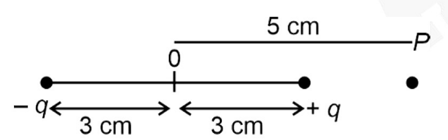
26. An electric dipole is placed at an angle of 30° with an electric field of intensity 2×10^5 NC^{-1}. It experiences a torque equal to 4 Nm. Calculate the magnitude of charge on the dipole, if the dipole length is 2 cm. **[NEET-2023]**

(1) 2 mC (2) 8 mC (3) 6 mC (4) 4 mC

27. If $\oint_S \vec{E}.\vec{dS} = 0$ over a surface, then : **[NEET-2023]**

(1) The electric field inside the surface is necessarily uniform.
(2) The number of flux lines entering the surface must be equal to the number of flux lines leaving it.
(3) The magnitude of electric field on the surface is constant.
(4) All the charges must necessarily be inside the surface.

28. An electric dipole is placed as shown in the figure.



The electric potential (in 10^2 V) at point P due to the dipole is ($\in_0$ = permittivity of free space and $\frac{1}{4\pi \in_0} = K$) **[NEET-2023]**

(1) $\left(\frac{8}{3}\right)qK$ (2) $\left(\frac{3}{8}\right)qK$

(3) $\left(\frac{5}{8}\right)qK$ (4) $\left(\frac{8}{5}\right)qK$

29. Given below are two statements : one is labelled as Assertion A and the other is labelled as **Reason R**.

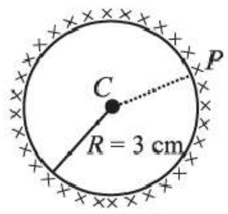
Assertion A : The potential (V) at any axial point, at 2 m distance (r) from the centre of the dipole of dipole moment vector $\vec{P}$ of magnitude, 4×10^{-6} C m, is $\pm 9 \times 10^3$ V. (Take $\frac{1}{4\pi \in_0} = 9 \times 10^3$ SI units)

Reason R : $V = \pm \frac{2P}{4\pi \in_0 r^2}$, where r is the distance of any axial point, situated at 2 m from the centre of the dipole.

In the light of the above statements, choose the correct answer from the options given below : **[NEET-2024]**

(1) A is true but R is false
(2) A is false but R is true
(3) Both A and R are true and R is the correct explanation of A
(4) Both A and R are true and R is NOT the correct explanation of A

30. A thin spherical shell is charged by some source. The potential difference between the two points C and P (in V) shown in the figure is (Take $\frac{1}{4\pi \in_0} = 9 \times 10^9$ SI units) **[NEET-2024]**



$q = 1\mu C$

(1) 0.5×10^5 (2) zero

(3) 3×10^5 (4) 1×10^5

31. An electric dipole with dipole moment 5×10^{-6} Cm is aligned with the direction of a uniform electric field of magnitude 4×10^{5} N/C. The dipole is then rotated through an angle of 60º with respect to the electric field. The change in the potential energy of the dipole is :

[NEET-2025]

(1) 1.2 J (2) 1.5 J (3) 0.8 J (4) 1.0 J

32. Two identical charged conducting spheres A and B have their centres separated by a certain distance. Charge on each sphere is q and the force of repulsion between them is F. A third identical uncharged conducting sphere is brought in contact with sphere A first and then with B and finally removed from both. New force of repulsion between spheres A and B (Radii of A and B are negligible compared to the distance of separation so that for calculating force between them they can be considered as point charges) is best given as :

[NEET-2025]

(1) $\frac{F}{2}$ (2) $\frac{3F}{8}$ (3) $\frac{3F}{5}$ (4) $\frac{2F}{3}$

ANSWER KEY

EXERCISE-1

Que.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Ans.	3	1	1	1	1	3	2	3	4	1	3	4	2	3	2	3	3	1	4	3
Que.	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
Ans.	4	4	3	2	2	1	2	3	4	1	1	2	3	1	1	3	3	2	2	3
Que.	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
Ans.	2	4	2	4	4	4	3	3	4	3	2	1	2	2	3	3	4	2	4	1
Que.	61	62	63																	
Ans.	3	1	2																	

EXERCISE-2

Que	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Ans	4	3	3	1	3	1	4	3	4	2	3	2	3	1	3	1	1	2	2	1
Que	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
Ans	3	3	1	3	3	2	1	2	1	3	1	1	4	3	1	2	3	4	2	3
Que	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
Ans	3	3	1	4	1	2	1	4	2	1	1	3	4	2	1	1	2	3	4	2
Que	61	62	63	64																
Ans	3	3	1	4																

EXERCISE-3

Que.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Ans.	2	4	4	4	3	4	1	2	3	2	3	4	4	3	3	1	4	3	4	2,3
Que.	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
Ans.	4	3	4	3	3	3	4	2	3	4	2	2	2	3	1	3	1	3	4	3
Que.	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
Ans.	4	2	1	1	4	3	1	4	35	3	1	4	3	3	1	4	48	4	1	543
Que.	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
Ans.	1	1	1	1	1	1	2	1	2	1	1	2	6	4	4	4	4	2	3	1
Que.	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
Ans.	2	2	288	1	12	2	5	640	2	2	1	3	2	2	1	1	3	2	2	16
Que.	101	102	103	104	105	106	107													
Ans.	NA	2	16	3	2	3	3													

EXERCISE-4

Que.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Ans.	3	1	4	3	4	2	1	2	1	1	3	3	4	3	3	2	3	2	4	4
Que.	21	22	23	24	25	26	27	28	29	30	31	32								
Ans.	2	4	2	1	1	1	2	2	1	2	4	2								