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- Half Yearly Exam - December 2024-25 Question Paper is given with answers.

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PREFACE

" The woods are lovely, dark and deep. "
But I have promises to keep, and
miles to go before I sleep
\- Robert Frost

Respected Principals, Correspondents, Head Masters / Head Mistresses, Teachers,

From the bottom of our heart, we at SURA Publications sincerely thank you for the support and patronage that you have extended to us for more than a decade.

It is in our sincerest effort we take the pride of releasing **SURA'S Physics Guide (Volume - I & II)** for +2 Standard. This guide has been authored and edited by qualified teachers having teaching experience for over a decade in their respective subject fields. This Guide has been reviewed by reputed Professors who are currently serving as Head of the Department in esteemed Universities and Colleges.

With due respect to Teachers, I would like to mention that this guide will serve as a teaching companion to qualified teachers. Also, this guide will be an excellent learning companion to students with exhaustive exercises and in-text questions in addition to precise answers for textual questions.

In complete cognizance of the dedicated role of Teachers, I completely believe that our students will learn the subject effectively with this guide and prove their excellence in Board Examinations.

I once again sincerely thank the Teachers, Parents and Students for supporting and valuing our efforts.

God Bless all.

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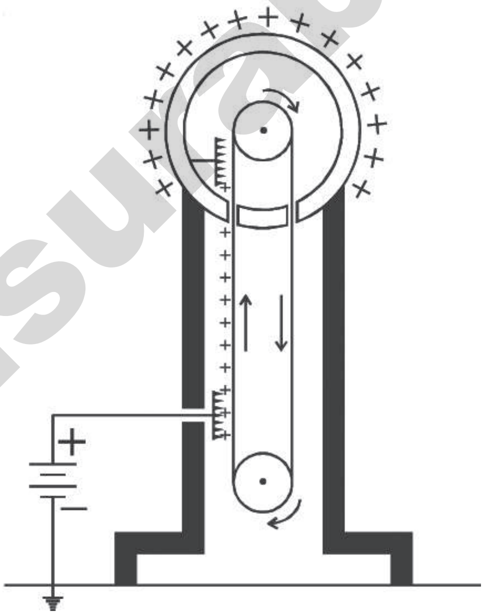

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UNIT 1 ELECTROSTATICS

CHAPTER SNAPSHOT

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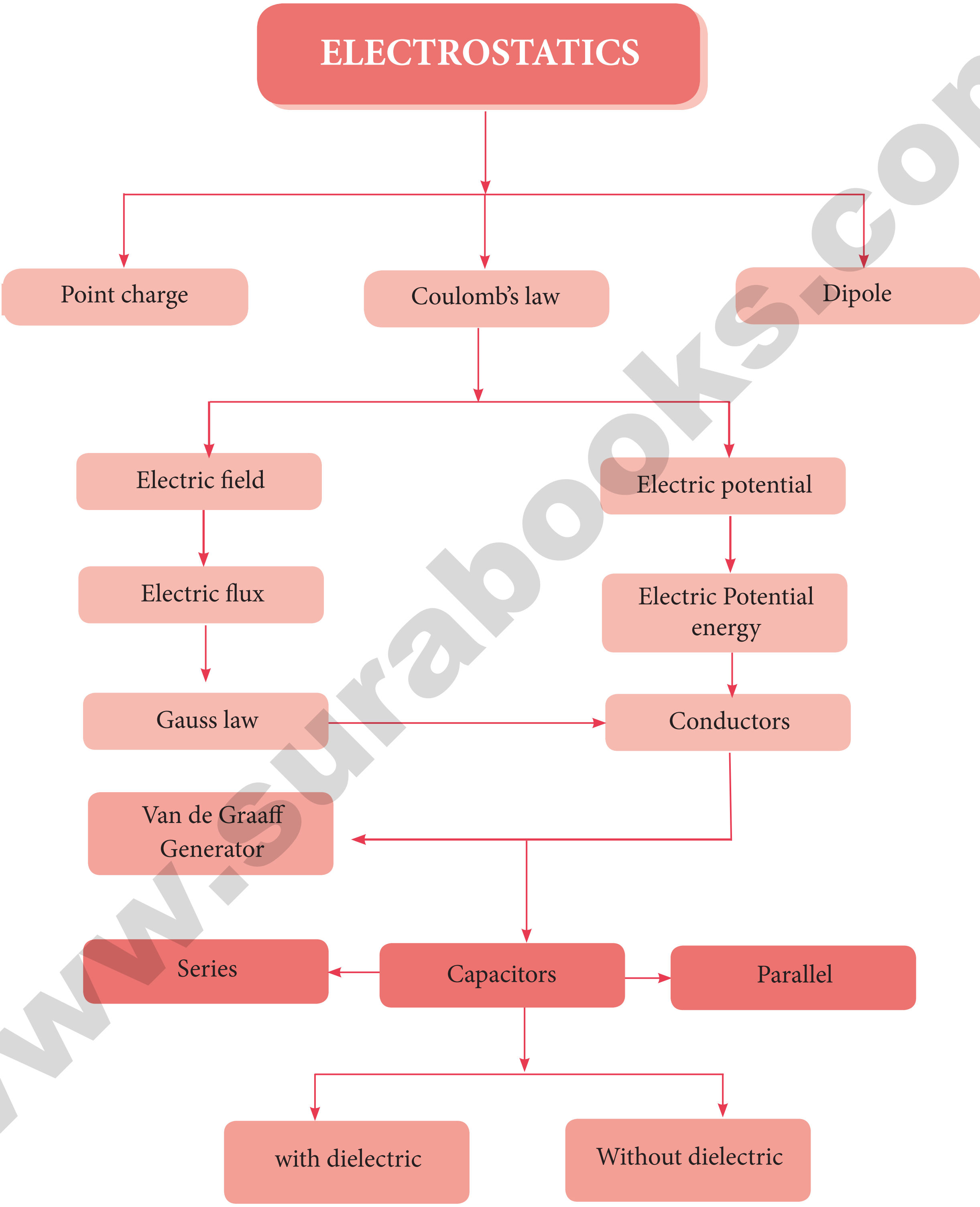
CONCEPT MAP


ELECTROSTATICS
Point charge
Coulomb's law
Dipole
Electric field
Electric potential
Electric flux
Electric Potential energy
Gauss law
Conductors
Van de Graaff Generator
Series
Capacitors
Parallel
with dielectric
Without dielectric

MUST KNOW DEFINITIONS

Electrostatics : Study of electric charges at rest or stationary charged bodies.

Electric charge : A basic property of some substances due to which they can exert a force of electrostatic attraction or repulsion on other charged bodies at a distance.

Frictional electricity :

600 B.C. Thales, a Greek Philosopher - amber with fur - electrification

17th century William Gilbert - glass, ebonite exhibit charging by rubbing.

Elektron (Greek word) - means amber

Positive charge	Negative charge
Glass rod	Silk cloth
Fur cap	Ebonite rod
Woollen cloth	Plastic object

Superposition principle : In an isolated system, the total force on a given charge is the vector sum of the individual forces exerted on it by all other charges, each individual force calculated by Coulomb's law.

$$\vec{F}_1^{tot} = k\left[\frac{q_1 q_2}{r_{21}^2}\hat{r}_{21} + \frac{q_1 q_3}{r_{31}^2}\hat{r}_{31} + ... + \frac{q_1 q_n}{r_{n1}^2}\hat{r}_{nl}\right]$$

Properties of charges :

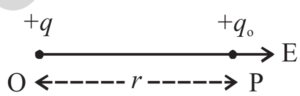
Quantisation of charge $q = ne$ [n = 0, ±1, ±2, ±3,....]

Charges are additive $Q = \Sigma Q_n$

Conservation of charges Q = Constant

A point charge : The dimension of the charged object is very small and neglected in comparison with the distances involved.

Electric field due to a point charge :



$$\vec{E} = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}\hat{r}$$

Direction of E is along line joining OP : Points outward for $+q$ at O

Points inward for $-q$ at O

Definition of Coulomb : It is defined as the quantity of charge which when placed at a distance of 1 metre in air or vacuum from an equal and similar charge experiences a repulsive force of 9×10^9 N.

Test charge : A charge which, on introduction in an existing field, does not alter the field.

Electric field : It is the space or the region around the source charge in which the effect of the charge can be felt.

Electric field intensity : Force experienced by a unit positive charge kept at that point in the field.

Electric lines of force	:	Imaginary straight or curved line along which a unit positive charge tends to move in an electric field. Each unit positive charge gives rise to $\frac{1}{\varepsilon_o}$ lines of force in free space.
Electric dipole	:	Two equal and opposite charges separated by a very small vector distance.
Importance of dipole	:	Any complicated array of a complex arrangement of charges, can be simplified as a number dipoles and analysed.
Potential difference	:	It is defined as the amount of work done in moving a unit positive charge from one point to the other in an electric field.
Volt	:	If 1 joule of work is done in moving 1 coulomb of charge from one point to another in an electric field.
Electric potential	:	It is defined as the amount of work done in moving a unit positive charge from infinity to that point.
Equipotential surface	:	If the potential at all points on a surface is the same, it is said to be an equipotential surface.
Electric flux	:	The total number of electric lines of force crossing a given area. $d\phi = \vec{E}.\vec{ds} = Eds\cos\theta$
Gauss' law	:	It states that the total flux of the electric field E over any closed surface is equal to $\frac{1}{\varepsilon_o}$ times the net charge enclosed by the surface, $\phi = \frac{q}{\varepsilon_o}$.
Gaussian surface	:	The closed imaginary surface over an enclosed net charge.
Electrostatic shielding	:	Process of isolating a certain region of space from external field. It is based on the fact that electric field inside a conductor is zero.
Electrostatic induction	:	It is the method of obtaining charges without any contact with another charge. They are called induced charges and the phenomenon of producing induced charges is called electrostatic induction. It is used in electrostatic machines like Van de Graaff generators and capacitors.
Capacitance	:	It is defined as the ratio of charge given to the conductor to the potential developed in the conductor. Its unit is farad (F). A conductor has a capacitance of one farad if a charge of 1 coulomb given to it raises its potential by 1 volt.
Dielectric	:	A dielectric is an insulating material in which all electrons are tightly bound to the nucleus of the atom. The electrons are not free to move under the influence of an external field. Hence, there are no free electrons to carry current.
Polar molecule	:	It is one in which the centre of gravity (mass) of the positive charges is separated from the centre of gravity of the negative charges by a finite distance. **e.g :** N_2O, H_2O, HCl, NH_3. These molecules have a permanent dipole moment.

Non-polar molecules	: A non-polar molecule is one in which centers of positive and negative charges coincide. It has no permanent dipole moment, e.g: H_2, O_2, CO_2 etc.
Electric polarisation	: The alignment of electric dipole moments of the permanent or induced dipoles in the direction of the external applied field.
Corona discharge	: The leakage of electric charges from the sharp points on the charged conductor is called action of points or corona discharge. It is used in machines like Van de Graaff generators and lightning arrestors (conductors).

Force - Displacing vector

Torque - Rotating vectors; it is the moment of force

Hint:

1. In a uniform electric field when equal and opposite forces act at the ends of the dipole, the net force is zero.
2. The forces act at different points. Hence, the moment of the force is non-zero and the torque is non-zero.
3. The non-zero torque, always tends to align the dipole in the direction of the field.
4. The direction of torque vector is along the axis of rotation.
5. Charges outside the Gaussian surface will not contribute to the flux inside.
6. Field outside the charged parallel sheets is zero.

Conduction	Induction
Charges are obtained in contact with other charged body.	Charges are obtained without any contact with other charged body.
Produces similar or one type of charge.	Both positive and negative charges are produced.
Only limited amount of charges are obtained.	Large quantity of charges can be induced.

	Capacitors in series	Capacitors in parallel
Total Charge	q is same for C_1 and C_2 and C_3	$q = q_1 + q_2 + q_3$ $q_1 = C_1V$; $q_2 = C_2V$ $q_3 = C_3V$
Total potential	$V = V_1 + V_2 + V_3$ $V_1 = \frac{q}{C_1}$; $V_2 = \frac{q}{C_2}$; $V_3 = \frac{q}{C_3}$	V is same for C_1, C_2 and C_3
Expression for equivalent capacitance	$\frac{1}{C_s} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$	$C_p = C_1 + C_2 + C_3$

Charge (q)	Mass(m)
Can be zero, +ve or −ve	Can never be zero, only +ve
Force between two charges can be positive or negative	Force between any two masses is always attractive in nature
Value of constant depends upon $\varepsilon, \varepsilon_r, \varepsilon_0$	Value of constant G is always fixed.

FORMULAE

(1) Electrostatic force between charges q_1 and q_2, $F = \vec{F}_{12} = \frac{1}{4\pi\varepsilon_o}\frac{q_1q_2}{r_{21}^2}\hat{r}_{21}$

(2) Value of $k = \frac{1}{4\pi\varepsilon_o} = 9 \times 10^9 \text{ Nm}^2\text{C}^{-2}$

(3) Value of $\varepsilon = 8.854 \times 10^{-12}\ \text{C}^2\text{N}^{-1}\text{m}^{-2}$

(5) Total charge $q = n \times e$; Number of electrons × Charge of an electron

(6) Components of force F, $F_1 = F\cos\theta$; $F_2 = F\sin\theta$; $|F| = \sqrt{F_1^2 + F_2^2}$

(7) Relative permittivity or Dielectric constant $\varepsilon_r = \frac{\varepsilon}{\varepsilon_o}$

(8) Force between charges in medium $F_m = \frac{F_{air}}{\varepsilon_r}$

(9) Electrostatic field, $E = \frac{\text{force}}{\text{charge}} = \frac{F}{q} \Rightarrow F = qE$

(10) Electric field due to a point charge $E = \frac{1}{4\pi\varepsilon_o}\frac{q}{r^2}\hat{r}$

(11) Electric dipole moment, $\vec{p} = q \times 2a\hat{i}$

(12) (i) Electric field due to a dipole at a point on the axial line, $\vec{E} = \frac{1}{4\pi\varepsilon_0}\frac{2\vec{p}}{r^3}$ $(r >> a)$

(ii) Electric field due to a dipole at a point on the equatorial line $E = \vec{E}_{tot} = \frac{-1}{4\pi\varepsilon_0}\frac{\vec{p}}{r^3}$ $(r >> a)$

(13) Magnitude of torque $\tau = \vec{p} \times \vec{E} = pE\sin\theta$ $(p = q\,2a)$

(14) Electric potential at a point due to a point charge, $V = \frac{1}{4\pi\varepsilon_o}\frac{q}{r}$

(15) Electric potential energy of dipole $U = -pE\cos\theta = -\vec{p}.\vec{E}$

(16) Electric potential at a point due to an electric dipole $V = \frac{p}{4\pi\varepsilon_o}\frac{\cos\theta}{r^2}$

(17) Electric flux $= \frac{q}{\varepsilon_0} \Rightarrow \phi_E = \vec{E}.\vec{A} = EA\cos\theta$

(18) Electric field due to infinite long straight charged wire, $E = \frac{\lambda}{2\pi\varepsilon_0 r}$

(19) Electric field due to plane sheet of charge $E = \frac{\sigma}{2\varepsilon_o} = \frac{q}{A}\frac{1}{2\varepsilon_o}$ Vector form, $\vec{E} = \frac{\sigma}{2\varepsilon_0}\hat{n}$

(20) Electric field at a point between two parallel sheets of charge $E = \frac{\sigma}{\varepsilon_o}$

(21) Electric field due to a uniformly charged sphere -

(i) at a point on the surface of the sphere, $E = \frac{1}{4\pi\varepsilon_o}\frac{Q}{R^2}\hat{r}$ $[\because r = R]$

(ii) at a point outside the sphere $E = \frac{1}{4\pi\varepsilon_o}\frac{Q}{r^2}\hat{r}$

(iii) at a point inside the sphere $E = 0$ $[r < R]$

(22) Capacitance of a conductor $C = \frac{q}{V}$

(23) Work done by a charge $W = qV$

(24) Charge density, $\sigma = \frac{q}{A}$

(25) Capacitance of a parallel plate capacitor $C = \frac{\varepsilon_o A}{d}$

(i) With a dielectric slab, $C = \frac{\varepsilon_o A}{\left[(d-t) + \frac{t}{\varepsilon_r}\right]}$

(ii) With the dielectric completely filled capacitor $C^1 = \frac{\varepsilon_o \varepsilon_r A}{d} = C \times \varepsilon_r$

(26) Energy stored in a capacitor $E = \frac{1}{2}CV^2$

(27) Capacitance of a spherical capacitor, $C = 4\pi\varepsilon_0 A$ or $C = \frac{A}{9\times10^9}$

(28) Equivalent capacitance

(i) C_1 and C_2 in series $C_s = \frac{C_1C_2}{C_1+C_2}$; $C_s = \frac{1}{C_S} = \frac{1}{C_1} + \frac{1}{C_2}$

(ii) C_1 and C_2 in parallel $C_p = C_1 + C_2$

(29) Polarisation, $\vec{p} = \chi_e \vec{E}_{ext}$ (χ_e - electric susceptibility)

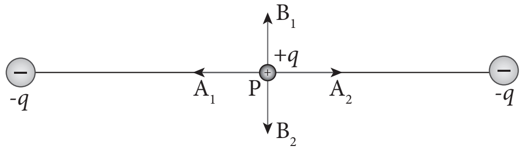
Values And Units

(1)	Permittivity of free space ε_o	=	8.854×10^{-12} $C^2N^{-1}m^{-2}$
(2)	$\frac{1}{4\pi\varepsilon_o}$	=	9×10^9 Nm^2C^{-2}
(3)	Charge of an electron, e	=	1.6×10^{-19} C
(4)	1 micro farad	=	10^{-6} farad
(5)	1 pico farad	=	10^{-12} farad
(6)	Permittivity of medium, ε	=	$C^2N^{-1}m^{-2}$
(7)	Electric charge (q)	=	Coulomb (C)
(8)	Electric field (E)	=	NC^{-1} or $V\ m^{-1}$
(9)	Electric potential (V)	=	JC^{-1} or volt
(10)	Electric dipole moment (p)	=	Coulomb metre
(11)	Electric potential energy (U)	=	Joule
(12)	Capacitance (C)	=	farad
(13)	Electric flux	=	Nm^2C^{-1}
(14)	Torque	=	Nm
(15)	Relative permittivity of air	=	1 (no unit)

Evaluation

I. Multiple choice questions :

1. Two identical point charges of magnitude $-q$ are fixed as shown in the figure below. A third charge $+q$ is placed midway between the two charges at the point P. Suppose this charge $+q$ is displaced a small distance from the point P in the directions indicated by the arrows, in which direction(s) will $+q$ be stable with respect to the displacement?



(a) A_1 and A_2 (b) B_1 and B_2
(c) both directions (d) No stable

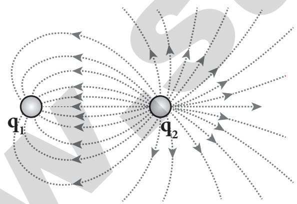
[*Ans.* (b) B_1 and B_2]

2. Which charge configuration produces a uniform electric field? *[HY-2019;Aug-2021;FRT-'22]*

(a) point Charge
(b) uniformly charged infinite line
(c) uniformly charged infinite plane
(d) uniformly charged spherical shell

[*Ans.* (c) uniformly charged infinite plane]

3. What is the ratio of the charges $\left|\frac{q_1}{q_2}\right|$ for the following electric field line pattern?



(a) $\frac{1}{5}$ (b) $\frac{25}{11}$ (c) 5 (d) $\frac{11}{25}$

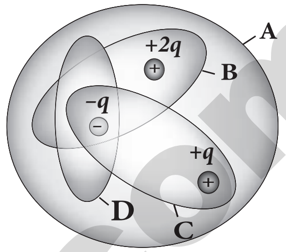
[*Ans.* (d) $\frac{11}{25}$]

4. An electric dipole is placed at an alignment angle of 30° with an electric field of 2×10^5 N C^{-1}. It experiences a torque equal to 8 N m. The charge on the dipole if the dipole length is 1 cm is *[QY-2019 & '24; July-'22; June-'23]*

(a) 4 mC (b) 8 mC
(c) 5 mC (d) 7 mC

[*Ans.* (b) 8 mC]

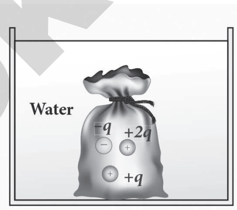
5. Four Gaussian surfaces are given below with charges inside each Gaussian surface. Rank the electric flux through each Gaussian surface in increasing order.



(a) D < C < B < A (b) A < B = C < D
(c) C < A = B < D (d) D > C > B > A

[*Ans.* (a) D < C < B <A]

6. The total electric flux for the following closed surface which is kept inside water



(a) $\frac{80q}{\varepsilon_o}$ (b) $\frac{q}{40\varepsilon_o}$
(c) $\frac{q}{80\varepsilon_o}$ (d) $\frac{q}{160\varepsilon_o}$

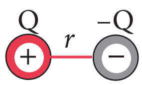
[*Ans.* (b) $\frac{q}{40\varepsilon_o}$]

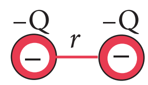
7. Two identical conducting balls having positive charges q_1 and q_2 are separated by a center to center distance r. If they are made to touch each other and then separated to the same distance, the force between them will be *(NSEP 04-05)* *[Sep-2020; FRT-'22; QY-'23; Mar.-'24]*

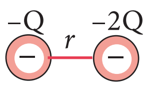
(a) less than before (b) same as before
(c) more than before (d) zero

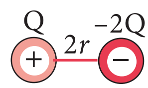
[*Ans.* (c) more than before]

8. Rank the electrostatic potential energies for the given system of charges in increasing order. *[PTA-4]*

(a) 

(b) 

(c) 

(d) 

(a) 1 = 4 < 2 < 3 (b) 2 = 4 < 3 < 1
(c) 2 = 3 < 1 < 4 (d) 3 < 1 < 2 < 4

[*Ans.* (a) 1 = 4 < 2 < 3]

Unit 1

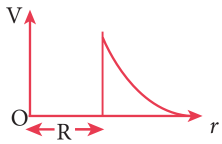
9. An electric field $\vec{E} = 10x\hat{i}$ exists in a certain region of space. Then the potential difference $V = V_0 - V_A$, where V_0 is the potential at the origin and V_A is the potential at $x = 2$ m is: *(HY-'23)*

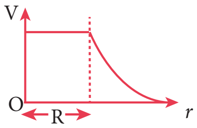
(a) 10 V (b) – 20 V

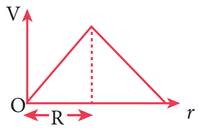
(c) +20 V (d) –10 V

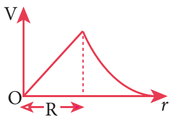
[Ans. (c) +20 V]

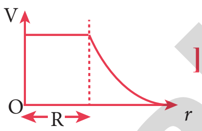
10. A thin conducting spherical shell of radius R has a charge Q which is uniformly distributed on its surface. The correct plot for electrostatic potential due to this spherical shell is *[PTA-1]*

(a) 

(b) 

(c) 

(d) 

[Ans. (b)  **]**

11. Two points A and B are maintained at a potential of 7 V and –4 V respectively. The work done in moving 50 electrons from A to B is *[June-'24]*

(a) 8.80×10^{-17} J (b) -8.80×10^{-17} J

(c) 4.40×10^{-17} J (d) 5.80×10^{-17} J

[Ans. (a) 8.80×10^{-17} J]

12. If voltage applied on a capacitor is increased from V to 2V, choose the correct conclusion. *[Govt. MQP-2019; Mar-2020]*

(a) Q remains the same, C is doubled

(b) Q is doubled, C doubled

(c) C remains same, Q doubled

(d) Both Q and C remain same

[Ans. (c) C remains same, Q doubled]

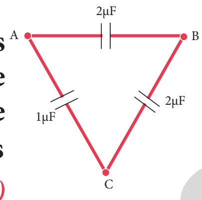
13. A parallel plate capacitor stores a charge Q at a voltage V. Suppose the area of the parallel plate capacitor and the distance between the plates are each doubled then which is the quantity that will change? *[QY-2019 & '23; Sep-2020; FRT-'22; Mar-2023; HY-'24]*

(a) Capacitance (b) Charge

(c) Voltage (d) Energy density

[Ans. (d) Energy density]

14. Three capacitors are connected in triangle as shown in the figure. The equivalent capacitance between the points A and C is *(Mar.'24)*



(a) 1μF

(b) 2 μF

(c) 3 μF

(d) $\frac{1}{4}$μF **[Ans. (b) 2 μF]**

15. Two metallic spheres of radii 1 cm and 3 cm are given charges of -1×10^{-2} C and 5×10^{-2} C respectively. If these are connected by a conducting wire, the final charge on the bigger sphere is *(AIIPMT -2012; May-2022)*

(a) 3×10^{-2} C (b) 4×10^{-2} C

(c) 1×10^{-2} C (d) 2×10^{-2} C

[Ans. (a) 3×10^{-2} C]

II. Short Answer Questions :

1. What is meant by quantisation of charges?

Ans. (i) The charge q on any object is equal to an integral multiple of the fundamental unit of charge e.

$$q = ne$$

(ii) Where n is any integer (0, ±1, ±2, ±3, ±4..........). This is called quantisation of electric charge.

2. Write down Coulomb's law in vector form and mention what each term represents.

Ans. (i) According to Coulomb, the force on the point charge q_2 exerted by another point charge q_1 is

$$\vec{F}_{21} = k\frac{q_1 q_2}{r^2}\hat{r}_{12}$$

where $\hat{r}_{12}$ is the unit vector directed from charge q_1 to charge q_2 and k is the proportionality constant.

(ii) Also $k = \frac{1}{4\pi\varepsilon_0}$ and its value is $k = 9 \times 10^9\ Nm^2C^{-2}$. Here ε_0 is the permittivity of free space or vacuum and its value is $\varepsilon_0 = \frac{1}{4\pi k} = 8.85 \times 10^{-12}\ C^2 N^{-1} m^{-2}$

ELECTROSTATICS

3. What are the differences between Coulomb force and gravitational force? *[QY; HY - 2019; Mar - 2023]*

Ans. *[June-'24]*

S. No	Coulomb	Gravitational
i)	It may be attractive or repulsive.	It is always attractive in nature.
ii)	It depends upon medium	It does not depend upon the medium
iii)	It is always greater in magnitude because of high value of $K = 9 \times 10^9$ Nm^2 C^{-2}	It is lesser than coulomb force because value of G is 6.67×10^{-11} Nm^2 kg^{-2}
iv)	The force between the charges will not be same during motion or rest.	It is always same whether the two masses are rest or motion

4. Write a short note on superposition principle.

Ans. According to this superposition principle, the total force acting on a given charge is equal to the vector sum of forces exerted on it by all the other charges.

Consider a system of n charges, namely q_1, q_2, q_3....q_n. The force on q_1 exerted by the charge q_2

$$\vec{F}_{12} = k\frac{q_1 q_2}{r_{21}^2}\hat{r}_{21}$$

The force on q_1 exerted by the charge q_3 is

$$\vec{F}_{13} = k\frac{q_1 q_3}{r_{31}^2}\hat{r}_{31}$$

The total force acting on the charge q_1 due to all other charges is given by

$$\vec{F}_1^{tot} = \vec{F}_{12} + \vec{F}_{13} + \vec{F}_{14} + ...\vec{F}_{1n}$$

$$\vec{F}_1^{tot} = k\left\{\frac{q_1 q_2}{r_{21}^2}\hat{r}_{21} + \frac{q_1 q_3}{r_{31}^2}\hat{r}_{31} + \frac{q_1 q_4}{r_{41}^2}\hat{r}_{41} + ... + \frac{q_1 q_n}{r_{n1}^2}\hat{r}_{n1}\right\}$$

5. Define 'electric field'. *[Mar-2023]*

Ans. **(i)** The electric field at the point P at a distance r from the point charge q is the force experienced by a unit charge and is given by

$$\vec{E} = \frac{\vec{F}}{q_0} = \frac{kq}{r^2}\hat{r} = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}\hat{r}$$

(ii) Here $\hat{r}$ is the unit vector pointing from q to the point of interest P.

(iii) The electric field is a vector quantity.

(iv) SI unit is Newton per Coulomb (NC^{-1}).

6. What is mean by 'electric field lines'?

Ans. Electric field vectors are visualized by the concept of electric field lines. They form a set of continuous lines which are the visual representation of the electric field in some region of space.

7. The electric field lines never intersect. Justify. *[PTA-4]*

Ans. If some charge is placed in the intersection point, then it has to move in two different directions at the same time, which is physically impossible. Hence, electric field lines do not intersect.

8. Define 'electric dipole'. Give the expression for the magnitude of its electric dipole moment and the direction. *[PTA-5]*

Ans. **(i)** Two equal and opposite charges separated by a small distance constitute an electric dipole.

(ii) The magnitude of the electric dipole moment is equal to the product of the magnitude of one of the charges and the distance between them.

$\left|\vec{p}\right|$ = $2qa$ and it is directed from $-q$ to $+q$

9. Write the general definition of electric dipole moment for a collection of point charge.

Ans. The electric dipole moment for a collection of 'n' point charges is given by, $\vec{P} = \sum_{i=1}^{n} q_i \vec{r}_i$

where $\vec{r}_i$ is the position vector of charge q_i from the origin.

10. Define 'electrostatic potential'. *[PTA-6; Aug-2021; Mar.-'24]*

Ans. The electric potential at a point P is equal to the work done by an external force to bring a unit positive charge with constant velocity from infinity to the point P in the region of the external electric field $\vec{E}$.

11. What is an equipotential surface?

Ans. An equipotential surface is a surface on which all the points are at the same electric potential.

Unit 1

12. What are the properties of an equipotential surface? *[QY & HY-'23]*

Ans. (i) The work done to move a charge q between any two points A and B, $W = q\,(V_B - V_A)$.

(ii) If the points A and B lie on the same equipotential surface, work done is zero because $V_A = V_B$.

(iii) The electric field is normal to an equipotential surface. If it is not normal, then there is a component of the field parallel to the surface.

13. Give the relation between electric field and electric potential. *[PTA-6]*

Ans. Consider a positive charge q kept fixed at the origin. To move a unit positive charge by a small distance dx towards q in the electric field E, the work done is given by $dW = -E\,dx$. The minus sign implies that work is done against the electric field. This work done is equal to electric potential difference. Therefore,

$$dW = dV$$
$$\text{(or)} \quad dV = -E\,dx$$
$$\text{Hence } E = -\frac{dV}{dx}$$

The electric field is the negative gradient of the electric potential.

14. Define 'electrostatic potential energy'.

Ans. It is defined as the amount of work done in assembling the charges at their locations by bringing them in from infinity.

15. Define 'electric flux'. *[QY-'23]*

Ans. (i) The number of electric field lines crossing a given area kept normal to the electric field lines is called electric flux.

(ii) It is a scalar quantity

(iii) Its unit is Nm^2C^{-1}

16. What is meant by electrostatic energy density?

Ans. The energy stored per unit volume of space is defined as energy density $u_E = \frac{U}{\text{Volume}}$. From equation $u_E = \frac{1}{2}\varepsilon_0 E^2$.

17. Write a short note on 'electrostatic shielding'.

Ans. (i) Consider a cavity inside the conductor. Whatever be the charges at the surfaces and whatever be the electrical disturbances outside, the electric field inside the cavity is zero.

(ii) A sensitive electrical instrument which is to be protected from external electrical disturbance can be kept inside this cavity. This is called electrostatic shielding.

18. What is Polarisation?

Ans. (i) Polarisation $\vec{p}$ is defined as the total dipole moment per unit volume of the dielectric.

$$\vec{p} = \chi_e \vec{E}_{ext}$$

(ii) χ_e = electric susceptibility.

19. What is dielectric strength?

Ans. The maximum electric field the dielectric can withstand before it breakdowns is called dielectric strength.

20. Define 'capacitance'. Give its unit. *[June-'23]*

Ans. (i) The capacitance C of a capacitor is defined as ratio of the magnitude of charge on either of the conductor plates to the potential difference existing between them.

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

(ii) The SI unit of capacitance is coulomb per volt or farad.

21. What is Corona discharge? *[Mar-2020; May-2022; QY-'24]*

Ans. (i) The electric field near the edge is very high and it ionizes the surrounding air.

(ii) The positive ions are repelled at the sharp edge and negative ions are attracted towards the sharper edge.

(iii) This reduces the total charge of the conductor near the sharp edge. This is called action of points or corona discharge.

III. Long Answer Questions :

1. Discuss the basic properties of electric charges.

Ans. **(I) Electric charge :**

(i) Most objects in the universe are made up of atoms, which in turn are made up of protons, neutrons and electrons.

(ii) These particles have mass, an inherent property of particles. Similarly, the electric charge is another intrinsic and fundamental property of particles.

(iii) The SI unit of charge is coulomb.

(II) Conservation of charges :

(i) Benjamin Franklin argued that when one object is rubbed with another object, charges get transferred from one to the other.

(ii) Before rubbing, both objects are electrically neutral and rubbing simply transfers the charges from one object to the other. (For example, when a glass rod is rubbed against silk cloth, some negative charge are transferred from glass to silk.

(iii) As a result, the glass rod is positively charged and silk cloth becomes negatively charged).

(III) Quantisation of charges :

(i) The charge q on any object is equal to an integral multiple of this fundamental unit of charge e. $q = ne$.

(ii) Here n is any integer (0, ±1, ±2, ±3, ±4………..). This is called quantisation of electric charge.

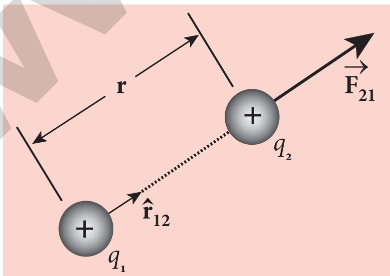
(iii) Robert Millikan in his famous experiment found that the value of e=1.6×10^{-19} C. The charge of an electron is −1.6×10^{-19}C and the charge of the proton is +1.6 × 10^{-19} C.

2. Explain in detail Coulomb's law and its various aspects. *[PTA-3]*

Ans. Consider two point charges q_1 and q_2 at rest in vacuum, and separated by a distance of r as shown in Figure. According to Coulomb, the force on the point charge q_2 exerted by another point charge q_1 is

$$\vec{F}_{21} = k\frac{q_1 q_2}{r^2}\hat{r}_{12}$$

where $\hat{r}_{12}$ is the unit vector directed from charge q_1 to charge q_2 and k is the proportionality constant.



Coulomb force between two positive point charges

Important aspects of Coulomb's law :

(i) Coulomb's law states that the electrostatic force is directly proportional to the product of the magnitude of the two point charges and is inversely proportional to the square of the distance between the two point charges.

(ii) The force on the charge q_2 exerted by the charge q_1 always lies along the line joining the two charges. $\hat{r}_{12}$ is the unit vector pointing from charge q_1 to q_2. The force on the charge q_1 exerted by q_2 is along $-\hat{r}_{12}$ (i.e., in the direction opposite to $\hat{r}_{12}$).

(iii) In SI units, $k = \frac{1}{4\pi\varepsilon_0} = 9 \times 10^9$ Nm^{2}C^{-2}

Here ε_0 is the permittivity of free space or vacuum and its value is $\varepsilon_0 = \frac{1}{4\pi k} = 8.85 \times 10^{-12}$ C^2 N^{-1} m^{-2}

(iv) The magnitude of the electrostatic force between two charges each of one coulomb and separated by a distance of 1 m is calculated as follows:

$$|F| = \frac{9\times10^9 \times 1 \times 1}{1^2} = 9\times10^9 \text{ N}$$

This is a huge quantity, almost equivalent to the weight of one million ton. We never come across 1 coulomb of charge in practice. Most of the electrical phenomena in day-to-day life involve electrical charges of the order of μC (micro coulomb) or nC (nano coulomb).

(v) In SI units, coulomb's law in vacuum takes the form $\vec{F}_{21} = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}\hat{r}_{12}$.

(vi) Coulomb's law has same structure as Newton's law of gravitation. Both are inversely proportional to the square of the distance between the particles.

There are some important differences between these two laws.

- The gravitational force between two masses is always attractive but Coulomb force between two charges can be attractive or repulsive, depending on the nature of charges.

(vii) The force on a charge q_1 exerted by a point charge q_2 is given by

$$\vec{F}_{12} = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}\hat{r}_{21}$$

Here $\hat{r}_{21}$ is the unit vector from charge q_2 to q_1.

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

$$\vec{F}_{12} = \frac{1}{4\pi\epsilon_\circ}\frac{q_1 q_2}{r^2}(-\hat{r}_{12}) = -\frac{1}{4\pi\epsilon_\circ}\frac{q_1 q_2}{r^2}(\hat{r}_{12})$$

$$\text{(or) } \vec{F}_{12} = -\vec{F}_{21}$$

Therefore, the electrostatic force obeys Newton's third law.

(viii) The expression for Coulomb force is true only for point charges. But the point charge is an ideal concept. However we can apply Coulomb's law for two charged objects whose sizes are very much smaller than the distance between them.

3. Define 'electric field' and discuss its various aspects.

Ans. **Electric Field :** The electric Field at the point P at a distance r from the point charge q is defined as the force that would be experienced by a unit positive charge placed at the point P

$$\vec{E} = \frac{\vec{F}}{q_0} = \frac{kq}{r^2}\hat{r} \quad E = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}\hat{r} \qquad ...(1)$$

Important aspects of the Electric field :

(i) If the charge q is positive then the electric field points away from the source charge and if q is negative, the electric field points towards the source charge q.

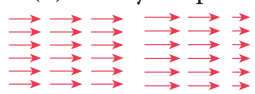
(ii) Force experienced by the test charge q_0 Placed at the point P is $\vec{F} = q_0\vec{E}$

(iii) From the equation (1) implies that the electric field is independent of q_0 (test charge) and it depends on q (source charge).

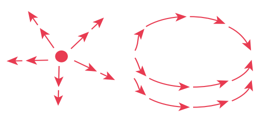
(iv) It is a vector quantity, which has unique direction and magnitude, and electric field decreases, when distance increases

(v) Test charge is very small. So that field value of source charge is unaltered.

(vi) Equation (1) is only for point charges.



Uniform Electric field Non uniform electric field



Non uniform electric field Non uniform electric field

(vii) There are uniform and non-uniform electric fields.

Uniform electric field : It has same direction and constant magnitude at all points.

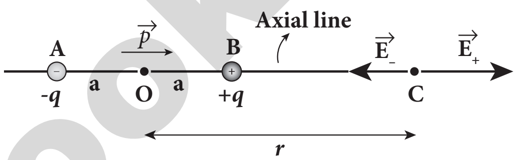
Non-uniform electric field : Different directions or different magnitudes or both at different points.

4. Calculate the electric field due to a dipole on its axial line and equatorial plane.

[PTA-5; Aug-2021; FRT-'22; HY-'23; Mar. & HY-'24]

Ans. **Electric field due to an electric dipole at points on the axial line :**

Consider an electric dipole placed on the x-axis. A point C is located at a distance of r from the midpoint of the dipole on the axial line.



The electric field at a point 'C' due to $+q$ is

$$\vec{E}_+ = \frac{1}{4\pi\varepsilon_0}\frac{q}{(r-a)^2}\hat{p} \text{ along BC}$$

The electric field at a point 'C' due to $-q$ is

$$\vec{E}_- = -\frac{1}{4\pi\varepsilon_0}\frac{q}{(r+a)^2}\hat{p} \text{ along CA}$$

The total electric field at point C is calculated using the superposition principle of the electric field.

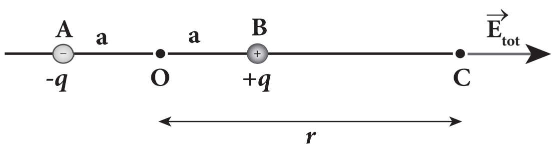
$$\vec{E}_{tot} = \vec{E}_+ + \vec{E}_-$$

at 'C' using superpostion principle

$$= \frac{1}{4\pi\varepsilon_0}\frac{q}{(r-a)^2}\hat{p} - \frac{1}{4\pi\varepsilon_0}\frac{q}{(r+a)^2}\hat{p} \qquad ...(1)$$

$$\vec{E}_{tot} = \frac{1}{4\pi\varepsilon_0}q\left(\frac{4ra}{(r^2-a^2)^2}\right)\hat{p} \qquad ...(2)$$

Note that the total electric field is along $\vec{E}_+$, since $+q$ is closer to C than $-q$.



If the point C is very far away from the dipole ($r >> a$). Then under this limit the term $(r^2 - a^2)^2 \approx r^4$. Substituting this into equation(2), we get

$$\vec{E}_{tot} = \frac{1}{4\pi\varepsilon_0}\left(\frac{4aq}{r^3}\right)\hat{p} \quad (r >> a)$$

since $2aq\,\hat{p} = \vec{p}$

$$\vec{E}_{tot} = \frac{1}{4\pi\varepsilon_0}\frac{2\vec{p}}{r^3} \quad (r >> a)$$

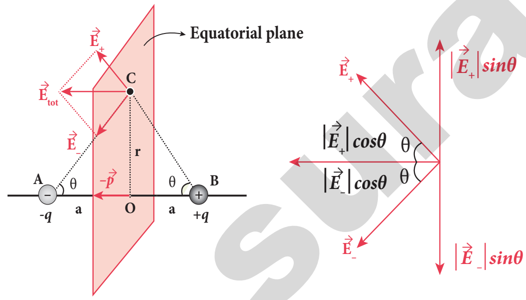
$$\vec{E}_{tot} = -\frac{1}{4\pi\varepsilon_0}\frac{\vec{p}}{r^3} \quad (r >> a)$$

If the point C is chosen on the left side of the dipole, the total electric field is still in the direction of $\vec{p}$.

Electric field due to an electric dipole at a point on the equatorial plane

Consider a point C at a distance r from the midpoint O of the dipole on the equatorial plane.

Since the point C is equi-distant from $+q$ and $-q$, the magnitude of the electric fields at C due to $+q$ and $-q$ are the same.



Electric field due to a dipole at a point on the equatorial plane

The direction of $\vec{E}_+$ is along BC and the direction of $\vec{E}_-$ is along CA. $\vec{E}_+$ and $\vec{E}_-$ can be resolved into two components; one component parallel to the dipole axis and the other perpendicular to it. Since perpendicular components $|\vec{E}_+|\sin\theta$ and $|\vec{E}_-|\sin\theta$ are equal in magnitude and oppositely directed, they cancel each other. The magnitude of the total electric field at point C is the sum of the parallel components of $\vec{E}_+$ and $\vec{E}_-$ and its direction is along $-\hat{p}$ as shown in the Figure.

$$\vec{E}_{tot} = -|\vec{E}_+|\cos\theta\,\hat{p} - |\vec{E}_-|\cos\theta\,\hat{p} \quad ...(1)$$

$$|E_+| = |E_-|$$

$$\therefore \quad \vec{E}_{tot} = -\frac{1}{4\pi\varepsilon_0}\frac{2q\cos\theta}{(r^2+a^2)}\hat{p}$$

$$\vec{E}_{tot} = -\frac{1}{4\pi\varepsilon_0}\cdot\frac{2qa}{(r^2+a^2)^{\frac{3}{2}}}\hat{p}$$

$$\left[\cos\theta = \frac{a}{\sqrt{r^2+a^2}}\right]$$

$$\vec{E}_{tot} = -\frac{1}{4\pi\varepsilon_0}\frac{\vec{p}}{(r^2+a^2)^{\frac{3}{2}}} \quad ...(2)$$

since $\vec{p} = 2qa\hat{p}$

At very large distances ($r >> a$), the equation(2) becomes

$$\vec{E}_{tot} = -\frac{1}{4\pi\varepsilon_0}\frac{\vec{p}}{r^3} \quad (r >> a)$$

5. Derive an expression for the torque experienced by a dipole due to a uniform electric field. *[PTA-3]*

Ans. Electric dipole in uniform electric field :

(i) Consider an electric dipole of dipole moment $\vec{p}$ placed in a uniform electric field $\vec{E}$ whose field lines are equally spaced and point in the same direction. The charge $+q$ will experience a force $q\vec{E}$ in the direction of the field and charge $-q$ will experience a force $-q\vec{E}$ in a direction opposite to the field.

(ii) These two forces acting at different points will constitute a couple and the dipole experience a torque.

(iii) This torque tends to rotate the dipole. The total torque on the dipole about the point O.

$$\vec{\tau} = \vec{OA} \times \left|-q\vec{E}\right| + \vec{OB} \times q\vec{E}$$

Using right-hand corkscrew rule, it is found that total torque is perpendicular to the plane of the paper and is directed into it.

The magnitude of the total torque

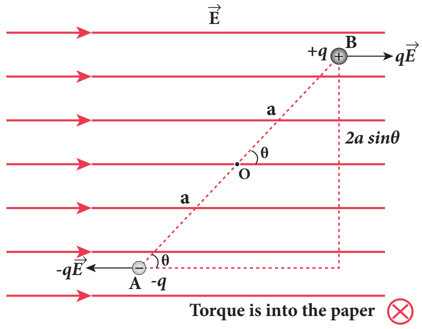
$$\tau = |\vec{OA}|\left|(-q\vec{E})\right|\sin\theta + |\vec{OB}||q\vec{E}|\sin\theta$$

$$\tau = qE \,.\, 2a\sin\theta\,;$$

where θ is the angle made by $\vec{p}$ with $\vec{E}$. Since $p = 2aq$, the torque is written in terms of the vector product as $\vec{\tau} = \vec{p} \times \vec{E}$,

The magnitude of this torque is $\tau = PE\sin\theta$ and is maximum when $\theta = 90°$.

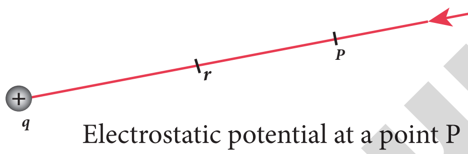
This torque tends to rotate the dipole and align it with the electric field $\vec{E}$. Once $\vec{p}$ is aligned with $\vec{E}$, the total torque on the dipole becomes zero.



Torque on dipole

6. Derive an expression for electrostatic potential due to a point charge. *[Mar-2023]*

***Ans.* (i)** Consider a positive charge q kept fixed at the origin. Let P be a point at distance r from the charge q. This is shown in Figure.



Electrostatic potential at a point P

(ii) The electric potential at the point P is

$$V = \int_{\infty}^{r} \left(-\vec{E}\right) \cdot d\vec{r} = -\int_{\infty}^{r} \vec{E} \cdot d\vec{r} \qquad ...(1)$$

Electric field due to positive point charge q is

$$\vec{E} = \frac{1}{4\pi\varepsilon_0} \frac{q}{r^2} \hat{r}$$

$$V = \frac{-1}{4\pi\varepsilon_0} \int_{\infty}^{r} \frac{q}{r^2} \hat{r} . d\vec{r}$$

The infinitesimal displacement vector, $d\vec{r} = dr\hat{r}$ and using $\hat{r} . \hat{r} = 1$, we have

$$V = -\frac{1}{4\pi\varepsilon_0} \int_{\infty}^{r} \frac{q}{r^2} \hat{r} . dr\hat{r} = -\frac{1}{4\pi\varepsilon_0} \int_{\infty}^{r} \frac{q}{r^2} dr$$

After the integration,

$$V = -\frac{1}{4\pi\varepsilon_0} q \left\{-\frac{1}{r}\right\}_{\infty}^{r} = \frac{1}{4\pi\varepsilon_0} \frac{q}{r}$$

Hence the electric potential due to a point charge q at a distance r is

$$V = \frac{1}{4\pi\varepsilon_0} \frac{q}{r} \qquad ...(2)$$

Important points :

(i) If the source charge q is positive, $V > 0$. If q is negative, then V is negative and equal to

$$V = \frac{1}{4\pi\varepsilon_0} \frac{q}{r}$$

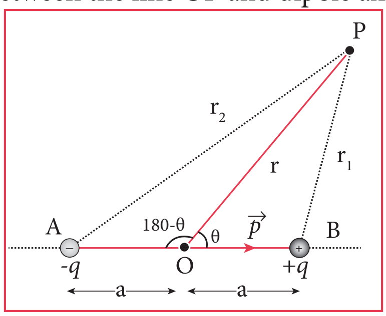
(ii) It is clear that the potential due to positive charge decreases as the distance increases, but for a negative charge the potential increases as the distance is increased. At infinity, ($r = \infty$) electrostatic potential is zero ($V = 0$).

(iii) A positive charge moves from a point of higher electrostatic potential to a point of lower electrostatic potential and a negative charge moves from lower electrostatic potential to higher electrostatic potential.

(iv) The electric potential at a point P due to a collection of charges $q_1, q_2, q_3 \ldots . q_n$ is equal to sum of the electric potentials due to individual charges.

7. Derive an expression for electrostatic potential due to an electric dipole. *[PTA-2,4 ; QY; HY-2019; May-2022; June & QY-'24]*

***Ans.* (i)** Consider two equal and opposite charges separated by a small distance 2a. The point P is located at a distance r from the midpoint of the dipole. Let θ be the angle between the line OP and dipole axis AB.



Potential due to electric dipole

(ii) Let r_1 be the distance of point P from $+q$ and r_2 be the distance of point P from $-q$.

Potential at P due to change $+q = \dfrac{1}{4\pi\varepsilon_0} \dfrac{q}{r_1}$

Potential at P due to change $-q = -\dfrac{1}{4\pi\varepsilon_0} \dfrac{q}{r_2}$

Total potential at at the point P,

$$V=\frac{1}{4\pi\varepsilon_0}q\left(\frac{1}{r_1}-\frac{1}{r_2}\right) \quad ...(1)$$

(iii) By the cosine law for triangle BOP,

$$r_1^2 = r^2 + a^2 - 2ra\cos\theta$$

$$r_1^2 = r^2\left(1+\frac{a^2}{r^2}-\frac{2a}{r}\cos\theta\right)$$

Since $r >> a$, Neglecting $\frac{a^2}{r^2}$

$$r_1^2 = r^2\left(1-2a\frac{\cos\theta}{r}\right)$$

$$\text{(or) } r_1 = r\left(1-\frac{2a}{r}\cos\theta\right)^{\frac{1}{2}}$$

$$\frac{1}{r_1}=\frac{1}{r}\left(1-\frac{2a}{r}\cos\theta\right)^{\frac{1}{2}}$$

(iv) Using binomial theorem, we get,

$$\frac{1}{r_1}=\frac{1}{r}\left(1+\frac{a}{r}\cos\theta\right) \quad ...(2)$$

Similarly applying the cosine law for triangle AOP,

$$r_2^2 = r^2 + a^2 - 2ra\cos(180-\theta)$$

Since $\cos(180 - \theta) = -\cos\theta$ we get

$$r_2^2 = r^2 + a^2 + 2ra\cos\theta$$

Neglecting $\frac{a^2}{r^2}$ (because $r>>a$)

$$r_2^2 = r^2\left(1+\frac{2a\cos\theta}{r}\right)$$

$$r_2 = r\left(1+\frac{2a\cos\theta}{r}\right)^{\frac{1}{2}}$$

Using Binomial theorem, we get

$$\frac{1}{r_2}=\frac{1}{r}\left(1-a\frac{\cos\theta}{r}\right) \quad ...(3)$$

Substituting equation (3) and (2) in equation (1),

$$V=\frac{1}{4\pi\varepsilon_0}q\left(\frac{1}{r}\left(1+a\frac{\cos\theta}{r}\right)-\frac{1}{r}\left(1-a\frac{\cos\theta}{r}\right)\right)$$

$$V=\frac{1}{4\pi\varepsilon_0}\frac{2aq}{r^2}\cos\theta$$

(v) $p = 2qa$,

$$V=\frac{1}{4\pi\varepsilon_0}\left(\frac{p\cos\theta}{r^2}\right)$$

Special cases

Case (i) If the point P lies on the axial line of $+q$ side, then $\theta = 0$, then

$$V=\frac{1}{4\pi\varepsilon_0}\frac{p}{r^2} \quad ...(4)$$

Case (ii) If the point P lies on $-q$ side then $\theta = 180^\circ$, then

$$V=-\frac{1}{4\pi\varepsilon_0}\frac{p}{r^2} \quad ...(5)$$

Case (iii) If the point P lies on the equatorial line, then $\theta = 90^\circ$. Hence

$$V = 0 \quad ...(6)$$

8. Obtain an expression for potential energy due to a collection of three point charges which are separated by finite distances.

Ans. **(i)** The electric potential at a point at a distance r from point charge q_1 is given by

$$V=\frac{1}{4\pi\varepsilon_0}\frac{q_1}{r}$$

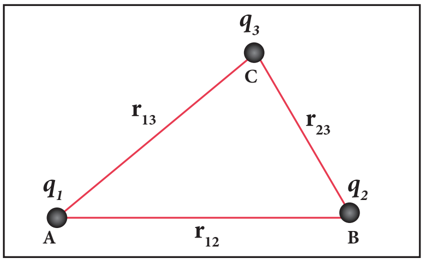
(ii) This potential V is the work done to bring a unit positive charge from infinity to the point. Now if the charge q_2 is brought from infinity to that point at a distance r from q_1, the work done is the product of q_2 and the electric potential at that point. Thus we have

$$W = q_2 V$$

(iii) This work done is stored as the electrostatic potential energy U of a system of charges q_1 and q_2 separated by a distance r. Thus we have

$$U=q_2 V=\frac{1}{4\pi\varepsilon_0}\frac{q_1q_2}{r} \quad ...(1)$$

(iv) Three charges are arranged in the following configuration as shown in Figure.



Electrostatic potential energy for Collection of point charges

Unit 1

(a) Bringing a charge q_1 from infinity to the point A requires no work, because there are no other charges already present in the vicinity of charge q_1.

(b) To bring the second charge q_2 to the point B, work must be done against the electric field created by the charge q_1. So the work done on the charge q_2 is $W = q_2 V_{1B}$. Here V_{1B} is the electrostatic potential due to the charge q_1 at point B.

$$U_I = \frac{1}{4\pi\varepsilon_0}\frac{q_1q_2}{r_{12}} \quad ...(2)$$

(c) Similarly to bring the charge q_3 to the point C, work has to be done against the total electric field due to both charges q_1 and q_2. So the work done to bring the charge q_3 is $= q_3 (V_{1C} + V_{2C})$. Here V_{1C} is the electrostatic potential due to charge q_1 at point C and V_{2C} is the electrostatic potential due to charge q_2 at point C.

The electrostatic potential energy is

$$U_{II} = \frac{1}{4\pi\varepsilon_0}\left(\frac{q_1q_3}{r_{13}}+\frac{q_2q_3}{r_{23}}\right) \quad ...(3)$$

(d) Adding equations (2) and (3), the total electrostatic potential energy for the system of three charges q_1, q_2 and q_3 is $U = U_I + U_{II}$

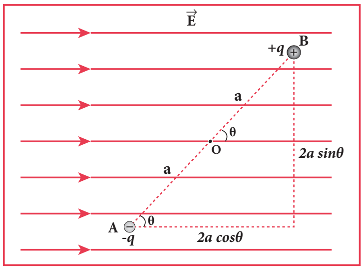
$$U = \frac{1}{4\pi\varepsilon_0}\left(\frac{q_1q_2}{r_{12}}+\frac{q_1q_3}{r_{13}}+\frac{q_2q_3}{r_{23}}\right) \quad ...(4)$$

This stored potential energy U is equal to the total external work done to assemble the three charges at the given locations.

(e) Electrostatic potential energy is independent of the configuration of charges since coulomb force is a conservative one.

9. Derive an expression for electrostatic potential energy of the dipole in a uniform electric field.

Ans. **(i)** Consider a dipole placed in the uniform electric field $\vec{E}$. A dipole experiences a torque when kept in a uniform electric field $\vec{E}$. This torque rotates the dipole to align it with the direction of the electric field. To rotate the dipole (at constant angular velocity) from its initial angle θ′ to another angle θ against the torque exerted by the electric field, an equal and opposite external torque must be applied on the dipole.



The dipole in a uniform electric field

(ii) The work done by the external torque to rotate the dipole at constant angular velocity is

$$W = \int_{\theta'}^{\theta} \tau_{ext}\, d\theta \quad ...(1)$$

(iii) Since $\vec{\tau}_{ext}$ is equal and opposite to $\vec{\tau}_E = \vec{p}\times\vec{E}$, We have

$$\left|\vec{\tau}_{ext}\right| = \left|\vec{\tau}_E\right| = \left|\vec{p}\times\vec{E}\right| \quad ...(2)$$

Substituting equation (2) in equation (1), we get

$$W = \int_{\theta'}^{\theta} pE\sin\theta\, d\theta$$

$$W = pE\,(\cos\theta' - \cos\theta)$$

(iv) This work done is equal to the potential energy difference. Between the angular positions θ and θ′.

$U(\theta) - U(\theta') = \Delta U = -pE\cos\theta + pE\cos\theta'$

If the initial angle is $\theta' = 90°$, then $U(\theta') = pE \cos 90° = 0$.

'U' also depends on the orientation 'θ' other than $\vec{p}$ and $\vec{E}$.

$$U = -pE\cos\theta = -\vec{p}\cdot\vec{E} \quad ...(3)$$

(v) The potential energy is maximum when the dipole is aligned anti-parallel (θ = π) and minimum when the dipole is aligned parallel (θ = 0) to the external electric field.

10. Obtain Gauss law from Coulomb's law.

[Sep-2020; Mar. & HY-'24]

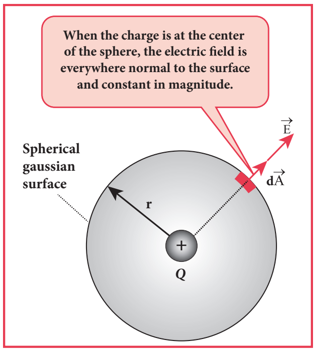
Ans. **(i)** A positive point charge Q is surrounded by an imaginary sphere of radius *r* as shown in the figure. We can calculate the total electric flux through the closed surface of the sphere

$$\Phi_E = \oint \vec{E}\cdot d\vec{A} = \oint E\, dA\cos\theta \quad ...(1)$$

ELECTROSTATICS

(ii) The electric field of the point charge is directed radially outward at all points on the surface of the sphere. Therefore, the direction of the area element $d\vec{A}$ is along the electric field $\vec{E}$ and $\theta = 0°$.

$\therefore \Phi_E = \oint E\,dA$ since $\cos 0° = 1$ ...(2)



E is uniform on the surface of the sphere,

$\because \oint dA = 4\pi r^2$

$\therefore \Phi_E = 4\pi r^2 E$ and $E = \dfrac{1}{4\pi\varepsilon_0}\cdot\dfrac{Q}{r^2}$

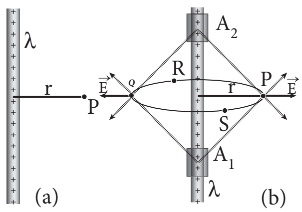
$$\Phi_E = \frac{1}{4\pi\varepsilon_0}\cdot\frac{Q}{r^2} \times 4\pi r^2 = 4\pi \frac{1}{4\pi\varepsilon_0} Q$$

$$\Phi_E = \frac{Q}{\varepsilon_0} \quad ...(3)$$

The equation (3) is called as Gauss's law and is true for any arbitrary shaped surface that encloses 'Q' and total electric flux is same for all surfaces.

11. Obtain the expression for electric field due to an infinitely long charged wire. *[PTA-1; Mar.2020; QY-'24]*

***Ans.* (i)**
- ➢ λ - Linear charge density of an infinitely long, uniformly charged wire, r - distance between wire and point 'P'.
- ➢ A_1, A_2 two charge elements.
- ➢ The resultant 'E' due to A_1 and A_2, act radially outward and is same at all points.
- ➢ r & L radius & length of cylindrical Gaussian surface of radius 'r'.



Electric field due to infinite long charged wire

(ii) The total electric flux

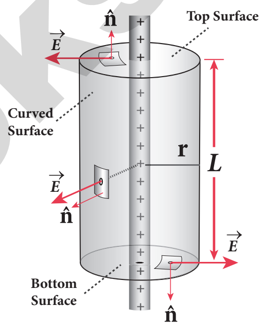
$$\Phi_E = \oint \vec{E}\cdot d\vec{A}$$

$$\underset{\text{Curved surface}}{\oint \vec{E}\cdot d\vec{A}} + \underset{\text{top surface}}{\oint \vec{E}\cdot d\vec{A}} + \underset{\text{bottom surface}}{\oint \vec{E}\cdot d\vec{A}} \quad ...(1)$$

(iii) For the curved surface, $\vec{E} \parallel \vec{A}$ and $\vec{E}\cdot d\vec{A}$ = E dA. For the top and bottom surfaces, $\vec{E} \perp r\ \vec{A}$ and $\vec{E}\cdot d\vec{A} = 0$

Applying Gauss law to the cylindrical surface,

$$\phi_E = \underset{\text{Curved surface}}{\int} E\cdot dA = \frac{Q_{encl}}{\varepsilon_0} \quad ...(2)$$



Cylindrical Gaussian surface

(vi) Since E is constant, $Q_{encl} = \lambda L$.

$$E\underset{\text{Curved surface}}{\int} dA = \frac{\lambda L}{\varepsilon_0} \quad ...(3)$$

But $\int dA$ = Total area of the curved surface = $2\pi r l$.

$$\therefore E \cdot 2\pi r L = \frac{\lambda L}{\varepsilon_0}$$

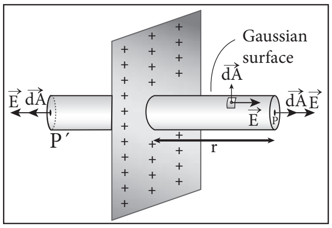
$$E = \frac{1}{2\pi\varepsilon_0}\frac{\lambda}{r} \quad \text{(or)}$$

In vector form $\vec{E} = \dfrac{1}{2\pi\varepsilon_0}\dfrac{\lambda}{r}\hat{r}$ and is true for an infinitely long wire.

12. Obtain the expression for electric field due to a charged infinite plane sheet.

***Ans.* Electric field due to charged infinite plane sheet :**

(i) Consider an infinite plane sheet of charges with uniform surface charge density σ (charge present per unit area). Let P be a point at a distance of r from the sheet.



Electric field due to charged infinite planar sheet

(ii) Since the plane is infinitely large, the electric field should be same at all points equidistant from the plane and radially directed outward at all points. A cylindrical Gaussian surface of length $2r$ and two flats surfaces each of area A is chosen such that the infinite plane sheet passes perpendicularly through the middle part of the Gaussian surface.

Total electric flux linked with the cylindrical surface,

$$\phi_E = \oint \vec{E} \cdot d\vec{A}$$

$$= \int_{\text{Curved surface}} \vec{E} \cdot d\vec{A} + \int_P \vec{E} \cdot d\vec{A} + \int_{P'} \vec{E} \cdot d\vec{A} = \frac{Q_{encl}}{\varepsilon_0} \quad ...(1)$$

(iii) The E is perpendicular to the area element on the curved surface at all points

Then, E is parallel to $\vec{A}$ at P & P'.

$$\phi_E = \int_P E\,dA + \int_{P'} E\,dA = \frac{Q_{encl}}{\varepsilon_0} \quad ...(2)$$

(iv) $\therefore \; Q_{encl} = \sigma A$,

$$2E\int_P dA = \frac{\sigma A}{\varepsilon_0}$$

The total area of surface either at P or P'

$$\int_P dA = A$$

$$\text{Hence } 2EA = \frac{\sigma A}{\varepsilon_0} \text{ or } E = \frac{\sigma}{2\varepsilon_0} \quad ...(3)$$

$$\text{or } \vec{E} = \frac{\sigma}{2\varepsilon_0}\hat{n} \quad ...(4)$$

Here $\hat{n}$ is the outward unit vector normal to the plane.

The electric field will be the same at any point farther away from the charged plane. Equation (4) implies that if $\sigma > 0$ the electric field at any point P is along outward perpendicular $\hat{n}$ drawn to the plane and if $\sigma < 0$, the electric field points inward perpendicularly to the plane ($-\hat{n}$).

For a finite charged plane sheet, equation(4) is approximately true only in the middle region of the plane and at points far away from both ends.

13. Obtain the expression for electric field due to a uniformly charged spherical shell. *[Govt. MQP-2019]*

Ans. Electric field due to a uniformly charged spherical shell :

Consider a uniformly charged spherical shell of radius - R, Total charge - Q

(a) At a point outside the shell (r > R) :

P is a point outside the shell at a distance r from the centre. The charge is uniformly distributed on the surface of the sphere.

(i) If Q > 0, field point radially outward.

If Q < 0, field point radially inward.

Applying Gauss law

$$\oint_{\text{Gaussian surface}} \vec{E}.\overline{dA} = \frac{Q}{\varepsilon_0} \quad ...(1)$$

$\vec{E}$ and $\overline{dA}$ are in the same direction at all points.

Hence $E\oint_{\text{Gaussian surface}} dA = \frac{Q}{\varepsilon_0}$

But $\oint dA$ = total area of Gaussian surface $= 4\pi r^2$

Substituting in (1)

$$E.\,4\pi r^2 = \frac{Q}{\varepsilon_0} \text{ (or) } E = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2}$$

In vector from $\vec{E} = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2}.\hat{r}$

E at a point outside the shell will be the same and entire charge 'Q' is concentrated at the centre.

(b) At a point on the surface of the spherical shell (r = R). Electric field at points on the spherical shell, is $r = R$

$$\vec{E} = \frac{Q}{4\pi\varepsilon_0 R^2}.\hat{r}$$

(c) At a point inside the shell (r < R) :

Consider a point P inside the shell at a distance r from the center.

$$\oint_{\substack{\text{Gaussian}\\\text{surface}}} \vec{E}.\vec{dA} = \frac{Q}{\varepsilon_0}$$

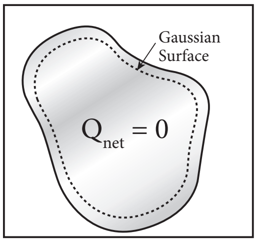
$$E \cdot 4\pi r^2 = \frac{Q}{\varepsilon_0}$$

Since Gaussian surface encloses no charge, so Q = 0.

$\therefore E = 0$. The electric field due to the uniformly charged spherical shell is zero at all points inside the shell.

14. Discuss the various properties of conductors in electrostatic equilibrium.

Ans. **(i)** The Electric Field is zero everywhere inside the conductor. This is true regardless of whether the conductor is solid or hallow.



No net charge inside the conductor

(ii) There is no net charge inside the conductors. The charges must reside only on the surface of the conductors.

(iii) The Electric Field outside the conductor is perpendicular to the surface of the conductor and has a magnitude of $\frac{\sigma}{\varepsilon_0}$ where σ is the surface charge density at the point (i.e. $E \propto \sigma$)

(iv) The electrostatic potential has the same value on the surface and inside of the conductor. Potential is constant within and on the surface of a conductor.

15. Explain the process of electrostatic induction.

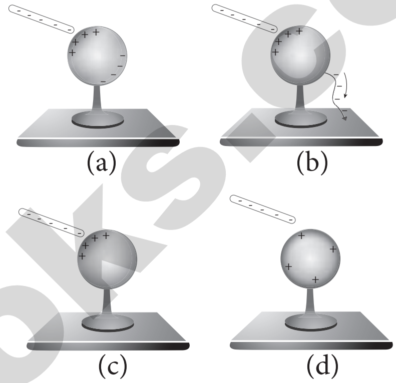
Ans. Charging without actual contact is called electrostatic induction.

(i) Consider an uncharged (neutral) conducting sphere at rest on an insulating stand. Suppose a negatively charged rod is brought near the conductor without touching it, as shown in Figure (a).

The negative charge of the rod repels the electrons in the conductor to the opposite side. As a result, positive charges are induced near the region of the charged rod while negative charges on the farther side.

Before introducing the charged rod, the free electrons were distributed uniformly on the surface of the conductor and the net charge is zero.

Once the charged rod is brought near the conductor, the distribution is no longer uniform with more electrons located on the farther side of the rod and positive charges are located closer to the rod. But the total charge is zero.



Various steps in electrostatic induction

(ii) Now the conducting sphere is connected to the ground through a conducting wire. This is called grounding. Since the ground can always receive any amount of electrons, grounding removes the electron from the conducting sphere.

Note that positive charges will not flow to the ground because they are attracted by the negative charges of the rod (Figure (b)).

(iii) When the grounding wire is removed from the conductor, the positive charges remain near the charged rod (Figure (c))

(iv) Now the charged rod is taken away from the conductor. As soon as the charged rod is removed, the positive charge gets distributed uniformly on the surface of the conductor (Figure (d)). By this process, the neutral conducting sphere becomes positively charged.

16. Explain dielectrics in detail and how an electric field is induced inside a dielectric.

Ans. **Induced Electric field inside the dielectric:**

(i) A dielectric, has no free electrons, the external electric field only realigns the charges so that an internal electric field is produced.

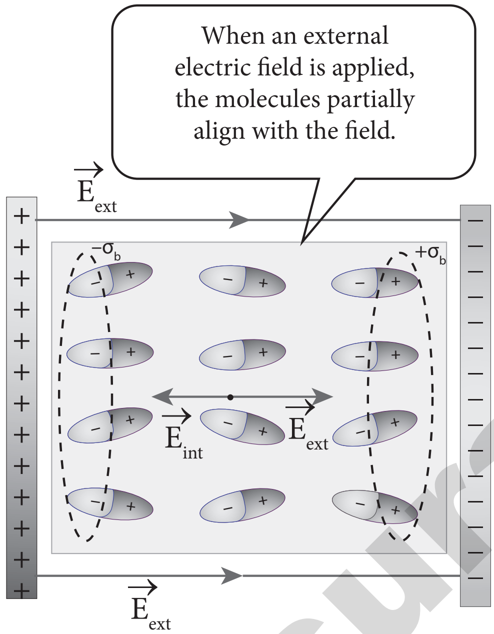
(ii) The magnitude of the internal electric field is smaller than that of external electric field.

(iii) Therefore the net electric filed inside the dielectric is not zero but is parallel to an external electric field with magnitude less than that of the external electric field.

(iv) For example, let us consider a rectangular dielectric slab placed between two oppositely charged plates (capacitor).

(v) The uniform electric field between the plates acts as an external electric field $\vec{E}_{ext}$ which polarizes the dielectric placed between plates.

(vi) The positive charges are induced on one side surface and negative charges are induced on the other side of surface.



Induced electric field lines inside the dielectric

(vii) But inside the dielectric, the net charge is zero even in a small volume.

(viii) So the dielectric in the external field is equivalent to two oppositely charged sheets with the surface charge densities $+\sigma_b$ and $-\sigma_b$.

(ix) These charges are called bound charges. They are not free to move like free electrons in conductors.

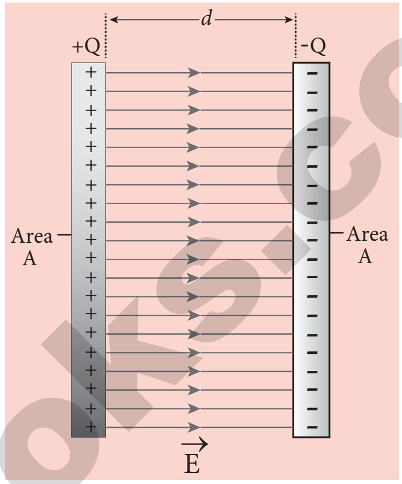
17. Obtain the expression for capacitance for a parallel plate capacitor. *[PTA-2; HY-'23]*

Ans. **Capacitance of a parallel plate capacitor**

Consider a capacitor with two parallel plates,
A - Area of each plate
d - Distance between the plates

σ - surface charge density on the plates $\sigma = \frac{Q}{A}$

If the separation distance d is very much smaller than the size of the plate (d^2 << A), then the above result can be used even for finite–sized parallel plate capacitor.



Capacitance of a parallel plate capacitor

The Electric Field between the plates is

$$E = \frac{Q}{A\varepsilon_0} \qquad ...(1)$$

Since the Electric Field is uniform, the electrical potential between the plates $V = Ed = \frac{Qd}{A\varepsilon_0}$ ...(2)

∴ Capacitance of the capacitor

$$C = \frac{Q}{V} = \frac{Q}{\left(\frac{Qd}{A\varepsilon_0}\right)} = \frac{\varepsilon_0 A}{d} \qquad ....(3)$$

From equation (3), it is evident that capacitance is directly proportional to the area of cross section and is inversely proportional to the distance between the plates.

18. Obtain the expression for energy stored in the parallel plate capacitor.

[Aug-2021; FRT, July-'22; QY-'23 & '24]

Ans. The capacitor not only stores the charge but also it stores energy.

When battery is connected to the capacitor, electrons of total charge - Q are transferred from one plate to another.

To transfer the charge, work is done by the battery. This work done is stored as Electrostatic Potential energy in the capacitor.

dQ - Infinitesimal charge

V - potential difference

Work done $dW = V.dQ$ .....(1)

where $V = \frac{Q}{C}$

The total work done to charge the capacitor is

$$W = \int_0^Q \frac{Q}{C}.dQ = \frac{Q^2}{2C} \quad .....(2)$$

This work done is stored as Electrostatic Potential Energy (U_E) in the capacitor

$$U_E = \frac{Q^2}{2C} = \frac{1}{2}.CV^2 \quad .....(3)$$

$[\because Q = CV]$

where Q = CV is used. This stored energy is thus directly proportional to the capacitance of the capacitor and the square of the voltage between the plates of the capacitor.

$$U_E = \frac{1}{2}\left(\frac{\varepsilon_0 A}{d}\right)(Ed)^2 = \frac{1}{2}.\varepsilon_0.(Ad)E^2 \quad .....(4)$$

where Ad = volume of the space between the capacitor plates. The energy stored per unit volume of space is defined as energy density

$U_E = \frac{U}{\text{Volume}}$ From equation (4), we get

$$u_E = \frac{1}{2}\varepsilon_0 E^2 \quad .....(5)$$

From equation (5), we infer that the energy is stored in the electric field existing between the plates of the capacitor. Once the capacitor is allowed to discharge, the energy is retrieved.

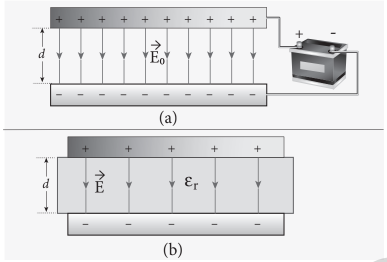
19. Explain in detail the effect of a dielectric placed in a parallel plate capacitor. *[PTA-6; Sep-2020]*

Ans. (a) When the capacitor is disconnected from the battery: *[FRT-'22]*

(i) Consider a capacitor with two parallel plates each of cross-sectional area *A* and are separated by a distance *d*. The capacitor is charged by a battery of voltage V_0 and the charge stored is Q_0. The capacitance of the capacitor without the dielectric is

$$C_0 = \frac{Q_0}{V_0}$$

(ii) The battery is then disconnected from the capacitor and the dielectric is inserted between the plates.



a) Capacitor is charged with a battery
b) Dielectric is inserted after the battery is disconnected.

(iii) The introduction of dielectric between the plates will decrease the electric field. Experimentally it is found that the modified electric field is given by

$$E = \frac{E_0}{\varepsilon_r}$$

(iv) Where E_0 is the electric field inside the capacitors when there is no dielectric and ε_r is the relative permittivity of the dielectric or simply known as the dielectric constant. Since $\varepsilon_r > 1$, the electric field $E < E_0$.

(v) As a result, the electrostatic potential difference between the plates ($V = Ed$) is also reduced. But at the same time, the charge Q_0 will remain constant once the battery is disconnected. Hence the new potential difference is

$$V = Ed = \frac{E_0}{\varepsilon_r}d = \frac{V_0}{\varepsilon_r}$$

(vi) We know that capacitance is inversely proportional to the potential difference. Therefore as V decreases, C increases.

(vii) Thus new capacitance in the presence of a dielectric is

$$C = \frac{Q_0}{V} = \varepsilon_r \frac{Q_0}{V_0} = \varepsilon_r C_0$$

(viii) Since $\varepsilon_r > 1$, we have $C > C_0$. Thus insertion of the dielectric increases the capacitance.

$$C = \frac{\varepsilon_r \varepsilon_0 A}{d} = \frac{\varepsilon A}{d}$$

(ix) Where $\varepsilon = \varepsilon_r \varepsilon_0$ is the permittivity of the dielectric medium.

(x) The energy stored in the capacitor before the insertion of a dielectric is given by

$$U_0 = \frac{1}{2}\frac{Q_0^2}{C_0}$$

(xi) After the dielectric is inserted, the charge Q_0 remains constant but the capacitance is increased. As a result, the stored energy is decreased.

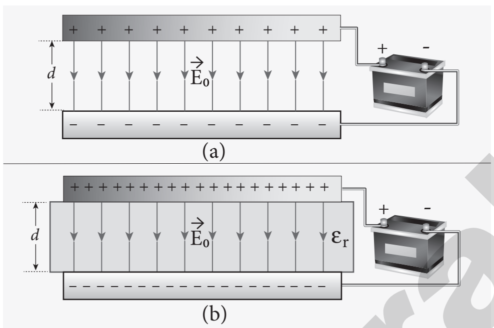
$$U=\frac{1}{2}\frac{Q_0^2}{C}=\frac{1}{2}\frac{Q_0^2}{\varepsilon_r C_0}=\frac{U_0}{\varepsilon_r}$$

(xii) Since $\varepsilon_r > 1$, we get $U < U_0$. There is a decrease in energy because, when the dielectric is inserted, the capacitor spends some energy in pulling the dielectric inside.

(b) When the battery remains connected to the capacitor:

(i) Let us now consider what happens when the battery of voltage V_0 remains connected to the capacitor when the dielectric is inserted into the capacitor.

The potential difference V_0 across the plates remains constant. But it is found experimentally that when dielectric is inserted, the charge stored in the capacitor is increased by a factor ε_r.



a) Capacitor is charged through a battery
b) Dielectric is inserted when the battery is connected.

$$Q = \varepsilon_r Q_0$$

(ii) Due to this increased charge, the capacitance is also increased. The new capacitance is

$$C=\frac{Q}{V_0}=\varepsilon_r\frac{Q_0}{V_0}=\varepsilon_r C_0$$

(iii) However the reason for the increase in capacitance in this case when the battery remains connected is different from the case when the battery is disconnected before introducing the dielectric.

Now, $C_0=\frac{\varepsilon_0 A}{d}$ and $C=\frac{\varepsilon A}{d}$

(iv) The energy stored in the capacitor before the insertion of a dielectric is given by

$$U_0=\frac{1}{2}C_0V_0^2$$

(v) After the dielectric is inserted, the capacitance is increased; hence the stored energy is also increased.

$$U=\frac{1}{2}CV_0^2=\frac{1}{2}\varepsilon_r C_0V_0^2=\varepsilon_r U_0$$

Since $\varepsilon_r > 1$ we have $U > U_0$.

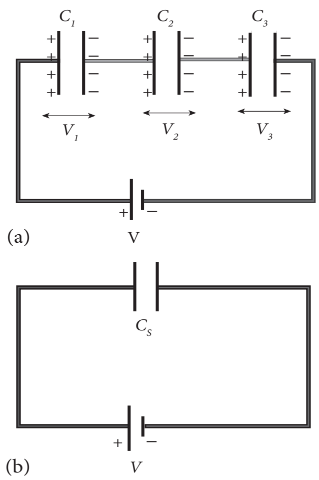
(vi) It may be noted here that since voltage between the capacitor V_0 is constant, the electric field between the plates also remains constant.

20. Derive the expression for resultant capacitance, when capacitors are connected in series and in parallel.

Ans. **Capacitors in series :** *[May-2022]*

(i) Consider three capacitors of capacitance C_1, C_2 and C_3 connected in series with a battery of voltage V as shown in the Figure.

(ii) As soon as the battery is connected to the capacitors in series, the electrons of charge –Q are transferred from negative terminal to the right plate of C_3 which pushes the electrons of same amount –Q from left plate of C_3 to the right plate of C_2 due to electrostatic induction. At the same time, electrons of charge –Q are transferred from left plate of C_1 to positive terminal of the battery.



(a) Capacitors connected in series
(b) Equivalent capacitors C_s

(iii) The capacitances of the capacitors are in general different, so that the voltage across each capacitor is also different and are denoted as V_1, V_2 and V_3 respectively. The sum of the voltages across the capacitor must be equal to the voltage of the battery.

$V = V_1 + V_2 + V_3$ ...... (1)

Since $Q = CV$; $V = \frac{Q}{C_1} + \frac{Q}{C_2} + \frac{Q}{C_3}$

$= Q\left(\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}\right)$ ...... (2)

(iv) If three capacitors in series are considered to form an equivalent single capacitor C_s shown in Figure (b), then we have $V = \frac{Q}{C_s}$. Substituting this expression into equation (2), we get

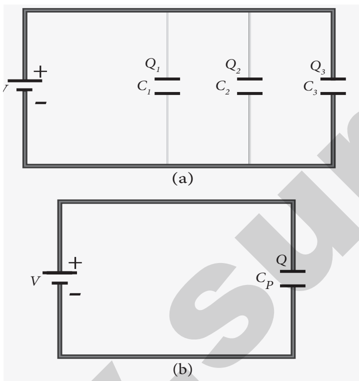
$$\frac{Q}{C_s} = Q\left(\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}\right)$$

$$\frac{1}{C_s} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} \quad \text{...... (3)}$$

This equivalent capacitance C_S is always less than the smallest individual capacitance in the series.

Capacitance in parallel :

Consider three capacitors of capacitance C_1, C_2 and C_3 connected in parallel with a battery of voltage V as shown in Figure (a).



(a) Capacitors in parallel
(b) Equivalent capacitance with the same total charge

Since capacitances of the capacitors are different, the charge stored in each capacitor is not the same. Let the charge stored in the three capacitors be Q_1, Q_2, and Q_3 respectively. According to the law of conservation of total charge, the sum of these three charges is equal to the charge Q transferred by the battery,

$Q = Q_1 + Q_2 + Q_3$ ...... (1)

Since $Q = CV$, we have

$Q = C_1V + C_2V + C_3V$ ...... (2)

If these three capacitors are considered to form a single equivalent capacitance C_p which stores the total charge Q as shown in the Figure(b), then we can write $Q = C_pV$. Substituting this in equation (2), we get

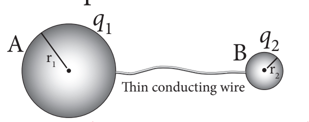
$C_pV = (C_1V + C_2V + C_3V)$

$C_p = C_1 + C_2 + C_3$

Thus, the equivalent capacitance of capacitors connected in parallel is equal to the sum of the individual capacitances. The equivalent capacitance C_p in a parallel connection is always greater than the largest individual capacitance.

21. Explain in detail how charges are distributed in a conductor, and the principle behind the lightning conductor.

Ans. **(i)** Consider two conducting spheres A and B of radii r_1 and r_2 respectively connected to each other by a thin conducting wire as shown in the Figure. The distance between the spheres is much greater than the radii of either spheres.



Two conductors are connected through conducting wire

(ii) If a charge Q is introduced into any one of the spheres, this charge Q is redistributed into both the spheres such that the electrostatic potential is same in both the spheres. Let q_1 be the charge residing on the surface of sphere A and q_2 is the charge residing on the surface of sphere B such that $Q = q_1 + q_2$.

The electrostatic potential at the surface of the sphere A is given by

$$V_A = \frac{1}{4\pi\varepsilon_0}\frac{q_1}{r_1} \quad \text{...(1)}$$

(iii) The electrostatic potential at the surface of the sphere B is given by

$$V_B = \frac{1}{4\pi\varepsilon_0}\frac{q_2}{r_2} \quad \text{...(2)}$$

(iv) The surface of the conductor is an equipotential. Since the spheres are connected by the conducting wire, the surfaces of both the spheres together form an equipotential surface. This implies that

$$V_A = V_B$$

or $$\frac{q_1}{r_1} = \frac{q_2}{r_2} \quad ...(3)$$

(v) Let the charge density on the surface of sphere A be σ_1 and that on the surface of sphere B be σ_2. This implies that $q_1 = 4\pi r_1^2\sigma_1$ and $q_2 = 4\pi r_2^2\sigma_2$. Substituting these values into equation (3), we get

$$\sigma_1 r_1 = \sigma_2 r_2 \quad ...(4)$$

from which we conclude that

$$\sigma r = \text{constant} \quad ...(5)$$

(vi) Thus the surface charge density σ is inversely proportional to the radius of the sphere. For a smaller radius, the charge density will be larger and vice versa.

Lightning conductors :

(i) This is a device used to protect tall buildings from lightning strikes. It works on the principle of action at points or corona discharge.

(ii) This device consists of a long thick copper rod passing from top of the building to the ground. The upper end of the rod has a sharp spike or a sharp needle.

(iii) The lower end of the rod is connected to copper plate which is buried deep into the ground. When a negatively charged cloud is passing above the building, it induces a positive charge on the spike.

(iv) Since the induced charge density on thin sharp spike is large, it results in a corona discharge. This positive charge ionizes the surrounding air which in turn neutralizes the negative charge in the cloud.

(v) The negative charge pushed to the spikes passes through the copper rod and is safely diverted to the Earth.

(vi) The lightning arrester does not stop the lightning; rather it diverts the lightning to the ground safely.

22. Explain in detail the construction and working of a Van de Graaff generator.

[QY-2019 & '23; FRT, July-'22; June-'23]

Ans. It is a machine that produces a large amount of electrostatic potential difference of the order of 10^7 V.

Principle:

Electrostatic induction and action at points.

Construction:

(i) A large hollow spherical conductor is fixed on the insulating stand as shown in the figure.

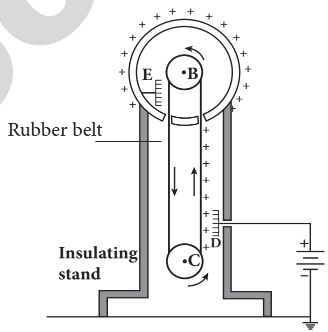
(ii) A pulley B is mounted at the centre of the hollow sphere and another pulley C is fixed at the bottom.

(iii) A belt made up of insulating materials like silk or rubber runs over both pulleys. The pulley C is driven continuously by the electric motor.

(iv) Two comb shaped metallic conductors E and D are fixed near the pulleys.

(v) The comb D is maintained at a positive potential 10^4 V by a power supply.

(vi) The upper comb E is connected to the inner side of the hollow metal sphere.



Working:

(i) Because of the high electric field near the comb D, the air gets ionized.

(ii) The negative charges in air move towards the needles and positive charges are repelled towards the belt due to action of points.

(iii) The +ve charges stick to the belt moves up end and reaches near the comb E.

(iv) E acquires negative charge and the sphere acquires positive charge due to electrostatic induction.

(v) Hence descending belt will be left uncharged.

(vi) Thus the machine, continuously transfers the positive charge to the sphere.

(vii) The leakage of charges can be reduced by enclosing it in a gas filled steel chamber at very high pressure.

(viii) The high voltage can be used to accelerate positive ions for the purpose of nuclear disintegrations and other applications.

EXERCISES :

1. When two objects are rubbed with each other, approximately a charge of 50 nC can be produced in each object. Calculate the number of electrons that must be transferred to produce this charge.

[PTA-6]

Sol.: Given: Charge produced $q = 50\ nC = 50 \times 10^{-9}$ C;

Charge of an electron $e = 1.6 \times 10^{-19}$ C

To find: No. of electrons n = ?

We know $q = ne$

$$n = \frac{q}{e} = \frac{50\times10^{-9}}{1.6\times10^{-19}} = 31.25 \times 10^{10} \text{ electrons.}$$

2. The total number of electrons in the human body is typically in the order of 10^{28}. Suppose, due to some reason, you and your friend lost 1% of this number of electrons. Calculate the electrostatic force between you and your friend separated at a distance of 1m. Compare this with your weight. Assume mass of each person is 60 kg and use point charge approximation.

Sol.: Given:

Number of electrons in human body = 10^{28}

Number of electrons in me and my friend after loss of 1% (ie)

1% of charge on 10^{28} electrons

$$= \frac{1}{100} \times 10^{28} = 10^{26} \text{ electrons.}$$

$d = r = 1m$

Charge of each person $q = ne$

∴ Charge of each person $q = 10^{26} \times 1.6 \times 10^{-19}$C

$= 1.6 \times 10^{7}$C

Electrostatic force between us is $F_e = \frac{Kq_1q_2}{r^2}$

$$= \frac{9\times10^9\times(1.6\times10^7)^2}{1^2} = 9 \times 2.56 \times 10^9 \times 10^{14}$$

$F_e = 23.04 \times 10^{23}$ N $= 23 \times 10^{23}$ N

Also mass of the person m = 60 kg

∴ weight = mg

= 60 × 9.8

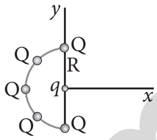
[∵ $g = 9.8$ ms^{-2}]

W = 588 N

$$\therefore \frac{F_e}{F_g} = \frac{F_e}{W} = \frac{23.04\times10^{23}}{588} = 3.9183 \times 10^{21}$$

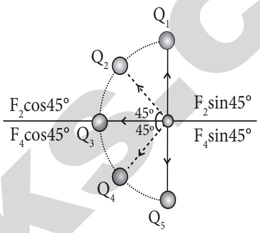
$= 3.9 \times 10^{21}$

3. Five identical charges Q are placed equidistant on a semicircle as shown in the figure. Another point charge q is kept at the centre of the circle of radius R. Calculate the electrostatic force experienced by the charge q.



Sol.:

The forces acting on q, due to Q_1 and Q_5 are F_1 and F_5. These forces are equal and opposite direction. So cancel to each other



Forces due to Q_2 and Q_4 on q is resolved into two components.

(i) Vertical component : $Q_2 \sin\theta$ and $Q_4 \sin\theta$ are equal and opposite. So they are cancel to each other.

(ii) Horizontal Component : $Q_2 \cos\theta$ and $Q_4 \cos\theta$ an equal and same direction. So they can get added.

$$\therefore F_{24} = K\frac{qQ_2}{R^2}\cos 45° + K\frac{qQ_4}{R^2}\cos 45°$$

Total force acting on q due to Q_3 is

$$F_3 = K\frac{qQ_3}{R^2}$$

Here $Q = Q_1 = Q_2 = Q_3 = Q_4 = Q_5$

Resultant net force $F = F_{15} + F_{24} + F_3$

$= 0 + F_{24} + F_3$

$= F_3 + F_{24}$

Total force

$$F = k.\frac{qQ_2}{R^2} + k.\frac{qQ_2}{R^2}.\cos45° + \frac{kqQ}{R^2}.\cos45°$$

$$= \frac{kqQ}{R^2}\left[1+\frac{2}{\sqrt{2}}\right] \quad [\because Q = Q_3 = Q_2 = Q_4]$$

In vector form,

$$\text{Total } \vec{F} = \frac{kqQ}{R^2}[1+\sqrt{2}]\hat{i}$$

$$\vec{F} = \frac{1}{4\pi\varepsilon_0}\frac{qQ}{R^2}[1+\sqrt{2}]\hat{i}\text{ N} \quad \left[\because k = \frac{1}{4\pi\varepsilon_0}\right]$$

Unit 1

4. Suppose a charge $+q$ on Earth's surface and another $+q$ charge is placed on the surface of the Moon. (a) Calculate the value of q required to balance the gravitational attraction between Earth and Moon (b) Suppose the distance between the Moon and Earth is halved, would the charge q change? (Take $m_E = 5.9 \times 10^{24}$ kg, $m_M = 7.9 \times 10^{22}$ kg)

Sol.: Given:

(a) Mass of the earth $m_E = 5.9 \times 10^{24}$ kg

Mass of the moon $m_M = 7.9 \times 10^{22}$ kg

Charge placed on earth and moon is q

To find: The amount of charge required to balance gravitational attraction between earth & moon = ?

If q is the charge placed on the moon & earth, then

$$F_e = \frac{1}{4\pi\varepsilon_0}\frac{q \times q}{r^2} \quad ...(1)$$

$$F_g = G.\frac{m_E \times m_M}{r^2} \quad ...(2)$$

$$F_e = F_g$$

$$\frac{1}{4\pi\varepsilon_0}\frac{q \times q}{r^2} = G.\frac{m_E \times m_M}{r^2}$$

$$q_2 = \frac{G\, m_E \times m_M}{\left(\frac{1}{4\pi\varepsilon_0}\right)}$$

$$q = \sqrt{\frac{G m_E \times m_M}{\left(\frac{1}{4\pi\varepsilon_0}\right)}}$$

$$q = \sqrt{\frac{6.67 \times 10^{-11} \times 5.9 \times 10^{24} \times 7.9 \times 10^{22}}{9 \times 10^9}}$$

$[\because G = 6.67 \times 10^{-11}\ Nm^{-2}\ kg^{-2}]$

$[\because \frac{1}{4\pi\varepsilon_0} = 9 \times 10^9]$

$$q = \sqrt{\frac{6.67 \times 5.9 \times 7.9 \times 10^{35}}{9 \times 10^9}}$$

$$q = \sqrt{34.532 \times 10^{26}}$$

$$q = 5.87 \times 10^{13}\ C.$$

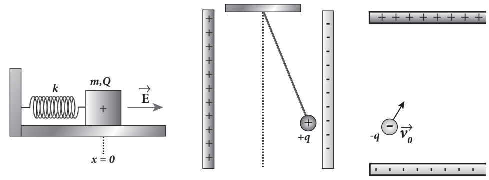
(b) To find : The distance between moon & earth is halved, the charge q = ?

$$\frac{1}{4\pi\varepsilon_0}.\frac{q_1 q_2}{\left(\frac{r}{2}\right)^2} = G.\frac{m_E.m_M}{\left(\frac{r}{2}\right)^2} \Rightarrow \frac{1}{4\pi\varepsilon_0} q_1 q_2 = G m_E m_M.$$

$\therefore q = 5.87 \times 10^3$ C (Similar to (a) part)

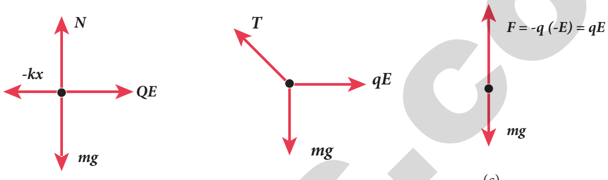
There will not be any change in the charge q.

5. Draw the free body diagram for the following charges as shown in the figure (a), (b) and (c).



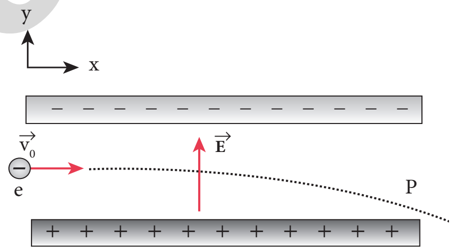
(a) (b) (c)

Sol.:



(a) (b) (c)

6. Consider an electron travelling with a speed v_o and entering into a uniform electric field $\vec{E}$ which is perpendicular to $\vec{v_o}$ as shown in the Figure. Ignoring gravity, obtain the electron's acceleration, velocity and position as functions of time.



Sol.: Given : Speed of an electrons $= v_0$

Uniform Electric field $= \vec{E}$

(a) Electron's Acceleration:

According to Newton's II law, $F = ma \Rightarrow a = \frac{F}{m}$

The force on the electrons due to uniform electric field is $F = eE \Rightarrow a = \frac{F}{m} = \frac{Ee}{m}$

Therefore the down acceleration of electron due to electric field, $a = -\frac{Ee}{m}$.

$\therefore$ Acceleration in vector form, $\vec{a} = -\frac{eE}{m}.\hat{j}$

(b) Electron's Velocity:

We know equation of motion $v = u + at$

Here speed of electron in horizontal direction $u = v_0$

$$\Rightarrow \quad v = v_0 + \left(\frac{-eE}{m}\right)t$$

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$$\Rightarrow \quad v = v_0 - \frac{-eE}{m} t$$

$\therefore$ Velocity in vector form $\vec{\upsilon} = v_0 \, \hat{i} - \frac{eE}{m} . t . \hat{j}$

(c) Position of an electron:

We know equation of motion, $s = ut + \frac{1}{2} at^2$

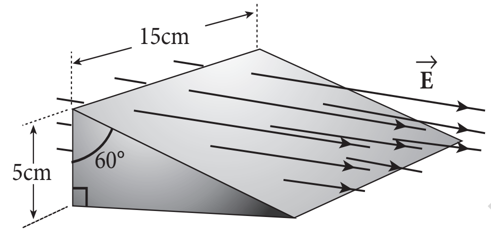
Here $s = r =$ the position of an electron, $u = v_0$

$$\therefore r = v_0 t + \frac{1}{2} \left(-\frac{eE}{m} \right) t^2 = v_0 t - \frac{eE}{2m} t^2$$

$\therefore$ Position in vector form

$$\vec{r} = v_0 t \, \hat{i} - \frac{Ee}{2m} . t^2 \, \hat{j}$$

7. A closed triangular box is kept in an electric field of magnitude E = 2 × 10³ N C⁻¹ as shown in the figure.



Calculate the electric flux through the (a) vertical rectangular surface (b) slanted surface and (c) entire surface.

Sol.: Given:

The magnitude of electric field $E = 2 \times 10^3$ NC^{-1}

Area of the surface $A = 0.15 \times 0.05$

[From the diagram l = 15 cm = 0.15 m, b = 5 cm = 0.05m]

To find:

The electric flux through

a) Vertical rectangular surface ϕ_{vert} = ?

According to Gauss law $\phi = E A \cos\theta$

$\phi_{\text{vertical surface}} = 2 \times 10^3 \times 0.15 \times 0.05 \times \cos 0°$

$= 0.015 \times 10^3 = 15$ Nm² C⁻¹

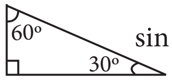
b) Electric flux through slanted surface

$\phi_{\text{slanted surface}}$ = ?

$\phi_{\text{slanted surface}} = E A \cos\theta$

$\theta = 60° \Rightarrow \cos 60° = \frac{1}{2}$

From the diagram,



$$\sin 30° = \frac{\text{opposite}}{\text{hyp}}$$

Opposite = 5 cm. $\quad \text{hyp} = \frac{\text{opposite}}{\sin 30°}$

$$\text{hyp.} = \frac{5 \times 10^{-2}}{\frac{1}{2}} = 2 \times 0.05$$

$= 0.10$ m

Area of the slanted surface

$A = (0.10 \times 0.15)$ m²

$\phi_{\text{slanted surface}} = EA\cos\theta$

$\phi_{\text{slanted surface}} = 2 \times 10^3 \times (0.10 \times 0.15) \times \cos 60°$

$= 0.015 \times 10^3 = 15$ Nm² C⁻¹

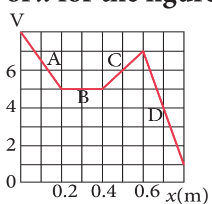
c) Entire surface ϕ_{tot} = ?

$\phi_{tot} = \phi_{vs} + \phi_{s.s} + \phi_{H.S}$ $\quad$ [Here $\phi_{H.S} = EA \cos\theta$

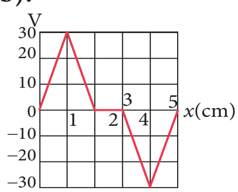
$= -15 + 15 + 0$ $\quad$ $\theta = 90°$; $\cos 90° = 0$

$\phi_{tot} = 0.$ $\quad$ $\therefore \phi_{ends} = 0$]

8. The electrostatic potential is given as a function of *x* in figure (i) and (ii). Calculate the corresponding electric fields in regions A, B, C and D. Plot the electric field as a function of *x* for the figure (b).



(a)



(b)

Sol.: (a) $E_x = -\frac{dV}{dx}\hat{i} = \frac{V_2 - V_1}{x_2 - x_1}$ (From 0 to 0.2m)

(i) Region A

$$E_x = \frac{dV}{dx} = \frac{3}{0.2} = \frac{30}{2} = -15 \text{ Vm}^{-1}$$

(ii) Region B

$$E_x = \frac{dV}{dx} = 0 \text{ (Since the potential is constant)}$$

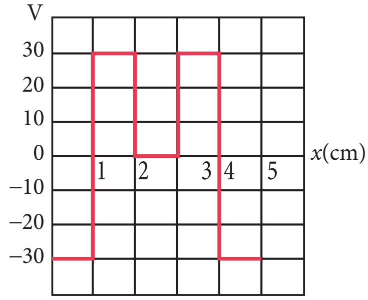
(iii) Region C

$$E_x = \frac{dV}{dx} = \frac{-2}{0.2} = \frac{-20}{2} = 10 \text{ Vm}^{-1}$$

(iv) Region D

$$E_x = \frac{dV}{dx} = \frac{6}{0.2} = \frac{60}{2} = 30 \text{ Vm}^{-1}$$

(b)



***Ans.* (b)**

$$E_x = \frac{dV}{dx} = -30\text{Vm}^{-1} \quad \text{(region 0–1 cm)}$$

$$E_x = \frac{dV}{dx} = 30\text{Vm}^{-1} \quad \text{(region 1–2 cm)}$$

$$E_x = \frac{dV}{dx} = 0 \quad \text{(region 2–3 cm)}$$

$$E_x = \frac{dV}{dx} = 30\text{Vm}^{-1} \quad \text{(region 3–4 cm)}$$

$$E_x = \frac{dV}{dx} = -30\text{Vm}^{-1} \quad \text{(region 4–5 cm)}$$

9. A spark plug in a bike or a car is used to ignite the air-fuel mixture in the engine. It consists of two electrodes separated by a gap of around 0.6 mm gap as shown in the figure.

To create the spark, an electric field of magnitude 3 × 10⁶ Vm⁻¹ is required. (a) What potential difference must be applied to produce the spark? (b) If the gap is increased, does the potential difference increase, decrease or remains the same? (c) find the potential difference if the gap is 1 mm.

***Sol.:* Given:**

(a) The distance between two electrodes $x = 0.6\text{mm}$

$= 0.6 \times 10^{-3}$ m

The magnitude of electric filed $E = 3 \times 10^6\ \text{Vm}^{-1}$

To find:

Potential difference need to produce spark

(ie) V = ?

Formula: $E = \frac{V}{x}$

$\therefore V = E\,.\,x$

$= 0.6 \times 10^{-3} \times 3 \times 10^6$

$= 1800$ V.

(b) Since V α x, we come to know when the gap is increased, potential also increases.

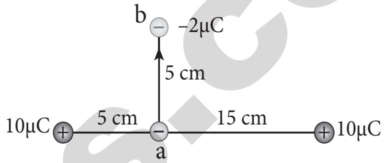
(c) The distance, $r = 1\text{ mm} = 1 \times 10^{-3}$ m

Electric field, $E = 3 \times 10^6\ \text{Vm}^{-1}$

New potential difference due to increase in the gap.

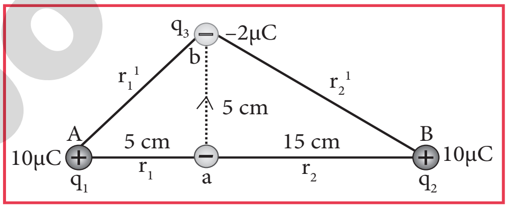
$V = E.\,d = 3 \times 10^6 \times 1 \times 10^{-3} = 3000$ V.

10. A point charge of +10 μC is placed at a distance of 20 cm from another identical point charge of +10 μC. A point charge of –2 μC is moved from point a to b as shown in the figure. Calculate the change in potential energy of the system? Interpret your result.



Sol.: $\Delta Aab = r_1' = \sqrt{5^2 + 5^2} = 5\sqrt{2}\ cm$

$\Delta aBb = r_2' = \sqrt{15^2 + 5^2} = 5\sqrt{10}$ cm



$$V = \frac{1}{4\pi\varepsilon_0}\left[\frac{q_1}{r_1} + \frac{q_2}{r_2}\right]$$

$$V_1 = 9\times10^9\left[\frac{10\times10^{-6}}{5\times10^{-2}} + \frac{10\times10^{-6}}{15\times10^{-2}}\right]$$

$$= 9 \times 10^5\left[\frac{10+30}{15}\right] = 9 \times 10^5\left[\frac{40}{15}\right] = \left[\frac{360}{15}\right] \times 10^5$$

$\therefore V_1 = 24 \times 10^5$v

$$V_2 = 9\times10^9\left[\frac{10\times10^{-6}}{5\sqrt{2}\times10^{-2}} + \frac{10\times10^{-2}}{5\sqrt{10}\times10^{-2}}\right]$$

$$= 18 \times 10^5\left[\frac{1}{\sqrt{2}} + \frac{1}{\sqrt{10}}\right]$$

$$= 18 \times 10^5\left[\frac{1}{1.414} + \frac{1}{3.162}\right] = 18 \times 10^5\,[1.0236]$$

$\therefore V_2 = 18.42 \times 10^5$v

$\therefore V_2 - V_1 = (18.42 - 24)\,10^5$v

$\Delta V = -5.58 \times 10^5$v

$\Delta U = \Delta VQ$

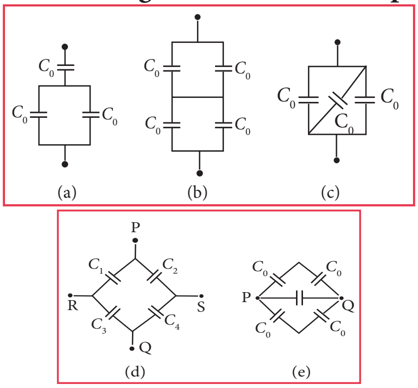
$= (-5.58 \times 10^5)\,(-2 \times 10^{-6}) = 1.116$J

$\Delta U = +1.12$J

$\therefore \Delta U = +1.12$J, positive sign implies that to move the charge –2μC external work is required.

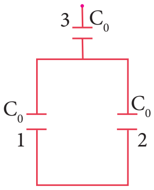
ELECTROSTATICS

11. **Calculate the resultant capacitances for each of the following combinations of capacitors.**



Sol.:

a.



Capacitor 1 & 2 are connected in parallel

$C_p = C_0 + C_0 = 2C_0$

Capacitor C_p and Capacitor 3 are in series.

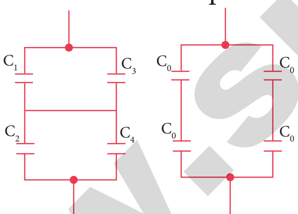
$$\frac{1}{C_s} = \frac{1}{C_p} + \frac{1}{C_3} \Rightarrow \frac{1}{C_s} = \frac{1}{2C_0} + \frac{1}{C_0}$$

$$= \frac{1+2}{2C_0} = \frac{3}{2C_0}$$

$$\therefore C_s = \frac{2}{3}.C_0$$

The resultant capacitance $= \frac{2}{3} C_0$

b.



C_1 & C_2 are in series $\frac{1}{Cs_1} = \frac{1}{C_0} + \frac{1}{C_0} = \frac{2}{C_0}$

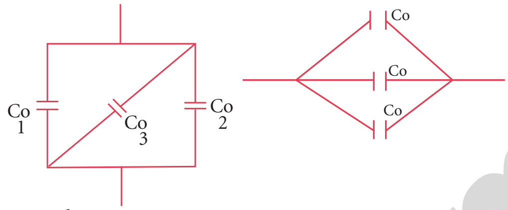
C_3 & C_4 are in series $\frac{1}{Cs_2} = \frac{2}{C_0}$

Cs_1 & Cs_2 are in parallel.

$\therefore C_p = Cs_1 + Cs_2 = \frac{C_0}{2} + \frac{C_0}{2} = C_0$

Resultant capacitance $= C_0$

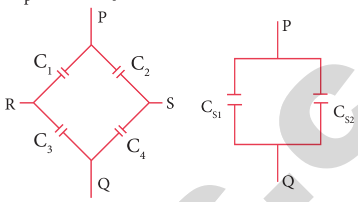
c.



Resultant capacitance $C_p = C_0 + C_0 + C_0$

$C_p = 3\,C_0$

d.



Across PQ :

C_1 and C_3 are in series $\frac{1}{Cs_1} = \frac{1}{C_1} + \frac{1}{C_3} = \frac{C_1+C_3}{C_1C_3}$

$$Cs_1 = \frac{C_1C_3}{C_1+C_3}$$

C_2 and C_4 are in series

$$\frac{1}{Cs_2} = \frac{1}{C_2} + \frac{1}{C_4}$$

$$Cs_2 = \frac{C_2+C_4}{C_2C_4} = \frac{C_2C_4}{C_2+C_4}$$

Now Cs_1 and Cs_2 are parallel

$$Cp = Cs_1 + Cs_2 = \frac{C_1C_3}{C_1+C_3} + \frac{C_2C_4}{C_2+C_4}$$

$$= \frac{(C_1C_3)(C_2+C_4)+(C_2C_4)(C_1+C_3)}{(C_1+C_3)(C_2+C_4)}$$

The resultant capacitance

$$= \frac{C_1C_2C_3+C_1C_3C_4+C_1C_2C_4+C_2C_3C_4}{(C_1+C_3)(C_2+C_4)}$$

Across Rs :

C_1 & C_2 are in series $\frac{1}{Cs_1} = \frac{1}{C_1} + \frac{1}{C_2} = \frac{C_2+C_1}{C_1C_2}$

$$\therefore Cs_1 = \frac{C_1C_2}{C_1+C_2}$$

C_3 & C_4 are in series $\frac{1}{Cs_2} = \frac{1}{C_3} + \frac{1}{C_4} = \frac{C_3+C_4}{C_3C_4}$

$$\therefore Cs_2 = \frac{C_3C_4}{C_3+C_4}$$

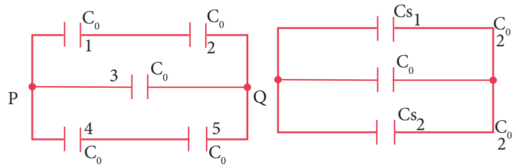
Now Cs_1 and Cs_2 are in parallel.

$$\therefore C_p = Cs_1 + Cs_2 = \frac{C_1C_2}{C_1+C_2} + \frac{C_3C_4}{C_3+C_4}$$

$$= \frac{C_1C_2(C_3+C_4)+C_3C_4(C_1+C_2)}{(C_1+C_2)(C_3+C_4)}$$

$$= \frac{C_1C_2C_3+C_1C_2C_4+C_1C_3C_4+C_2C_3C_4}{(C_1+C_2)(C_3+C_4)}$$

e.



Capacitors 1 and 2 are in series

$$\frac{1}{Cs_1} = \frac{1}{C_0}+\frac{1}{C_0}=\frac{2}{C_0}$$

$$Cs_1 = \frac{C_0}{2}$$

Capacitors 4 and 5 are in series

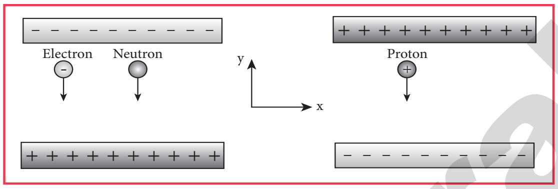
$$Cs_2 = \frac{C_0}{2}$$

Cs_1, Cs_2, Capacitor 3 are in parallel

$$\therefore \; C_p = \frac{C_0}{2}+\frac{C_0}{2}+C_0 = C_0 + C_0$$

Resultant capacitance = $2C_0$.

12. An electron and a proton are allowed to fall through the separation between the plates of a parallel plate capacitor of voltage 5 V and separation distance h = 1 mm as shown in the figure.



(a) Calculate the time of flight for both electron and proton (b) Suppose if a neutron is allowed to fall, what is the time of flight? (c) Among the three, which one will reach the bottom first?

(Take $m_p = 1.6 \times 10^{-27}$ kg, $m_e = 9.1 \times 10^{-31}$ kg and $g = 10$ m s^{-2})

Sol.: **Given:** *Potential difference between the plates of Parallel plate capacitor = V = 5V*

Distance between the plates of

$h = 1$ mm $= 1 \times 10^{-3}$ m

Mass of proton $m_p = 1.6 \times 10^{-27}$ kg

Mass of electron $m_e = 9.1 \times 10^{-31}$ kg

Charge of proton, $e = 1.6 \times 10^{-19}$ C

To find:

a. Time of flight of an electron t_e = ?

$$s = ut + \frac{1}{2}at^2, \text{ initial velocity } (u) = 0$$

$$s = \frac{1}{2}at^2 \Rightarrow t = \sqrt{\frac{2s}{a}}$$

$$a = \frac{F}{m} \text{ (according to Newton's II law) [F = ma]}$$

Force due to electric field is F = Ee

$$\text{Here } E = \frac{\Delta V}{\Delta d} = \frac{5}{10^{-3}}$$

$$\therefore a = \frac{Ee}{m} \qquad \therefore t = \sqrt{\frac{2sm}{Ee}}$$

s = h distance of separation $= 1 \times 10^{-3}$ m

$$\therefore t_e^2 = \frac{2hm_e}{\frac{\Delta V}{\Delta d}.e}$$

$$t_e^2 = \Delta d\,\frac{2hm_e}{\Delta Ve} = \frac{2\times10^{-3}\times9.1\times10^{-31}\times10^{-3}}{5\times1.6\times10^{-19}}$$

$$t_e = \sqrt{\frac{2\times10^{-3}\times9.1\times10^{-31}\times10^{-3}}{5\times1.6\times10^{-19}}}$$

$$= \sqrt{2.275\times10^{-18}} = 1.5 \times 10^{-9} \text{ s (or) } 1.5 \text{ ns}$$

Time of flight of an proton is t_p

$$t_p = \sqrt{\frac{2\times10^{-3}\times\cancel{1.6}\times10^{-27}\times10^{-3}}{5\times\cancel{1.6}\times10^{-19}}}$$

$$= \sqrt{\frac{2}{5}\times10^{-33}\times10^{19}} = \sqrt{0.4\times10^{-14}}$$

$t_p = 0.63 \times 10^{-7}$ s (or) 63×10^{-9}s (or) 63 ns

b. If Neutron falls, it is a neutral charge so it does not experience any electric filed. (It is like a force fall)

$$t_n^2 = \frac{2h}{g} \qquad \left[\text{i.e. } t = \frac{2s}{a}, a = g, s = h\right.$$

$$t_n = \sqrt{\frac{2\times10^{-3}}{10}} = \sqrt{2\times10^{-4}}$$

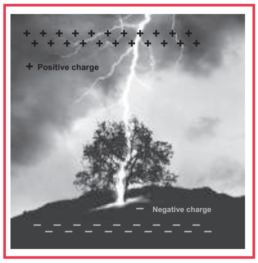
$t_n = 1.414 \times 10^{-2} = 14.14$ ms

c. Electron will reach first

$\because$ The time to reach the bottom first by electron is 1.5 ns.

13. During a thunder storm, the movement of water molecules within the clouds creates friction, partially causing the bottom part of the clouds to become negatively charged. This implies that the bottom of the cloud and the ground act as a parallel plate capacitor. If the electric field between the cloud and ground exceeds the dielectric breakdown of the air (3×10^6 Vm^{-1}), lightning will occur.

(a) **If the bottom part of the cloud is 1000 m above the ground, determine the electric potential difference that exists between the cloud and ground.**



(b) **In a typical lightning phenomenon, around 25 C of electrons are transferred from cloud to ground. How much electrostatic potential energy is transferred to the ground?**

***Sol.:* Given:**

a. Electric field between ground and cloud

$E = 3 \times 10^6 \text{ Vm}^{-1}$

Distance between ground and the cloud

$d = 1000\text{m}$

To find: Electric potential between ground and the cloud (i.e) V = ?

Formula: $E = \dfrac{V}{d} \Rightarrow V = E.d.$

$V = 3 \times 10^6 \times 10^3 = 3 \times 10^9$ V

b. The amount of electrons transfered from cloud to ground $Q = 25$ C

To find: Electrostatic potential transfered from cloud to ground, (i.e) U = ?

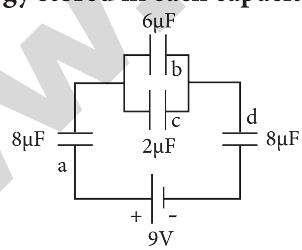
$$U = QV$$
$$= 25 \times 3 \times 10^9$$
$$U = 75 \times 10^9 \text{ J.}$$

14. For the given capacitor configuration *[QY-2019]*

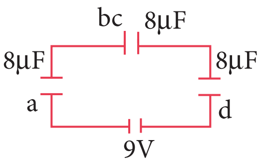
(a) Find the charges on each capacitor

(b) potential difference across them

(c) energy stored in each capacitor



Sol.:



Capacitor b and c are parallel,

so $C_p = 6\,\mu F + 2\,\mu F = 8\mu F$

Now a, b & c, d are in series.

(i) Potential difference across the capacitor :

$V_a = V_{bc} = V_d = V$ (Since a, b, c, d are in series)

$\Rightarrow V_a + V_{bc} + V_d = 9$

$\Rightarrow 3V = 9$

$\Rightarrow V = \dfrac{9}{3} = 3$ V

$\therefore V_a = V_b = V_c = V_d = 3$ V

(ii) Change on each capacitor :

We know Q = CV

$\therefore Q_a = CV = 8 \times 10^{-6} \times 3 = 24 \times 10^{-6} = 24\,\mu C$

$\therefore Q_b = CV = 6 \times 10^{-6} \times 3 = 18 \times 10^{-6} = 18\,\mu C$

$\therefore Q_c = CV = 2 \times 10^{-6} \times 3 = 6 \times 10^{-6} = 6\,\mu C$

$\therefore Q_d = CV = 8 \times 10^{-6} \times 3 = 24 \times 10^{-6} = 24\,\mu C$

(iii) Energy stored in each capacitor :

We know $U = \dfrac{1}{2} CV^2$

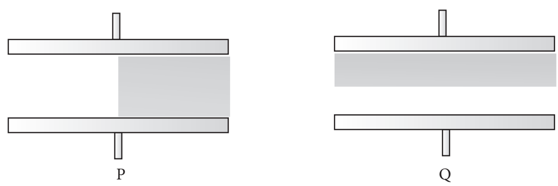
$\therefore U_a = \dfrac{1}{2} \times 8 \times 10^{-6} \times 3 \times 3 = 36 \times 10^{-6} = 36\,\mu J$

$\therefore U_b = \dfrac{1}{2} \times 6 \times 10^{-6} \times 3 \times 3 = 27 \times 10^{-6} = 27\,\mu J$

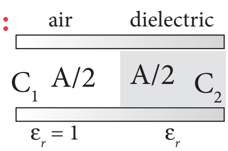
$\therefore U_c = \dfrac{1}{2} \times 2 \times 10^{-6} \times 3 \times 3 = 9 \times 10^{-6} = 9\,\mu J$

$\therefore U_d = \dfrac{1}{2} \times 4 \times 10^{-6} \times 3 \times 3 = 36 \times 10^{-6} = 36\,\mu J$

15. Capacitors P and Q have identical cross sectional areas A and separation d. The space between the capacitors is filled with a dielectric of dielectric constant ε_r as shown in the figure. Calculate the capacitance of capacitors P and Q. *[PTA-4]*



***Sol.:* (i) For Capacitor P:**



The given arrangement is equivalent to parallel combination of two capacitors each of areas = $\dfrac{A}{2}$

Plate of separation = d

The medium of one dielectric constant = $K_1 = \varepsilon_r = 1$ (air), $K_1 = 1$

The medium of other dielectric constant = K_2, i.e, $K_2 = \varepsilon_r$

The capacitance for $K_1 = C_1$

The capacitance for $K_2 = C_2$

$$C_1 = \frac{\varepsilon_0 \frac{A}{2}.K_1}{d} = \frac{\varepsilon_0 K_1 A}{2d} \qquad [\because C = \frac{\varepsilon A}{d}]$$

$$C_2 = \frac{\varepsilon_0 \frac{A}{2}.K_2}{d} = \frac{\varepsilon_0 K_2 A}{2d}$$

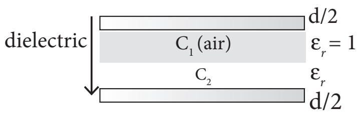
If C_p is the capacitance of the capacitor. then

$$C_p = C_1 + C_2$$

$$= \frac{\varepsilon_0 K_1 A}{2d} + \frac{\varepsilon_0 K_2 A}{2d} = \frac{\varepsilon_0 (K_1 + K_2) A}{2d}$$

$$C_p = \frac{\varepsilon_0 (1+\varepsilon_r) A}{2d}$$

(ii) For capacitor Q.



This is equivalent to a series combination of two capacitors

Plate of separation $\frac{d}{2}$

Dielectric constant for first medium = K_1 [air $K_1 = \varepsilon_r = 1$]

Dielectric constant for second medium = K_2 [direction $K_2 = \varepsilon_r$]

$$\text{Capacitance of first} = C_1 = \frac{\varepsilon_0 K_1 A}{\frac{d}{2}} = \frac{2\varepsilon_0 K_1 A}{d}$$

$$\text{For second Capacitance} = C_2 = \frac{\varepsilon_0 K_2 A}{\frac{d}{2}} = \frac{2\varepsilon_0 K_2 A}{d}$$

If C_Q is the capacitance of the capacitor

$$\frac{1}{C_Q} = \frac{1}{C_1} + \frac{1}{C_2}$$

$$= \frac{d}{2\varepsilon_0 A}\left[\frac{1}{K_1} + \frac{1}{K_2}\right] = \frac{d}{2\varepsilon_0 A}.\left[\frac{K_1 + K_2}{K_1 K_2}\right]$$

$$\frac{1}{C_Q} = \frac{d}{2\varepsilon_0 A}\left[\frac{1+\varepsilon_r}{\varepsilon_r}\right]$$

$$C_Q = \frac{2\varepsilon_0 A}{d}\left[\frac{\varepsilon_r}{1+\varepsilon_r}\right].$$

PTA Model Questions & Answers

Choose the Correct Answer — 1 Mark

1. An air-core capacitor is charged by a battery. After disconnecting it from the battery, a dielectric slab is fully inserted in between its plates. Now, which of the following quantities remains constant? *[PTA-1]*

(a) Energy (b) Voltage
(c) Electric field (d) Charge

[*Ans.* (d) Charge]

2. The unit of permittivity is: *[PTA-2]*

(a) $C^2 N^{-1} m^{-2}$ (b) $N m^2 C^{-2}$
(c) $H m^{-1}$ (d) $N C^{-2} m^{-2}$

[*Ans.* (a) $C^2 N^{-1} m^{-2}$]

3. A coil of area of cross-section 0.5 m² with 10 turns is in a plane which is parallel to a uniform electric field of 100 NC⁻¹. The flux through the plane is: *[PTA-2]*

(a) 100 V.m (b) 500 V.m
(c) 20 V.m (d) zero

[*Ans.* (b) 500 V.m]

4. Dimension and unit of Electric flux is ________ *[PTA-3; Aug-2021; FRT-'22]*

(a) $ML^2T^3A^{-2}$, Nm^2C^{-1}
(b) $ML^3T^{-3}A^{-1}$, Nm^2C^{-1}
(c) $ML^2T^{-1}A^{-2}$, Nm^2C^{-1}
(d) $ML^{-4}T^{-3}A^{-2}$, Nm^2C^{-1}

[*Ans.* (b) $ML^3T^{-3}A^{-1}$, Nm^2C^{-1}]

5. At infinity, the electrostatic potential is *[PTA-4]*

(a) infinity (b) maximum
(c) minimum (d) zero

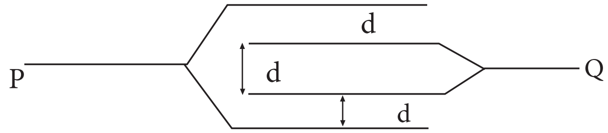
[*Ans.* (d) zero]

6. Five balls marked 1, 2, 3, 4 and 5 are suspended by separate threads. The pairs (1, 2) (2, 4) and (4, 1) show mutual attraction and the pairs (2,3) and (4, 5) show repulsion. The number of ball marked as 1 is *[PTA-5]*

(a) positive (b) negative
(c) neutral (d) can't determine

[*Ans.* (c) neutral]

7. The resultant capacitance of four plates, each is having an area A, arranged as shown above, will be (plate separation is d) *[PTA-5]*



(a) $\frac{A\varepsilon_0}{d}$ (b) $\frac{A\varepsilon_0}{2d}$

(c) $\frac{2A\varepsilon_0}{d}$ (d) $\frac{3A\varepsilon_0}{d}$

[Ans. (c) $\frac{2A\varepsilon_0}{d}$]

Hint:	$C = C_1 + C_2 = 2C$ $\therefore C = \frac{2\varepsilon_0 A}{d}$

8. An electric dipole is placed at an angle 30° with an electric field intensity of 2 × 10⁵ N C⁻¹. It experiences a torque equal to 4 N m. The charge on the dipole if the dipole length is 2 cm is *[PTA-6]*

(a) 8 mC (b) 2 mC

(c) 5 mC (d) 7 μC

[Ans. (b) 2 mC]

Very Short Answer Questions — 2 Marks

1. The electric field outside a conductor is perpendicular to its surface. Justify. *[PTA-1]*

Ans. (i) The electric field outside the conductor is perpendicular to the surface of the conductor and has a magnitude of $\frac{\sigma}{\varepsilon_0}$ where σ is the surface charge density at that point.

(ii) If the electric field has components parallel to the surface of the conductor, then free electrons on the surface of the conductor would experience acceleration.

(iii) This means that the conductor is not in equilibrium. Therefore at electrostatic equilibrium, the electric field must be perpendicular to the surface of the conductor.

2. State the law of conservation of electric charges. *[PTA-2]*

Ans. The total electric charge in the universe is constant and charge can neither be created nor be destroyed. In any physical process, the net change in charge will always be zero.

3. Define the physical quantity whose unit is V.m, and state whether it is scalar or vector. *[PTA-3]*

Ans. Unit of Electric flux is V.m or N m^2 C^{-1}

It is a scalar quantity.

4. Can two equipotential surfaces intersect? Give reason. *[PTA-5]*

Ans. Since the electric field is normal to the equipotential surface and also the potential difference between any two points on the surface is nullified, the intersection is not possible.

5. Define electric dipole. *[PTA-5; FRT-'22; HY-'24]*

Ans. Two equal and opposite charges separated by a very small vector distance.

Short Answer Questions — 3 Marks

1. Four point charges +q, +q, −q and −q are to be arranged respectively at the four corners of a square PQRS of side r. Find the work needed to assemble this arrangement. *[PTA-1]*

Sol. The work done to arrange the charges in the corners of the square is independent of the way they are arranged. We can follow any order

(i) First, the charge $+q$ is brought to the corner P. This requires no work since no charge is already present, $W_P = 0$

(ii) Work required to bring the charge $-q$ to the corner Q = $(-q)$ × potential at a point Q due to $+q$ located at a point P.

$$W_Q = -q \times \frac{1}{4\pi\varepsilon_0}\frac{q}{a} = \frac{1}{4\pi\varepsilon_0}\frac{q^2}{a}$$

(iii) Work required to bring the charge $+q$ to the corner R= q × potential at the point R due to charges at the point P and Q.

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

(iv) Work required to bring the fourth charge $-q$ at the position S = q × potential at the point S due the all the three charges at the point P, Q and R

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

2. Two capacitors of unknown capacitances are connected in series and parallel. If net capacitances in two combinations are 6 μF and 25 μF respectively, find their capacitances. *[PTA-2]*

Sol. $$\frac{1}{C_s} = \frac{1}{C_1}+\frac{1}{C_2} = \frac{C_1+C_2}{C_1C_2}$$

Unit 1

$$\Rightarrow C_s = \frac{C_1C_2}{C_1+C_2} \quad \text{But } C_p = C_1 + C_2$$

$$\text{Hence } C_s = \frac{C_1C_2}{C_P} \Rightarrow 6 = \frac{C_1C_2}{25}$$

$$\therefore C_1 C_2 = 25 \times 6 = 150$$

$$\Rightarrow C_2 = \frac{150}{C_1}; C_1 + C_2 = 25$$

$$\Rightarrow C_1 + \frac{150}{C_1} = 25 \Rightarrow C_1^2 + 150 = 25\, C_1$$

(or)

$$C_1^2 - 25\, C_1 + 150 = 0$$
$$C_1^2 - 10\, C_1 - 15\, C_1 + 150 = 0$$
$$C_1 (C_1-10) - 15 (C_1 - 10) = 0$$
$$(C_1-10)(C_1-15) \text{ or } C_1 = 10 \text{ or } 15$$
$$\text{if } C_1 = 10\mu F ; C_2 = 15\mu F$$
$$C_1 = 15\mu F ; C_2 = 10\mu F$$

3. Calculate the force between electron and proton in Hydrogen atom.($e = 1.6 \times 10^{-19}$ C and $r_0 = 0.53$Å) *[PTA-3]*

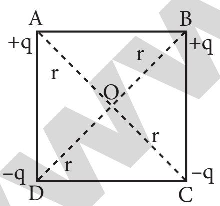
Sol. The proton and the electron attract each other. The magnitude of the electrostatic force between these two particles is given by

$$F_e = \frac{ke^2}{r^2} = \frac{9\times10^9 \times (1.6\times10^{-19})^2}{(5.3\times10^{-11})^2}$$

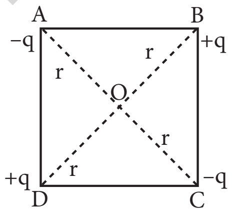
$$= \frac{9 \times 2.56}{28.09} \times 10^{-7} = 8.2 \times 10^{-8} \text{ N}$$

4. Four point charges are placed at the four corners of a square in two ways (a) and (b) as shown in figure. Will the (i) electric potential and (ii) electric field, at the centre of the square be the same or different in the two configurations and why? *[PTA-5]*

(a)



(b)



***Ans.* (i)** Electric field at the centre of fig (b) will be zero because same charges on the diagonally opposite corners of a square give zero electric field at the centre whereas it will be 'non zero' in fig (a).

(ii) Electric potential will be the same in case of fig(a) and (b) because there are two positive and two negative charges of same magnitude at equal distance from centres in both figures.

Government Exam Questions & Answers

Choose the Correct Answer — 1 Mark

1. When a point charge of 6mC is moved between two points in an electric field, the work done is 1.8×10^{-5} J. The potential difference between the two points is *[Govt. MQP-2019]*

(a) 1.08 V (b) 1.08 μV
(c) 3 V (d) 30 V

[*Ans.* (c) 3 V]

Hint: $V = \frac{W}{q} = \frac{1.8\times10^{-5}}{6\times10^{-6}} = 3$ V

2. Two point charges A and B having charges +Q and –Q respectively, are placed at certain distance, apart and force acting between them is F. If 25% charge of A is transformed to B, then force between the charges becomes. *[QY-2019]*

(a) $\frac{16}{9}$F (b) $\frac{4}{3}$ F (c) F (d) $\frac{9}{16}$ F

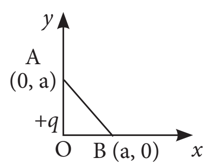
[*Ans.* (d) $\frac{9}{16}$ F]

3. A cylinder of radius R and length L is placed in a uniform electric field E parallel to the cylinder axis. The total flux for the surface of the cylinder is given by *[QY-2019]*

(a) $2\pi R^2E$ (b) $\frac{\pi}{E} R^2$
(c) $(\pi R^2 - \pi R)/E$ (d) Zero

[*Ans.* (d) Zero]

4. In the given diagram a point charge +q is placed at the origin O. Work done in taking another point charge –Q from point A to point B is : *[Mar-2020]*



(a) $\frac{qQ}{4\pi\varepsilon_0 a^2}\left(\frac{a}{\sqrt{2}}\right)$ (b) Zero

(c) $\left[\frac{-qQ}{4\pi\varepsilon_0}\frac{1}{a^2}\right]\sqrt{2a}$ (d) $\left[\frac{qQ}{4\pi\varepsilon_0}\frac{1}{a^2}\right]\sqrt{2a}$

[*Ans.* (b) Zero]

5. The electric field in the region between two concentric charged spherical shells. *[QY-'24]*

(a) is zero
(b) increases with distance from centre
(c) decreases with distance from centre
(d) is constant

[*Ans.* (c) decreases with distance from centre]

ELECTROSTATICS

6. A charge Q is placed at the corner of a cube. The electric flux through all the six faces of the cube is *[HY - 2024]*

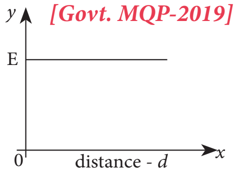
(a) $\frac{Q}{3\varepsilon_o}$ (b) $\frac{Q}{6\varepsilon_o}$ (c) $\frac{Q}{8\varepsilon_o}$ (d) $\frac{Q}{\varepsilon_o}$

[Ans. (d) $\frac{Q}{\varepsilon_0}$**]**

Very Short Answer Questions — 2 Marks

1. Show graphically the variation of electric field E (*y*-axis) due to a charged infinite plane sheet with distance *d* (*x*-axis) from the plate. *[Govt. MQP-2019]*

Ans. It is independent of the distance. It is a straight line parallel to x-axis.



2. A parallel plate capacitor has square plates of side 5 cm and separated by a distance of 1mm, then calculate the capacitance of the capacitor. *[QY-2019]*

Ans. The capacitance of the capacitor is

$$C = \frac{\varepsilon_0 A}{d} = \frac{8.85\times10^{-12}\times25\times10^{-4}}{1\times10^{-3}}$$

$$= 221.2 \times 10^{-13}\ F$$

$$C = 22.12 \times 10^{-12}\ F = 22.12\ pF$$

3. Dielectric strength of air is 4×10^6 Vm^{-1}. Suppose the radius of a hollow sphere in the Van de Graaff generator is R = 0.4 m, calculate the maximum potential difference created by this Van de Graaff generator. *[Aug-2021]*

Ans. The electric field on the surface of the sphere is given by (by Gauss law)

$$E = \frac{1}{4\pi\varepsilon_0}\cdot\frac{Q}{R^2}$$

The potential on the surface of the hollow metallic sphere is given by

$$V = \frac{1}{4\pi\varepsilon_0}\cdot\frac{Q}{R} = ER$$

Since $V_{max} = E_{max} R$

Here $E_{max} = 4\times10^6$ Vm^{-1}. So the maximum potential difference created is given by

$$V_{max} = 4\times10^6 \times 0.4$$
$$= 1.6 \times 10^6\ V \text{ (or) } 1.6 \text{ million volt}$$

4. State : Gauss Law. *[FRT & July-'22; QY-'24]*

Ans. Gauss's law states that if a charge Q is enclosed by an arbitrary closed surface, then the total electric flux Φ_E through the closed surface is

$$\phi_E = \oint \vec{E}.d\vec{A} = \frac{Q_{encl}}{\varepsilon_0}$$

5. Calculate the electric flux through the rectangle of sides 5 cm and 10 cm kept in the region of a uniform electric field 100 NC^{-1}. The angle θ is 60°. What is the electric flux? *[FRT-'22; June-'23; QY-'24]*

Sol. The electric flux through the rectangular area

$\theta = 60°$

$\Phi_E = \vec{E}.\vec{A} = EA\cos\theta$

$\Phi_E = 100 \times 5 \times 10 \times 10^{-4} \times \cos 60°$

$\Phi_E = 5000 \times 10^{-4} \times \frac{1}{2} = 2500 \times 10^{-4}$

$\Phi_E = 0.25\ Nm^2C^{-1}$

6. A sample of HCl gas is placed in a uniform electric field of magnitude 3×10^4 NC^{-1}. The dipole moment of each HCl molecule is 3.4×10^{-30} cm. Calculate the maximum torque experienced by each HCl molecule. *[June-'24]*

Sol. The maximum torque experienced by the dipole is when it is aligned perpendicular to the applied field.

$\tau_{max} = p\,E \sin 90° = 3.4 \times 10^{-30} \times 3 \times 10^4$

$\tau_{max} = 10.2 \times 10^{-26}$Nm

7. Define Dipole moment. *[HY-'24]*

Ans. Dipole Moment : The electric dipole moment vector lies along the line joining two charges and is directed from $-q$ to $+q$. The SI unit of dipole moment is coulomb metre (Cm).

Short Answer Questions — 3 Marks

1. Define and derive an expression for the energy density in parallel plate capacitor. *[Govt. MQP-2018]*

Ans. The total work done to charge a capacitor is stored as electrostatic potential energy in the capacitor

Energy stored in the capacitor

$$U_E = \frac{1}{2}CV^2 \quad ...(1)$$

This is rewritten as using $C = \frac{\varepsilon_0 A}{d}$ & $V = Ed$.

$$U_E = \frac{1}{2}\left(\frac{\varepsilon_0 A}{d}\right)(Ed)^2 = \frac{1}{2}\varepsilon_0 (Ad)E^2 \quad ...(2)$$

where Ad = volume of the space between the capacitor plates. The energy stored per unit volume of space is defined as energy density $u_E = \frac{U}{\text{Volume}}$ From equation (4),

We get $\boxed{u_E = \frac{1}{2}\varepsilon_0 E^2}$ ...(3)

The energy density depends only on the electric field and not on the size of the plates of the capacitor.

2. State the rules followed while drawing electric field lines for the representation of electric field. *[QY-2019]*

Ans. The following rules are followed while drawing electric field lines for charges.

(i) The electric field lines start from a positive charge and end at negative charges or at infinity.

(ii) The electric field vector at a point in space is tangential to the electric field line at that point.

(iii) The electric field lines are denser (more closer) in a region where the electric field has larger magnitude and less dense in a region where the electric field is of smaller magnitude.

(iv) No two electric field lines intersect each other. If two lines cross at a point, then there will be two different electric field vectors at the same point.

(v) The number of electric field lines that emanate from the positive charge or end at a negative charge is directly proportional to the magnitude of the charges.

3. What are the application of Capacitors? *[FRT-'22]*

Ans. Capacitors are used in various electronics circuits. A few of the applications.

(a) Flash capacitors are used in digital cameras for taking photographs.

(b) During cardiac arrest, a device called heart defibrillator is used to give a sudden surge of a large amount of electrical energy to the patient's chest to retrieve the normal heart function.

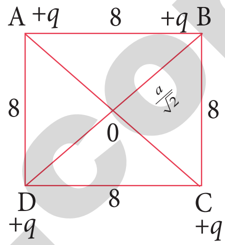
(c) Capacitors are used in the ignition system of automobile engines to eliminate sparking

(d) Capacitors are used to reduce power fluctuations in power supplies and to increase the efficiency of power transmission.

NUMERICAL PROBLEMS — 3 MARKS

1. Charges of $+\frac{10}{3} \times 10^{-9}$ C are placed at each of the four corners of a square of side 8 cm. Find the potential at the intersection of the diagonals. *[QY-2019]*

Sol.:



$$l = \frac{a}{\sqrt{2}} = \frac{8}{\sqrt{2}} = 4\sqrt{2} \text{ cm}$$

$$= 4\sqrt{2} \times 10^{-2} \text{ m}$$

Potential at the intersection of the diagonals

$$V = 4 \times \frac{kq}{l} = \frac{\cancel{4} \times \cancel{9} \times \cancel{10^9} \times \frac{10}{\cancel{3}1} \times \cancel{10^{-9}}}{\cancel{4}\sqrt{2} \times 10^{-2}}$$

$$= \frac{30 \times 10^2}{\sqrt{2}} = \frac{3000}{\sqrt{2}}$$

$$= \frac{3000}{\sqrt{2}} \times \frac{\sqrt{2}}{\sqrt{2}} = 1500\sqrt{2} \text{ Volt}$$

2. A dipole is formed by two charges of 5 μC and –5 μC at a distance of 8 mm. Find the electric field at

a) a point 25 cm away from center of dipole along its axial line.

b) a point 20 cm away from center of dipole along its equatorial line. *[HY-2019]*

Sol.: Given : $q = 5$ μC, E along axial line at 25 cm = ?, E along equatorial line at 20 cm = ?

a) E along axial line at 25 cm

∴ Dipole moment

$p = 2qd = 2 \times 5 \times 10^{-6} \times 8 \times 10^{-3} = 80 \times 10^{-9}$

$$E = \frac{1}{4\pi\varepsilon_0}\frac{2p}{r^3} = 9 \times 10^9 \times \frac{2 \times 80 \times 10^{-9}}{(25 \times 10^{-2})^3}$$

$= 0.09216 \times 10^6 = 9.2 \times 10^4$ NC^{-1}

b) E along equatorial line at 20 cm

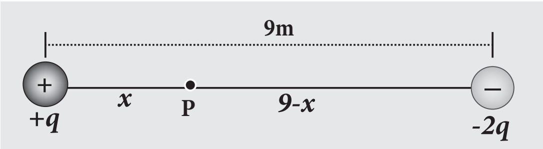
$$E = \frac{1}{4\pi\varepsilon_0}\frac{p}{r^3} = 9 \times 10^9 \times \frac{80 \times 10^{-9}}{(20 \times 10^{-2})^3}$$

$= 0.09 \times 10^6 = 9 \times 10^4$ NC^{-1}

3. Consider a point charge +q placed at the origin and another point charge - 2q placed at a distance of 9m from the charge +q. Determine the point between the two charges at which the electric potential is zero. *[QY-'23]*

Ans. According to the superposition principle, the total electric potential at a point is equal to the sum of the potentials due to each charge at that point.

Consider the point at which the total potential zero is located at a distance x from the charge $+q$ as shown in the figure.



Since the total electric potential at P is zero,

$$V_{tot} = \frac{1}{4\pi\epsilon_\circ}\left(\frac{q}{x} - \frac{2q}{(9-x)}\right) = 0 \text{ (or)}$$

$$\frac{q}{x} - \frac{2q}{(9-x)} \text{ (or) } \frac{1}{x} = \frac{2}{(9-x)}$$

Hence, x = 3m

Long Answer Questions — 5 marks

1. State Coulomb's Law in electrostatics. *[Mar - 2023]*

Ans. According to Coulomb, the force on the point charge q_2 exerted by another point charge q_1 is

$$\vec{F}_{21} = k\frac{q_1 q_2}{r^2}\hat{r}_{12}$$

where $\hat{r}_{12}$ is the unit vector directed from charge q_1 to charge q_2 and k is the proportionality constant.

ADDITIONAL QUESTIONS AND ANSWERS

Choose the Correct Answer — 1 mark

1. Based on Franklin's convention amber rods are ________

(a) positively charged (b) negatively charged
(c) neutral (d) none of the above

[Ans. (b) negatively charged]

2. The electrostatic force obeys ________

(a) Newton's I law (b) Newton's II law
(c) Newton's III law (d) none of the above

[Ans. (c) Newton's III law]

3. In electrostatics if the charges are in motion, another force named ________ comes into play in addition to coulomb force.

(a) Lorentz force (b) Repulsive force
(c) Attractive force
(d) electromagnetic force

[Ans. (a) Lorentz force]

4. The value of constant 'k' in coulomb law is

(a) 0.9×10^9 Nm^2 C^2 (b) 9×10^{-9} Nm^{2}C^2
(c) 9×10^9 Nm^{-2} C^{-2} (d) 9×10^9 Nm^2 C^{-2}

[Ans. (d) 9×10^9 Nm^2 C^{-2}]

5. The electrostatic force is always greater in magnitude than gravitational force for ______ object

(a) bigger size (b) smaller size
(c) medium size (d) all the above

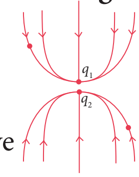
[Ans. (b) smaller size]

6. ______and Coulomb's law form fundamental principles of electrostatics

(a) Newton's law of gravitation
(b) Superposition principle
(c) Ohm's law (d) Kepler's law

[Ans. (b) Superposition principle]

7. The given figure is a plot of lines of force due to two charges q_1 & q_2. Find out the sign of charges



(a) both negative
(b) both positive
(c) upper positive and lower negative
(d) upper negative and lower positive

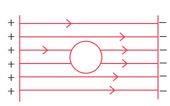
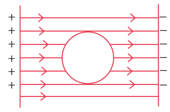
[Ans. (a) both negative]

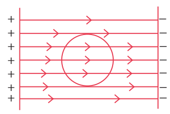
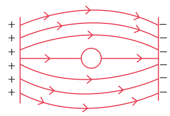
8. Which one of these is a vector quantity?

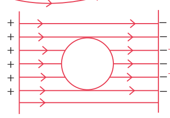
(a) Electric charge (b) Electric field
(c) Electric flux (d) Electric potential

[Ans. (b) Electric field]

9. An uncharged metal sphere is placed between two equal and oppositely charged metal plates. The nature of lines of force will be

(a)  (b) 

(c)  (d) 

[Ans. (b)  **]**

10. The electric field created by a ______ is basically a non-uniform electric field.

(a) Test charge (b) Positive charge
(c) Negative charge (d) Point charge

[Ans. (d) Point charge]

11. **An isolated metal sphere of radius 'r' is given a charge 'q'. The potential energy of the sphere is**

(a) $\frac{q^2}{4\pi\varepsilon_0 r}$ (b) $\frac{q}{4\pi\varepsilon_0 r}$

(c) $\frac{q}{8\pi\varepsilon_0 r}$ (d) $\frac{q^2}{8\pi\varepsilon_0 r}$

[Ans. (d) $\frac{q^2}{8\pi\varepsilon_0 r}$]

Hint:

$$P.E = \frac{1}{2}CV^2 \qquad [\because C = 4\pi\varepsilon_0 r]$$

$$V = \frac{q}{4\pi\varepsilon_0 r}$$

$$P.E = \frac{1}{2} \times (4\pi\varepsilon_0 r) \times \left(\frac{q}{4\pi\varepsilon_0 r}\right)^2$$

$$P.E = \frac{q^2}{8\pi\varepsilon_0 r}$$

12. **In a hydrogen atom the electron revolves around the proton in an orbit of 0.53 Å . The potential produced by the electron on the nucleus is**

(a) 6.8 V (b) 13.6 V

(c) 54.4 V (d) 27.2 V

[Ans. (d) 27.2 V]

Hint: $V = \left(\frac{1}{4\pi\varepsilon_0}\right)\frac{q}{r} = (9 \times 10^9) \times \frac{1.6 \times 10^{-19}}{0.53 \times 10^{-10}} = 27.2\ V$

13. **The expression for electric field in vector form is**

(a) $\frac{1}{4\pi\varepsilon_0}\frac{q}{r}\hat{r}$ (b) $\frac{-1}{4\pi\varepsilon_0}\frac{q}{r}\hat{r}$

(c) $\frac{-1}{4\pi\varepsilon_0}\frac{q}{r^2}\hat{r}$ (d) $\frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}\hat{r}$

[Ans. (d) $\frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}\hat{r}$]

14. **Eight mercury droplets having a radius of 1 mm and charge of 0.066 pC each merge to form one droplet. Its potential is**

(a) 2.4 V (b) 1.2 V

(c) 3.6 V (d) 4.8 V

[Ans. (a) 2.4 V]

Hint:

$$8 \times \text{volume of one droplet of Hg} = \frac{4}{3}\pi R^3$$

$$8 \times \cancel{\frac{4}{3}}\cancel{\pi} r^3 = \cancel{\frac{4}{3}}\cancel{\pi} R^3$$

$$2^3 \times r^3 = R^3$$

$$(2r)^{\cancel{3}} = (R)^{\cancel{3}}$$

$$R = 2r \qquad [\because r = 1\ mm]$$

$$R = 2 \times \frac{1}{q/R} \times 10^{-3}\ m\ (or)\ 2\ mm \qquad [\because q = ne]$$

$$\therefore V = \frac{1}{4\pi\varepsilon_0} \times \frac{q}{R}$$

$$V = \frac{9 \times 10^9 \times 0.066 \times 10^{-12} \times 8}{2 \times 10^{-3}}$$

$$V = 2.4\ V$$

15. **A force of 40 N is acting between two charges in air if the space between them is filled with glass $\varepsilon_r = 8$. Then the force between them is**

(a) 20 N (b) 10 N (c) 5 N

(d) the same and does not change **[Ans. (c) 5 N]**

Hint:

$$F_a = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q_1 q_2}{r^2}$$

$$F_g = \frac{1}{4\pi\varepsilon_0\varepsilon_r} \cdot \frac{q_1 q_2}{r^2}$$

$$\frac{F_g}{F_a} = \frac{1}{\varepsilon_r} = \frac{1}{8}$$

$$F_g = \frac{F_a}{8} = \frac{40}{8} = 5\ N$$

16. **The concept of 'Field' was introduced by**

(a) Faraday (b) Gauss

(c) Maxwell (d) None

[Ans. (a) Faraday]

17. **The electric potential V as a function of distance x (metres) is given by V = ($5x^2 + 10x - 9$) volt. The value of electric field at a point x = 1m is**

(a) 20 Vm^{-1} (b) 6 Vm^{-1}

(c) 11 Vm^{-1} (d) – 23 Vm^{-1}

[Ans. (a) 20 Vm^{-1}]

Hint:

We know that, $E = \frac{dV}{dx}$

$V = 5x^2 + 10x - 9$

Differentiating w.r. to 'x' on both sides

$\frac{dV}{dx} = 10x + 10 = E$

At a point, x = 1m,

$\frac{dV}{dx} = 10(1) + 10$

$\therefore E = \frac{dV}{dx} = 20\ Vm^{-1}$

ELECTROSTATICS

18. **Two condensers (capacitors) of capacity C_1 and C_2 are connected in parallel. A charge Q given to then is shared. The ratio of the charges Q is**

(a) $\frac{C_2}{C_1}$ (b) $\frac{C_1}{C_2}$
(c) $C_1 . C_2$ (d) $\frac{1}{C_1 \times C_2}$

[*Ans.* (b) $\frac{C_1}{C_2}$]

Hint: As they are in parallel, the potential is same across the two,
$\therefore Q_1 = C_1V$ and $Q_2 = C_2V$
$\therefore \frac{Q_1}{Q_2} = \frac{C_1}{C_2}$

19. **Charge per unit volume is called**

(a) Linear charge density (λ)
(b) Surface charge density (σ)
(c) Volume charge density (ρ)
(d) Electric flux

[*Ans.* (c) Volume charge density (ρ)]

20. **What will happen if two conducting spheres are separately charged and then brought in contact?**

(a) Total charge on the two spheres is conserved
(b) The total energy is conserved
(c) Both charge and energy are conserved
(d) The final potential is the mean of the original potentials.

[*Ans.* (a) Total charge on the two spheres is conserved]

Hint: This is in accordance with the law of conservation of charge.

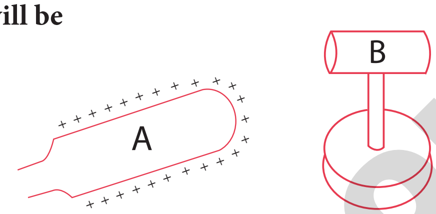
21. **A condenser is charged to a potential of 200V and has a charge of 0.1C. The energy stored in it is**

(a) 1 J (b) 2 J (c) 10 J (d) 20 J

[*Ans.* (c) 10 J]

Hint:
Energy stored, $U = \frac{1}{2}CV^2$
$U = \frac{1}{2}(CV)V \quad [\because q = CV]$
$U = \frac{1}{2}qV = \frac{1}{2} \times 0.1 \times 200$
$U = 10$ J

22. **A positively charged body 'A' has been brought near a brass cylinder 'B' mounted on a glass stand as shown in the figure. The potential of 'B' will be**



(a) Zero (b) Negative
(c) Positive (d) Infinite

[*Ans.* (c) Positive]

23. **The expression for electric potential difference is**

(a) $\int_R^P +\vec{E}.\vec{dr}$ (b) $-\int_\infty^P \vec{E}.\vec{dr}$
(c) $\int_\infty^P \vec{E}.\vec{dr}$ (d) $\int_R^P -\vec{E}.\vec{dr}$

[*Ans.* (d) $\int_R^P -\vec{E}.\vec{dr}$]

24. **The magnitude of electric dipole moment of water molecule is**

(a) 6×10^{-30} Cm (b) 6.2×10^{-30} Cm
(c) 6.1×10^{-30} Cm (d) 5.9 5 10^{-30} Cm

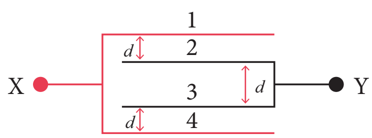
[*Ans.* (c) 6.1×10^{-30} Cm]

25. **The magnitude of torque on dipole is maximum if**

(a) θ = 0° (b) θ = 90°
(c) θ = 180° (d) θ = 180°

[*Ans.* (b) θ = 90°]

26. **Four plates each of area 'A' are separated by a distance 'd'. The connection is as shown in figure. What is equivalent capacitance between X and Y?**



(a) $\frac{\varepsilon_0 A}{d}$ (b) $\frac{2\varepsilon_0 A}{d}$
(c) $\frac{3\varepsilon_0 A}{d}$ (d) $\frac{4\varepsilon_0 A}{d}$

[*Ans.* (b) $\frac{2\varepsilon_0 A}{d}$]

Hint: They constitute two parallel plate capacitors in parallel with each other.

27. **The expression for the electric field due to a surface of total charge 'Q' is given by**

(a) $\vec{E} = \dfrac{1}{4\pi\varepsilon_0}\int \dfrac{\sigma dA}{r^2}\hat{r}$ (b) $\vec{E} = \dfrac{1}{4\pi\varepsilon_0}\int \dfrac{\rho dA}{r^2}\hat{r}$

(c) $\vec{E} = \dfrac{1}{4\pi\varepsilon_0}\int \dfrac{\lambda dl}{r^2}\hat{r}$ (d) $\vec{E} = \dfrac{1}{4\pi\varepsilon_0}\int \dfrac{dq}{r^2}\hat{r}$

[*Ans.* (a) $\vec{E} = \dfrac{1}{4\pi\varepsilon_0}\int \dfrac{\sigma dA}{r^2}\hat{r}$]

28. **The unit for electric flux is**

(a) $C^2 N^{-1} m^{-2}$ (b) $Nm^2 C^{-2}$
(c) $Nm^2 C^{-1}$ (d) $Nm^{-2} C^{-1}$

[*Ans.* (c) $Nm^2 C^{-1}$]

29. **The electric flux is negative, if the angle between $\vec{dA}$ and $\vec{E}$ is**

(a) Less than 90° (b) greater than 90°
(c) equal to 90° (d) equal to 0°

[*Ans.* (b) greater than 90°]

30. **The time taken by a conductor to reach electrostatic equilibrium is in the order of**

(a) 10^{-18} (b) 10^{-14} s
(c) 10^{-16} s (d) 10^{-20} s

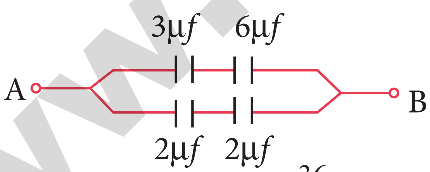
[*Ans.* (c) 10^{-16} s]

31. **A non-conducting material which has no free electrons is called**

(a) capacitor (b) Dielectric
(c) conductor (d) Inductor

[*Ans.* (b) Dielectric]

32. **In the given circuit the effective capacitance between A and B will be**



(a) 3μ*f* (b) $\dfrac{36}{13}$ μ*f*
(c) 13 μ*f* (d) 7 μ*f*

[*Ans.* (a) 3μ*f*]

Hint:

$$C = \left(\frac{3\times 6}{3+6}\right) + \left(\frac{2\times 2}{2+2}\right) = 2 + 1$$
$$C = 3\mu f$$

33. **The unit for electric susceptibility is**

(a) $Nm^2 C^{-2}$ (b) $C^2 N^{-1} m^{-2}$
(c) $C^{-2}Nm^2$ (d) $N^{-1} m^{-2}C^2$

[*Ans.* (b) $C^2 N^{-1} m^{-2}$]

34. **The direction of electric field at a point on the equatorial line due to an electric dipole is**

(a) along the equatorial line towards the dipole.
(b) along the equatorial line away from the dipole.
(c) parallel to the axis of the dipole and opposite to the direction of dipole moment.
(d) parallel to the axis of the dipole and in the direction of dipole moment.

[*Ans.* (c) parallel to the axis of the dipole and opposite to the direction of dipole moment.]

35. **Two charges are kept at a distance in air what should be the relative permittivity of the medium in which the two charges should be kept at the same distance so that they experience half of the force which they experienced in air?**

(a) $\dfrac{1}{2}$ (b) $\dfrac{1}{0.2}$ (c) 2 (d) 0.2

[*Ans.* (c) 2]

Hint:

$$\frac{F}{F_m} = \varepsilon_r \Rightarrow F_m = \frac{F}{2} \text{ (given)}$$
$$\frac{F}{\left(F/2\right)} = \varepsilon_r \Rightarrow \varepsilon_r = 2$$

36. **An uniformly charged conducting shell of 2cm diameter has a surface charge density of 80μC / m². The charge on the shell is**

(a) 100.48 nC (b) 100.48 μC
(c) 100.48 C (d) 100.48 × 10^{-12} C

[*Ans.* (a) 100.48 nC]

Hint:

$$\sigma = \frac{Q}{A} \Rightarrow Q = \sigma A$$
$$= (80 \times 10^{-6}) \times 4\pi R^2$$
$$Q = (80 \times 10^{-6}) \times 4 \times 3.14 \times (1\times 10^{-2})$$
$$= 100.48 \times 10^{-9}\ C = 100.48\ nC$$

37. **In tuning radio we use,**

(a) capacitors (b) transistors
(c) diodes (d) LEDs

[*Ans.* (a) capacitors]

38. **The lower comb of van de graaff generator is maintained at a positive potential of**

(a) 10 kV (b) 10^7 V
(c) 100 V (d) 10^3 V

[*Ans.* (a) 10 kV]

39. **A bird sitting on a high power line**

(a) gets killed instantly (b) gets a mild shock
(c) is not affected practically
(d) gets a fatal shock

[*Ans.* (c) is not affected practically]

40. **If C is the capacitance of an air filled capacitor and C' is the capacitance of dielectric filled capacitor, then**

(a) $C' = \varepsilon_r C$ (b) $C' = \dfrac{C}{\varepsilon_r}$
(c) $C' = \dfrac{\varepsilon_r}{C}$ (d) $C' = \varepsilon_0 \varepsilon_r C$

[*Ans.* (a) $C' = \varepsilon_r C$]

41. **The capacitance of a parallel plate capacitor increases from 5μ*f* of 50μ*f* when a dielectric is filled between the plates. The permitivity of the dielectric is**

(a) 8.854×10^{-12} C² N⁻¹ m⁻²
(b) 8.854×10^{-11} C² N⁻¹ m⁻²
(c) 10×10^{-12} C² N⁻¹ m⁻²
(d) 12×10^{-12} C² N⁻¹ m⁻²

[*Ans.* (b) 8.854×10^{-11} $C^2 N^{-1} m^{-2}$]

Hint:
$$\varepsilon = \varepsilon_0 \varepsilon_r \qquad \left[\varepsilon_r = \frac{C_2}{C_1}\right]$$
$$= 8.854 \times 10^{-12} \times \left(\frac{C_2}{C_1}\right)$$
$$= 8.854 \times 10^{-12} \times \frac{50 \times 10^{-6}}{5 \times 10^{-6}}$$
$$= 8.854 \times 10^{-11}\ C^2 N^{-1} m^{-2}$$

42. **An electric dipole placed at an angle in a non-uniform electric field experiences**

(a) neither a force nor a torque
(b) torque
(c) both force and torque
(d) force only **[*Ans.* (c) both force and torque]**

43. **Two copper spheres A and B of same size are charged to same potential. A is hollow and B is solid. Which of the two holds more charge?**

(a) Solid sphere cannot hold any charge
(b) hollow sphere cannot hold any charge
(c) both have zero charge
(d) both have the same charge

[*Ans.* (d) both have the same charge]

44. **Two conducting charged spheres *x* and *y* having unequal charges are connected by a wire. Which of the following is true?**

(a) charge is conserved
(b) electrostatic energy is conserved
(c) both the charge and electrostatic energy are conserved
(d) neither of these is conserved

[*Ans.* (a) charge is conserved]

45. **Which of the following statement on equipotential surface is wrong?**

(a) The potential difference between any two points on the surface, is zero.
(b) The electric field is always perpendicular to the surface.
(c) Equipotential surface is always spherical.
(d) No work is done in moving a charge along the surface. **[*Ans.* (c) Equipotential surface is always spherical]**

46. **Value of *k* in Coulomb's law depends upon**

(a) magnitude of charges
(b) distance between charges
(c) both (a) and (b)
(d) medium between two charges

[*Ans.* (d) medium between two charges]

47. **Two identical metal balls with charges +2Q and –Q are separated by some distance and exerts a force F on each other. They are joined by a conducting wire, which is then removed. The force between them will now.**

(a) $F/12$ (b) $F/8$ (c) F (d) $F/4$

[*Ans.* (b) $F/8$]

48. **A spherical equipotential surface is not possible**

(a) for a point charge (b) for a dipole
(c) inside a spherical capacitor
(d) inside a uniformly charged sphere

[*Ans.* (b) for a dipole]

49. **Charge Q is divided into two parts which are then kept some distance apart. The force between them will be maximum if the two parts are**

(a) each $\dfrac{Q}{2}$ (b) each $\dfrac{Q}{5}$
(c) $\dfrac{Q}{3}$ and $\dfrac{2Q}{3}$ (d) $\dfrac{Q}{4}$ and $\dfrac{3Q}{4}$

[*Ans.* (a) each $\dfrac{Q}{2}$]

Unit 1

50. In a parallel plate capacitor of capacitance C, a metal sheet is inserted between the plates, parallel to them. The thickness of the sheet is half of the separation between the plates. The capacitance now becomes

(a) 2C (b) $\frac{C}{4}$ (c) 4C (d) $\frac{C}{2}$

[*Ans.* (a) 2C]

51. When 4V emf is applied across a 1F capacitor, it will store energy of

(a) 2J (b) 4J (c) 6J (d) 8J

[*Ans.* (d) 8J]

52. Dielectric constant for the metals is

(a) Zero (b) >1
(c) <1 (d) Infinite

[*Ans.* (d) Infinite]

53. Region around a charge *q* in which it exerts force on a test charge is called

(a) electric flux intensity (b) electric force
(c) electric field
(d) Coulomb's force **[*Ans.* (c) electric field]**

54. Which of the following cannot be the units of electric field intensity?

(a) NC^{-1} (b) Vm^{-1}
(c) JC^{-1} /m (d) JC^{-1}

[*Ans.* (d) JC^{-1}]

55. The electric flux through a surface will be minimum when the angle between E and A is

(a) 90° (b) 60° (c) 0° (d) 45°

[*Ans.* (a) 90°]

56. One Joule per Coulomb is called

(a) Gauss (b) ampere
(c) farad (d) volt

[*Ans.* (d) volt]

57. When three capacitors are joined in series, the total capacitance is

(a) equal to the sum of the capacitance
(b) greater than the value of the maximum capacitance
(c) less than the value of the minimum capacitance
(d) none of the above **[*Ans.* (b) greater than the value of the maximum capacitance]**

58. The concentric spheres of radii R and r have similar charges with equal surface densities (σ). What is the electric potential at their common centre?

(a) $\frac{\sigma}{\varepsilon_o}(R-r)$ (b) $\frac{\sigma}{\varepsilon_o}(R+r)$
(c) $R\frac{\sigma}{\varepsilon_o}$ (d) $\frac{\sigma}{\varepsilon_o}$

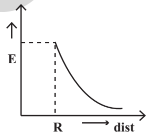
[*Ans.* (b) $\frac{\sigma}{\varepsilon_0}(R+r)$]

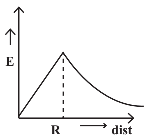
59. A charge Q µC is placed at the center of a cube. The flux coming out from any surface will be

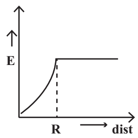
(a) $\frac{Q}{24\varepsilon_o}$ (b) $\frac{Q}{8\varepsilon_o}$
(c) $\frac{Q}{6\varepsilon_o}\times 10^{-6}$ (d) $\frac{Q}{6\varepsilon_o}\times 10^{-3}$

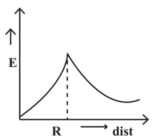
[*Ans.* (c) $\frac{Q}{6\varepsilon_0}\times 10^{-6}$]

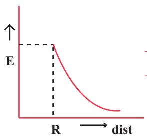
60. Which graph shows the variation of electric field E due to a hollow spherical conductor of radius R as a function of distance from the centre of the sphere?

(a) 

(b) 

(c) 

(d) 

[*Ans.* (a) 

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61. In two concentric hollow spheres of radii r and R (>r), the charge Q is distributed such that their surface densities are same. Then the potential at their common centre is

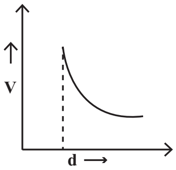
(a) $\frac{Q(R^2+r^2)}{4\pi\varepsilon_o(R+r)}$ (b) $\frac{QR}{R+r}$
(c) Zero (d) $\frac{Q(R+r)}{4\pi\varepsilon_o(R^2+r^2)}$

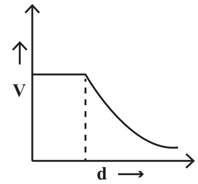
[*Ans.* (d) $\frac{Q(R+r)}{4\pi\varepsilon_0(R^2+r^2)}$]

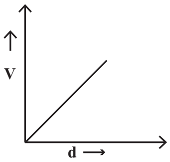
ELECTROSTATICS

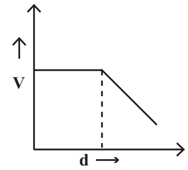
62. **Which graph shows that in a hollow spherical shell potential (V) changes with respect to distance (r) from centre?**

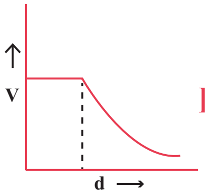
$$\left[V_{inside} = \frac{Q}{4\pi\varepsilon_o R} r \leq R,\ \ V_{outside} = \frac{Q}{4\pi\varepsilon_o r} r \geq R,\ \ V \alpha \frac{1}{r}\right]$$

(a) 

(b) 

(c) 

(d) 

[***Ans.*** **(b)** 

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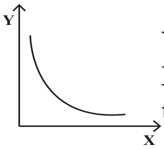
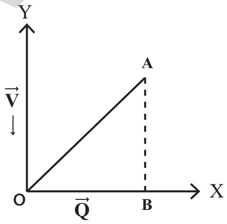
63. 

What physical quantities may X and Y represent? [Y represents the first mentioned quantity].

(a) K.E - velocity of a particle
(b) pressure - temperature of a given gas (constant volume)
(c) capacitance - charge to give a constant potential
(d) potential - capacitance to give a constant charge [***Ans.*** **(d) potential - capacitance to give a constant charge**]

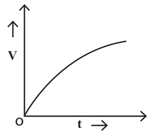
64. **Charge Q on a capacitor varies with voltage V as shown in graph, where Q is along X-axis and V along Y-axis. The area of triangle OAB represents**

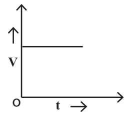


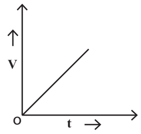
(a) capacitance
(b) capacitive reactance
(c) magnetic field between the plates
(d) energy stored in the capacitor

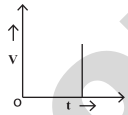
[***Ans.*** **(d) energy stored in the capacitor**]

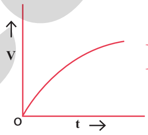
65. **During charging a capacitor variation of potential V of the capacitor with time *t* is shown as**

(a) 

(b) 

(c) 

(d) 

[***Ans.*** **(a)** 

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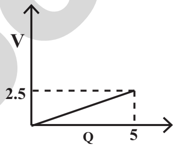
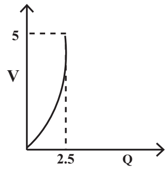
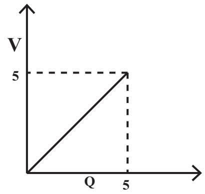
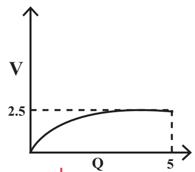
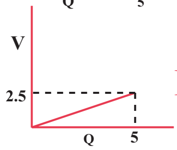
66. **A condenser of 2μF capacitance is charged steadily from 0 to 5 coulomb. Which of the following graphs correctly represents the variation of potential difference across its plates with respect to the charge on the condenser [Q = C V]**

(a) 

(b) 

(c) 

(d) 

[***Ans.*** **(a)** 

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67. **A point charge *q* is placed at a distance $a/2$ directly above the centre of a square of side '*a*'. The electric flux through the square is**

(a) $\frac{q}{\varepsilon_o}$ (b) $\frac{q}{\pi\varepsilon_o}$ (c) $\frac{q}{4\varepsilon_o}$

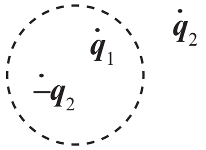
(d) $\frac{q}{6\varepsilon_o}$ [***Ans.*** **(d)** $\frac{q}{6\varepsilon_0}$]

68. **Electric field intensity at a point due to an infinite sheet of charge having surface charge density σ is E. If the sheet were conducting, electric intensity would be**

(a) $\frac{E}{2}$ (b) E (c) 2E (d) 4E

[***Ans.*** **(c) 2E**]

69. A Gaussian surface in the figure is shown by dotted line. The electric field on the surface will be



(a) due to q_1 and q_2 only
(b) due to q_2 only (c) zero
(d) due to all **[Ans. (d) due to all]**

70. A charge q is placed at the centre of a cubical box of side with top open. The flux of electric field through the surface of the cubical box is

(a) zero (b) $\frac{q}{\varepsilon_o}$

(c) $\frac{q}{6\varepsilon_o}$ (d) $\frac{5q}{6\varepsilon_o}$

[Ans. (d) $\frac{5q}{6\varepsilon_0}$]

71. Surface density of charge on a sphere of radius R in terms of electric intensity E at a distance r in free space is

(a) $\varepsilon_o E\left(\frac{R}{r}\right)^2$ (b) $\frac{\varepsilon_o ER}{r^2}$

(c) $\varepsilon_o E\left(\frac{r}{R}\right)^2$ (d) $e_o E\frac{r}{R^2}$

[Ans. (c) $\varepsilon_o E\left(\frac{r}{R}\right)^2$]

72. The electric flux over a sphere of radius 1m is ϕ. If radius of the sphere were doubled without changing the charge enclosed, electric flux would become

(a) 2ϕ (b) $\frac{\phi}{2}$ (c) $\frac{\phi}{4}$ (d) ϕ

[Ans. (d) ϕ]

73. A charge q is enclosed as shown in fig. The electric flux is

(i) $\boxed{q}$ (ii) q (iii) q

(a) maximum in (i) (b) maximum in (ii)
(c) maximum in (iii) (d) equal in all

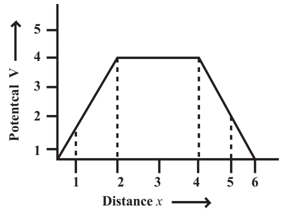
[Ans. (d) equal in all]

74. Electric field at a distance r from infinitely long conducting sheet is proportional to

(a) r^{-1} (b) r^{-2}
(c) $r^{3/2}$ (d) independent of r

[Ans. (d) independent of r]

75. Find the electric field at $x = 5$m from the graph.



(a) 2 V/m (b) –2.5 V/m
(c) 2/5 V/m (d) –2/5 V/m

[Ans. (a) 2 V/m]

76. The negative gradient of potential is

(a) torque (b) electric current
(c) electric field intensity (d) electric force

[Ans. (c) electric field intensity]

77. The force experienced by a unit charge is called

(a) Electric potential (b) Electric flux
(c) Electric field (d) Static electricity

[Ans. (c) Electric field]

Match the following

1.

1.	Benjamin Franklin	(a)	Electrical battery
2.	Michael Faraday	(b)	Frictional electricity
3.	Alessandro Volta	(c)	Concept of field
4.	Thales	(d)	Lightning Arrestor

	(1)	(2)	(3)	(4)
(a)	b	c	d	a
(b)	c	d	b	a
(c)	d	c	a	b
(d)	b	d	a	c

[Ans. (c) d c a b]

2.

1.	Amber	(a)	negatively charged
2.	Rubber	(b)	$\varepsilon_r = 1$
3.	glass rod	(c)	a kind of resin
4.	Air	(d)	Positively charged

	(1)	(2)	(3)	(4)
(a)	c	b	d	a
(b)	c	a	d	b
(c)	b	c	d	a
(d)	d	c	a	b

[Ans. (b) c a d b]

3.

1.	Dielectric	(a)	Faraday cage
2.	Capacitor	(b)	Insulator
3.	Electrostatic shielding	(c)	Van de graaff generator
4.	Electrostatic Induction	(d)	Condenser

	(1)	(2)	(3)	(4)
(a)	b	d	a	c
(b)	c	d	a	b
(c)	d	a	b	c
(d)	d	c	a	b

[Ans. (a) b d a c]

4.

1.	Permittivity of free space	(a)	Newton's III law
2.	Electrostatic force	(b)	Inverse law
3.	Coulomb law	(c)	Conservative force
4.	Coulomb force	(d)	8.854×10^{-12} $C^2N^{-1}m^{-2}$

	(1)	(2)	(3)	(4)
(a)	b	d	a	c
(b)	d	b	c	a
(c)	b	a	c	d
(d)	d	a	b	c

[Ans. (d) d a b c]

5.

1.	Electric flux	(a)	Maximum electric field
2.	Electric field	(b)	Scalar quantity
3.	Electric dipole moment	(c)	Vector quantity
4.	Dielectric strength	(d)	acts from $-q$ to $+q$

	(1)	(2)	(3)	(4)
(a)	a	d	b	c
(b)	b	c	d	a
(c)	c	d	b	a
(d)	b	a	d	c

[Ans. (b) b c d a]

Fill in the Blanks

1. Van de Graaff generator produces an electrostatic potential difference of _______ volts.
(a) 10^8 (b) 10^9
(c) 10^7 (d) 10^{10} **[Ans. (c) 10^7]**

2. For sharper edge, the _____ is greater. This principle is used in Lightning arrester.
(a) linear charge density
(b) surface charge density
(c) volume charge density (d) capacitance
[Ans. (b) surface charge density]

3. For continuous charge distributions, _______ methods can be used.
(a) integration (b) differentiation
(c) multiplication (d) addition
[Ans. (a) integration]

4. For a large charge accumulation, the end of the conductor should have larger curvature that is _________.
(a) bigger radius (b) Smaller radius
(c) maximum radius (d) less bent
[Ans. (b) Smaller radius]

5. Relative permittivity (ε_r) is also known as ________.
(a) dielectric strength
(b) dielectric constant (c) polarisability
(d) susceptibility **[Ans. (b) dielectric constant]**

6. The energy stored per unit volume of space is defined as ___________.
(a) linear density (b) surface density
(c) volume density
(d) energy density **[Ans. (d) energy density]**

7. _________ is a very large unit of capacitance.
(a) Farad (b) Microfarad
(c) Picofarad (d) Nanofarad
[Ans. (a) Farad]

8. The total dipole moment per unit volume of the dielectric is ________.
(a) induction
(b) charge distribution (c) polarisation
(d) quantisation **[Ans. (c) polarisation]**

9. An example for a Non-polar molecule is
(a) H_2O (b) N_2O
(c) CO_2 (d) NH_3
[Ans. (c) CO_2]

10. Which instrument was used to demonstrate the electrostatic shielding?
(a) Lightning arrester
(b) Van de graaff generator
(c) Faraday cage
(d) Gold leaf electroscope
[Ans. (c) Faraday cage]

11. Gauss law is another form of ________.
(a) Newton's law (b) Kepler's law
(c) Ohm's law (d) Coulomb's law
[Ans. (d) Coulomb's law]

12. If a cube of side 5cm has a charge of 6 micro coulomb, then the surface charge density is __________.
(a) $4 \times 10^2\ \mu C / m^2$ (b) $4 \times 10^2\ C / m^2$
(c) $4 \times 10^3\ \mu C / m^2$ (d) $4 \times 10^3\ C / m^2$
[Ans. (a) $4 \times 10^2\ \mu C / m^2$]

Unit 1

Hint:

$$\sigma = \frac{Q}{6 \times A} = \frac{6\times10^{-6}}{6\times5\times10^{-2}\times5\times10^{-2}}$$

Where, [A = (side)²]

$$\sigma = \frac{10^{-6}\times10^{4}}{25} = 0.04 \times 10^{-2}\ C/m^2$$

$$= 4 \times 10^{-4}\ C/m^2 \text{ (or) } 400\ \mu C/m^2.$$

13. Electrostatic force is stronger than gravitational force by ______.
(a) 2.23×10^{39} times (b) 2.25×10^{39} times
(c) 2.41×10^{39} times (d) 2.29×10^{39} times
[Ans. (c) 2.41×10^{39} times]

14. Which of the following is a scalar quantity?
(a) electric dipole moment
(b) electric field intensity
(c) electric potential (d) current density
[Ans. (c) electric potential]

15. Capacitors use the principle of _________.
(a) self induction (b) mutual induction
(c) electrostatic induction
(d) dielectric polarisation
[Ans. (c) electrostatic induction]

16. Electrostatics deals with the _______.
(a) charges in motion
(b) static electric charges
(c) charges through conductors
(d) accelerated charges
[Ans. (b) static electric charges]

17. When the amber is rubbed with fur, it absorbs bits of papers. This was invented by _______.
(a) Amber (b) Thales
(c) Gilbert
(d) Benjamin Franklin **[Ans. (b) Thales]**

18. The force between like charges is _______.
(a) attraction (b) repulsion
(c) no force (d) none
[Ans. (b) repulsion]

19. The charge of an electron is _______.
(a) 1.6×10^{-19} C (b) 1.6×10^{-91} C
(c) 16×10^{-20} C (d) 6.1×10^{-19} C
[Ans. (a) 1.6×10^{-19} C]

20. Device used for storing charges is _______.
(a) resistor (b) capacitor
(c) inductor (d) insulator
[Ans. (b) capacitor]

21. The force between two charges at a particular distance in air is 36 N. If the distance between the charges is filled by a medium of dielectric constant 6, then the force is _______.
(a) 216 N (b) 6 N
(c) 30 N (d) 24 N
[Ans. (b) 6 N]

22. A closed system contains four charges –8.1C, 14.6C, 20.2C and –200 mC. The total charge in the system _______.
(a) 26.5 C (b) –173.3 C
(c) 43.1 C (d) 243.9 C
[Ans. (a) 26.5 C]

23. The repulsive force between two like charges of 1 coulomb each separated by a distance of 1 m in vacuum is equal to :
(a) 9×10^9 N (b) 10^9 N
(c) 9×10^{-9} N (d) 9 N
[Ans. (a) 9×10^9 N]

24. Two charged bodies of charges +q, –3q are brought in contact and separated. The charges possessed by each body after separation.
(a) $-q, -q$ (b) $+q, -2q$
(c) $-q, +3q$ (d) $+q, +q$
[Ans. (a) $-q, -q$]

25. The unit of relative permittivity is
(a) $C^2N^{-1}m^{-2}$ (b) Nm^2C^{-2}
(c) No unit (d) $NC^{-2}\ m^{-2}$
[Ans. (c) No unit]

26. The value of relative permittivity of air is
(a) $8.854 \times 10^{-12}\ C^2N^{-1}m^{-2}$
(b) $9 \times 10^9\ C^2N^{-1}m^{-2}$ (c) 1
(d) 8.854×10^{12} **[Ans. (c) 1]**

27. By using law of conservation of electric charge balance the following equations :
$_{92}U^{238} \rightarrow {}_{90}Th^{234} +$ _______.
(a) $_2He^4$ (b) $_1H^3$ (c) $_1H^2$ (d) $_1H^1$
[Ans. (a) $_2He^4$]

28. Torque on a dipole in a uniform electric field is maximum when the angle between $\vec{P}$ and $\vec{E}$ is _______.
(a) 0° (b) 90°
(c) 45° (d) 180°
[Ans. (b) 90°]

29. The unit of electric field intensity is _______.
(a) NC^{-1} (b) $NC^{-1}C^2m^{-1}$
(c) Cm (d) JC^{-1}
[Ans. (a) NC^{-1}]

ELECTROSTATICS

30. **Electric field intensity and electric potential are related by _______.**

(a) $E = -\frac{dV}{dt}$ (b) $E = -\frac{dV}{dx}$

(c) $E = \frac{dV}{dt}$ (d) $E = \frac{-dx}{dV}$

[**Ans.** (b) $E = -\frac{dV}{dx}$]

31. **Torque experienced by a dipole in an electric field when it is placed parallel to the field is_______.**

(a) $pE \sin \theta$ (b) $-pE \cos \theta$

(c) infinity (d) zero

[**Ans.** (d) zero]

32. **Which one of the following relation is correct?**

(a) $V = \frac{q}{C}$ (b) $C = q \tan q$

(c) $V = qC$ (d) $q = \frac{1}{2} C^2V$

[**Ans.** (a) $V = \frac{q}{C}$]

33. **The intensity of the electric field that produces a force of 10^{-5} N on a charge of 5 μC is**

(a) 5×10^{-11} NC^{-1} (b) 50 NC^{-1}

(c) 2 NC^{-1} (d) 0.5 NC^{-1}

[**Ans.** (c) 2 NC^{-1}]

34. **The electric field intensity at a short distance *r* from uniformly charged infinite plane sheet of charge is**

(a) proportional to r (b) proportional to $\frac{1}{r}$

(c) proportional to $\frac{1}{r^2}$ (d) independent of *r*

[**Ans.** (d) independent of *r*]

35. **The intensity of electric field at a point is**

(a) the force experienced by a charge *q*

(b) the work done in bringing unit positive charge from infinity to that point

(c) the positive gradient of the potential

(d) the negative gradient of the potential

[**Ans.** (a) the force experienced by a charge *q*]

36. **Two point charges +*q* and –*q* are placed at points A and B respectively separated by a small distance. The electric field intensity at the midpoint O of AB :**

(a) is zero (b) acts along AB

(c) acts along BA

(d) acts perpendicular to AB

[**Ans.** (b) acts along AB]

37. **The number of electric lines of forces moving outwards from 1C charge is _______.**

(a) 1.13×10^{11} (b) 8.85×10^{-11}

(c) 9×10^{9} (d) infinite

[**Ans.** (c) 9×10^{9}]

38. **Electric lines of force _______.**

(a) intersect each other (b) never intersect

(c) intersect at infinity

(d) are always parallel

[**Ans.** (b) never intersect]

Find the odd one out

1. (a) Electric dipole moment

(b) Electric field intensity

(c) Electric potential difference

(d) Electrostatic shielding

[**Ans.** (d) Electrostatic shielding]

Hint: (a), (b), (c) are quantities, (d) is a process.

2. (a) Mica (b) Ebonite

(c) Aluminium (d) Oil

[**Ans.** (c) Aluminium]

Hint: (a), (b), (d) are dielectrics, (c) is a conductor.

3. (a) O_2 (b) HCl

(c) CO_2 (d) H_2

[**Ans.** (b) HCl]

Hint: (a), (c), (d) are Non-polar molecules, but (b) is a polar molecule.

4. (a) α - particle (b) electron

(c) proton (d) deutron

[**Ans.** (b) electron]

Hint: electron cannot be accelerated using van de graaff generator, but (a), (c) & (d) can be accelerated by it.

5. (a) To eliminate sparkling in engines

(b) To reduce voltage fluctuations

(c) To protect tall buildings

(d) To generate electromagnetic oscillations

[**Ans.** (c) To protect tall buildings]

Hint: (a), (c) and (d) are the applications of capacitors but (c) is the usage of lightning arrester.

Choose the incorrect pair

1.

(a)	Franklin	-	+ve, –ve charges
(b)	Gauss	-	electrical battery
(c)	Van de graaff	-	high potential
(d)	Faraday	-	Unit of capacitance

[**Ans.** (b) Gauss - electrical battery]

2.

(a)	Corona discharge	-	Lightning arrester
(b)	Electrostatic induction	-	Van de graaff generator
(c)	ε_r of any medium	-	Less than one
(d)	Charge per unit area	-	Surface charge density

[*Ans.* (c) ε_r of any medium - Less than one]

Choose the correct pair

1.

(a)	NH_3	-	Non - polar molecule
(b)	O_2	-	Polar molecule
(c)	Mica	-	Conductor
(d)	Ceramic	-	Capacitor

[*Ans.* (d) Ceramic - Capacitor]

2.

(a)	Volt	-	electric current
(b)	C/m	-	electric dipole moment
(c)	NC^{-1}	-	electric field intensity
(d)	C^2Nm^2	-	electric flux

[*Ans.* (c) NC^{-1} - electric field intensity]

Assertion - Reason

Direction:

(a) Assertion and Reason are correct and Reason is the correct explanation of Assertion.
(b) Assertion and Reason are true but Reason is the false explanation of the Assertion.
(c) Assertion is true but Reason is false.
(d) Assertion is false but Reason is true.

1. **Assertion :** Two surfaces of spheres A and B of radii r_1 and r_2 when connected by a wire, form an equipotential surface. i.e $V_A = V_B$

Reason : Surface charge density (σ) is inversely proportional to the radius of the sphere i.e $\sigma \propto \frac{1}{r}$. [If radius is smaller, σ will be larger]

[*Ans.* (a) Assertion and Reason are correct and Reason is the correct explanation of Assertion]

2. **Assertion :** When dielectrics like mica or paper or oil are introduced between the plates of a capacitor then the capacitance will increase.

Reason : Capacitance is directly proportional to the potential difference.

[*Ans.* (c) Assertion is true but Reason is false]

Choose the correct or Incorrect statements

1. (I) **For most dielectrics the polarisation is directly proportional to the strength of external electronic field $(\vec{E}_{ext})$.**

(II) **A dielectric is made up of only non-polar molecules.**

Which is correct statement?

(a) I only (b) II only
(c) both are correct (d) none of these

[*Ans.* (a) I only]

2. (I) **There is no net charge inside the conductors. The charges must reside only one the surface of the conductors.**

(II) **The electric field is not zero everywhere inside the conductor .**

Which one is Incorrect statement?

(a) I only (b) II only
(c) both are correct (d) none of these

[*Ans.* (b) II only]

Very Short Answer Questions 2 marks

1. **Write basic properties of charges.**

Ans. (i) Electric Charges
(ii) Conservation of charges
(iii) Quantisation of charges

2. **State Coulomb's law.**

Ans. Force between 2 charges is directly proportional to product of charges. Inversely proportional to the square of distance between them.

$$\vec{F} = k.\frac{q_1 q_2}{r^2}.\hat{r}$$

3. **Give a comparison of electrical and gravitational forces?**

Ans. (i) Both forces obey inverse square law, F α $\frac{1}{r^2}$
(ii) Both forces are proportional to product of masses or charges.
(iii) Both forces are conservative forces.
(iv) Both forces can operate in vacuum.

4. **What are Non-polar molecules?**

Ans. The centers of positive and negative charges coincide and there is no permanent dipole moment. Examples hydrogen (H_2), oxygen (O_2), and carbon dioxide (CO_2) etc.

5. When does a dielectric said to be polarized?

Ans. When an external electric field is applied, the centers of positive and negative charges are separated by a small distance which induces dipole moment in the direction of the external electric field. Then the dielectric is said to be polarized by an external electric field.

6. Two field lines don't intersect each other why?

Ans. (i) If it intersects, there will be two tangents at that particular point.

(ii) Then the charges are supposed to move in two paths in same time.

(iii) Hence it is not possible.

7. What are induced dipoles?

Ans. When an external electric field applied, the dipoles inside the material tend to align in the direction of the electric field. Hence a net dipole moment is induced in it. Then the dielectric is said to be polarized by an external electric field and the dipoles are known as induced dipoles.

8. What are Polar molecules?

Ans. (i) In polar molecules, the centers of the positive and negative charges are separated.

(ii) A permanent dipole moment. H_2O, N_2O, HCl, NH_3.

9. What is dielectric breakdown?

Ans. When the external electric field applied to a dielectric is very large, it tears the atoms apart so that the bound charges become free charges. Then the dielectric starts to conduct electricity. This is called dielectric breakdown.

10. What is a Capacitor?

Ans. Capacitor is a device used to store electric charge and electrical energy. It consists of two conducting objects (usually plates or sheets) separated by some distance.

11. When we rotate the blades, it starts to rotate as usual. Why is it so?

Ans. To rotate any object, there must be a torque applied on the object. For the ceiling fan, the initial torque is given by the capacitor widely known as a condenser. If the condenser is faulty, it will not give sufficient initial torque to rotate the blades when the fan is switched on.

12. What is the electric flux through a cube of side 1 cm which encloses on electric dipole?

Ans. Net electric flux is zero because

(i) It is independent of the shape and size

(ii) Net charge of the electric dipole is zero.

13. (i) Two insulated charged copper spheres A & B of identical size have charges q_A and $-3q_A$ respectively. When they are brought in contact with each other and then separated, what are the new charges on them?

(ii) When a third sphere of same size but uncharged is brought in contact with first and then with second and finally removed from both, what are the new charges?

Ans. (i) Charge on each sphere = $\frac{q_A - 3q_A}{2} = -q_A$

(ii) New charge on A is $\frac{q_A}{2}$

New charge on B is $\frac{q_A + (2q_B)}{4}$

$$\because \frac{\frac{q_A}{2} + q_B}{2} = \frac{q_A}{4} + \frac{q_B}{2} = \frac{q_A + 2q_B}{4}$$

$$q_B = -3q_A$$

$$\because \quad q_B = -3q_A$$

$\therefore$ New charge on B_1 is $\frac{q_A - 6q_A}{4}$

New charge on B = $-\frac{5}{4}q_A$

14. A charge Q μc is placed at the centre of a cube what would be the (i) flux through one face? (ii) flux passing through two opposite faces of the cube?

Electric flux through whole cube = $\frac{Q}{\varepsilon_0}$

Ans. (i) Electric flux through one face = $\frac{1}{6}\cdot\frac{Q}{\varepsilon_0}$ μV_m

(ii) By symmetry the flux through each of the six faces of cube will be same when charge is placed at the centre.

$$\therefore \varphi_E = \frac{1}{6}\cdot\frac{Q}{\varepsilon_0}$$

Thus electric flux passing through two opposite faces of the cube

$$= 2\cdot\frac{1}{6}\cdot\frac{Q}{\varepsilon_0}$$

$$\varphi = \frac{1}{3}\cdot\frac{Q}{\varepsilon_0}$$

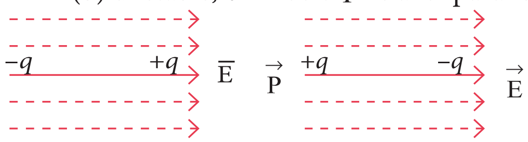
15. What orientation of an electric dipole in a uniform electric field corresponds to its (i) stable and (ii) unstable equilibrium? Depict the orientations.

Ans. (i) In stable equilibrium the dipole moment is parallel to the direction of electric field. i.e. $\theta = 0$.

(ii) In unstable equilibrium, P.E. is max., so $\theta = \pi$. i.e. dipole moment is anti-parallel to electric field.

(iii) $\theta = 0^\circ$ $\vec{P}$ is parallel to $\vec{E}$ stable equilibrium

(b) unstable, $\theta = 180^\circ$. $\vec{P}$ is anti-parallel



16. An electric dipole is held in a uniform electric field.
(i) Show that the net force acting on it is zero.
(ii) The dipole is aligned parallel to the field. Find the work done in rotating it through the angle of 180°

Ans. (i) The dipole moment of dipole $|\vec{P}| = q \times 2a$

Force on $-q$ at A $= -q\vec{E}$

Force on $+q$ at B $= +q\vec{E}$

Net force on the dipole $= q\vec{E} - q\vec{E} = 0$

(ii) Work done on dipole when it is rotated through 180°

$$W = \Delta U = pE(\cos\theta_1 - \cos\theta_2)$$
$$= pE(\cos 0^\circ - \cos 180^\circ)$$
$$= pE(1 - (-1))$$
$$W = 2pE$$

17. A sphere of charge +Q is fixed. A smaller sphere of charge +q is placed near the larger sphere and released from rest. The small sphere will move away from large sphere with
a. decreasing velocity & decreasing acceleration.
b. decreasing velocity & increasing acceleration.
c. decreasing velocity & constant acceleration
d. increasing velocity & decreasing acceleration
e. increasing velocity & increasing acceleration
Which of the above statement is correct?

Ans. (a) At a distance r, the force on the small sphere due to large sphere

$$F = \frac{1}{4\pi\varepsilon_0}\cdot\frac{Qq}{mr^2}$$

(b) If m is the mass of small sphere then its acceleration

$$a = \frac{F}{m} = \frac{1}{4\pi\varepsilon_0}\cdot\frac{Qq}{mr^2}$$

(c) As the small sphere is pushed away (i.e. r increased) 'a' decreases.

(d) As 'a' is always +ve the speed of the small sphere goes on increasing.

(e) ∴ increasing velocity and decreasing acceleration. **(d) is correct.**

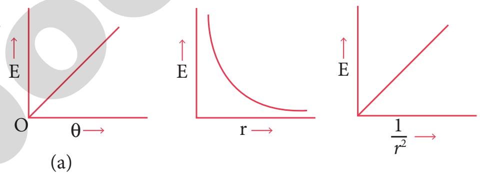
18. (i) Electric field lines do not have sudden breaks why is it so?
(ii) Explain why two field lines never cross each other at any point.

Ans. (i) Electric field line is the path of movement of a charge. A moving charge experiences a continuous force in an electric field, so field line is always continuous

(ii) The field lines never intersect since if they cross, there will be two directions of electric field at the point of intersection, which is impossible.

19. Graphically represent the variation of electric field due to point charge Q with (a) magnitude of charge Q (b) r and (c) $\frac{1}{r^2}$ where r is the distance of the observation point from the charge.

Ans.



20. A positive charge $+q$ is located at a point, what is the work done, if a unit positive charge is carried once around this charge along a circle of radius r about this point?

Ans. The potential at each point on the circular path around the charge is same i.e. potential difference between the initial and final position is zero.

∴ Work done W = V ×q = 0 × 1 = 0.

21. What do you mean by Potential Energy of an electric dipole, when placed in electric field?

Ans. An electric dipole always tends to rotate itself along the direction of electric field. Work has to be done in rotating the dipole to some other orientation θ. This work done in rotating dipole gets stored in the dipole in the form of potential energy.

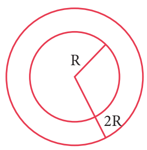
22. Two concentric metallic spherical shells of radii R and 2 R are given charges Q_1 & Q_2 respectively. The surface charge density on the outer surfaces of the shells are equal. Determine the ratio $Q_1 = Q_2$.

Ans. Surface charge density σ is same

∴ charge $Q_1 = 4\pi R^2\sigma$

charge $Q_2 = 4\pi(2R^2)\sigma$

$$\frac{Q_1}{Q_2} = \frac{4\pi R^2\sigma}{4\pi(4R^2)\sigma} = \frac{1}{4}$$



23. Two isolated metal spheres A & B have radii R & 2R respectively and same charge q. Find which of the two spheres have greater energy density just outside the surface of the sphere.

Ans. Energy density $U = \frac{1}{2}\varepsilon_0 E^2$

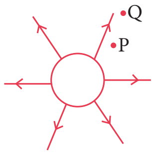
But $E = \frac{\sigma}{\varepsilon_0} = \frac{Q}{A\varepsilon_0}$

$$\therefore U = \frac{1}{2}\cdot\frac{\varepsilon_0 Q^2}{A^2\varepsilon_0} \Rightarrow U = \frac{Q^2}{2A^2}$$

$$U \propto \frac{1}{A^2} \Rightarrow U_A > U_B$$

24. What is the work done by the field in moving a small positive charge from Q to P? Give reason.

Ans. The work done by the field is negative. This is since the charge is moved against the force exerted by the field.



25. A point charge Q is placed at point O. Potential difference $V_A - V_B$ is positive. Is the charge Q negative or positive?

Ans. The electric potential $V = \frac{1}{4\pi\varepsilon_0}\cdot\frac{Q}{r}$

$$V = \frac{1}{r}$$

The potential due to a point charge decreases with increase of distance.

$V_A - V_B > 0 \Rightarrow V_A > V_B$.

Hence the charge Q is positive.

26. The electric field due to a point charge depends on the distance *r* as parallel indicate how each of the following quantities depends on *r*?

a. Intensity of light from a point source.

b. Electrical potential due to a point charge.

c. Electrical potential at a distance *r* from centre of a charged metallic sphere

Given *r* < radius of the sphere.

Ans. (a) $I \propto \frac{1}{r^2}$

(b) $V \propto \frac{1}{r}$

(c) V does not depend on *r*.

27. What are the factors on which the capacity of a parallel plate capacitor with dielectric depend?

Ans. (i) Area of the plates

(ii) Separation between the plates.

(iii) Dielectric constant of the dielectric between the plates. The capacitance of a capacitor depend upon geometrical dimension and the nature of the dielectric between the plates.

28. A parallel plate capacitor is charged by a battery. After some time, the battery is disconnected and a dielectric slab with its thickness equal to the plate separation is inserted between the plates. How will be (i) the capacitance of the capacitor (ii) potential difference between the plates & (iii) the energy stored in the capacitor gets affected?

Ans. Q_0 - charge, V_0 - potential difference, C_0 - capacitance, U_0 - energy stored, before the dielectric slab is inserted.

(i) The Capacitance of the capacitor without the dielectric is $C_0 = \frac{Q_0}{V_0}$

When the battery is disconnected and the dielectric is inserted, the capacitance increases from C_0 to C.

$\therefore C = \varepsilon_r C_0$, where ε_r is the dielectric constant.

(ii) The electrostatic potential difference is reduced and the charge Q_0 will remain constant, after the battery is disconnected.

$\therefore$ The new potential difference is, $V = \frac{V_0}{\varepsilon_r}$.

(iii) The energy stored in the capacitor before the insertion of the dielectric is,

$$U_0 = \frac{1}{2}\frac{Q_0^2}{C_0}$$

After the dielectric is inserted, the charge Q_0 remains constant but the capacitance is increased. As a result, the stored energy is decreased.

$$U = \frac{1}{2}\frac{Q_0^2}{C} = \frac{1}{2}\frac{Q_0^2}{\varepsilon_r C_0} = \frac{U_0}{\varepsilon_r}$$

Short Answer Questions — 3 marks

1. How do we determine the electric field due to a continuous charge distribution? Explain.

Ans. Electric filed due to continuous charge distribution :

Consider the charged object of irregular shape. It is divided into large number of charge elements.

$\Delta q_1, \rightarrow 1^{st}$ charge element; r_{1p} - distance of the point P from I^{st} charge

$\Delta q_2, \rightarrow$ Second charge element; r_{2p} - distance of the point P from 2^{st} charge

$\Delta q_n, \rightarrow n^{th}$ charge element; r_{np} - distance of the point P from n^{th} charge

Then. electric filed at point P due to all charge elements is given by

$$\vec{E} \approx \frac{1}{4\pi\varepsilon_0}\left(\frac{\Delta q_1}{r_{1P}^2}\hat{r}_{1P} + \frac{\Delta q_2}{r_{2P}^2}\hat{r}_{2P} + \ldots\ldots + \frac{\Delta q_n}{r_{nP}^2}\hat{r}_{nP}\right)$$

$$\approx \frac{1}{4\pi\varepsilon_0}\sum_{i=1}^{n}\frac{\Delta q_i}{r_{iP}^2}\hat{r}_{iP} \qquad (1)$$

Unit 1

For continuous distribution of charge,

Lt $\Delta q \to 0 \ (= dq)$

$$\therefore \vec{E} = \frac{1}{4\pi\varepsilon_0} \cdot \int \frac{dq}{r^2} \hat{r}$$

$r \to$ distance of point P from infinitesimal charge dq.

$\hat{r}$ Unit vector from dq to point P.

(i) For linear charge distribution :

Linear density $\lambda = \frac{Q}{L}$ C m^{-1}.

i.e. charge per unit length. Where Q is uniformly distributed charge along the wire of length L. For infinitesimal length $dq = \lambda\, dl$.

(ii) Surface charge distribution :

$\sigma = \frac{Q}{A}$ C m^{-2}.

$\sigma \to$ surface charge density (charge per unit area)

Q $\to$ uniformly distributed charge on surface of area A.

For infinitesimal area, $dq = \sigma dA$.

(iii) Volume charge distribution :

$\rho = \frac{Q}{V}$ C m^{-3}.

$\rho \to$ Volume charge density (charge per unit volume)

Q $\to$ uniformly distribution of charge in a volume V.

2. Deduce an expression for the electric field due to the system of point charges.

Ans. **(i)** Suppose a number of point charges are distributed in space. To find the electric field at some point P due to this collection of point charges, superposition principle is used.

(ii) The electric field at an arbitrary point due to a collection of point charges is simply equal to the vector sum of the electric fields created by the individual point charges. This is called superposition of electric fields.

(iii) Consider a collection of point charges q_1, q_2, q_3,..........q_n located at various points in space. The total electric field at some point P due to all these n charges is given by

$$\vec{E}_{tot} = \vec{E}_1 + \vec{E}_2 + \vec{E}_3 + ...+ \vec{E}_n \qquad ...(1)$$

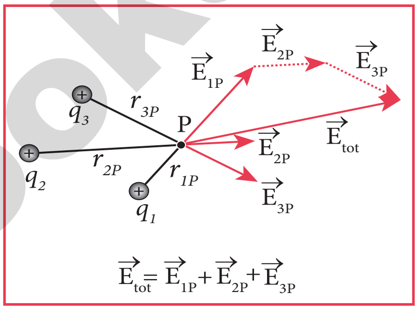
$$\vec{E}_{tot} = \frac{1}{4\pi\varepsilon_0}\left\{\frac{q_1}{r_{1P}^2}\hat{r}_{1P} + \frac{q_2}{r_{2P}^2}\hat{r}_{2P} + \frac{q_3}{r_{3P}^2}\hat{r}_{3P} + ... + \frac{q_n}{r_{nP}^2}\hat{r}_{nP}\right\} \qquad ...(2)$$

(iv) Here r_{1P}, r_{2P}, r_{3P}........r_{nP} are the distance of the charges q_1, q_2, q_3 .... q_n from the point P respectively. Also $\hat{r}_{1P}, \hat{r}_{2P}, \hat{r}_{3P}$ ....$\hat{r}_{nP}$ are the corresponding unit vectors directed from q_1, q_2, q_3 .... q_n to P. Equation (2) can be re-written as,

$$\vec{E}_{tot} = \frac{1}{4\pi\varepsilon_0}\sum_{i=1}^{n}\left(\frac{q_i}{r_{iP}^2}\hat{r}_{iP}\right) \qquad ...(3)$$

(v) For example in Figure, the resultant electric field due to three point charges q_1, q_2, q_3, at point P is shown.

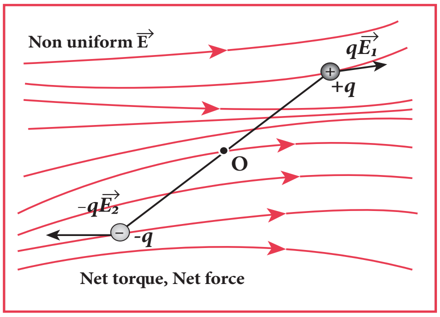
Note that the relative lengths of the electric field vectors for the charges depend on relative distances of the charges to the point P.



Superposition of Electric field

3. What happens when an electric dipole is held in a non-uniform electric field?

Ans. If the electric field is not uniform, then the force experienced by $+q$ is different from that experienced by $-q$. In addition to the torque, there will be net force acting on the dipole.



The dipole in a non-uniform electric field

4. What is principle used in Microwave oven? Explain.

Ans. **(i)** Microwave oven works on the principle of torque acting on an electric dipole. Water molecules in food are permanent electric dipoles.

(ii) Oven produces oscillating electromagnetic fields and torque.

(iii) Due to this water molecule & rotate very fast and produce heat. Thus, heat generated is used to cook the food.

5. Define potential difference and derive.

Ans. (i) The potential energy difference per unit charge is given by

$$\frac{\Delta U}{q'} = \frac{q'\int_R^P \left(-\vec{E}\right).d\vec{r}}{q'} = -\int_R^P \vec{E}.d\vec{r} \quad ...(1)$$

(ii) The above equation (1) is independent of q'. The quantity $\frac{\Delta U}{q'} = -\int_R^P \vec{E}.d\vec{r}$ is called electric potential difference between P and R and is denoted as $V_P - V_R = \Delta V$.

(iii) The electric potential difference is also defined as the work done by an external force to bring unit positive charge from point R to point P.

$$V_P - V_R = \Delta V = \int_R^P -\vec{E}.d\vec{r}$$

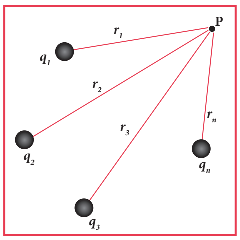
(iv) The electric potential energy difference can be written as $\Delta U = q'\Delta V$.

6. Derive the expressions for the potential energy of a system of point charges.

Ans. (i) The electric potential at a point P due to a collection of charges $q_1, q_2, q_3 \ldots q_n$ is equal to sum of the electric potentials due to individual charges.

$$V_{tot} = \frac{kq_1}{r_1} + \frac{kq_2}{r_2} + \frac{kq_3}{r_3} + \ldots + \frac{kq_n}{r_n}$$
$$= \frac{1}{4\pi\varepsilon_0}\sum_{i=1}^{n}\frac{q_i}{r_i}$$

(ii) where $r_1, r_2, r_3 \ldots\ldots r_n$ are the distances of $q_1, q_2, q_3 \ldots\ldots q_n$ respectively from P.



Electrostatic potential due to collection of charges

7. How is electric flux related to electric field?

Ans. (i) Consider a uniform electric field in a region of space. Let us choose an area A normal to the electric field lines as shown in Figure (a). The electric flux for this case is

$$\Phi_E = EA \quad ...(1)$$

(ii) Suppose the same area A is kept parallel to the uniform electric field, then no electric field lines pass through the area A , as shown in Figure (b). The electric flux for this case is zero.

$$\Phi_E = 0 \quad ...(2)$$

(iii) If the area is inclined at an angle θ with the field, then the component of the electric field perpendicular to the area alone contributes to the electric flux. The electric field component parallel to the surface area will not contribute to the electric flux. This is shown in Figure (c). For this case, the electric flux

$$\Phi_E = (E\cos\theta)A \quad ...(3)$$

(iv) Further, θ is also the angle between the electric field and the direction normal to the area. Hence in general, for uniform electric field, the electric flux is defined as

$$\Phi_E = \vec{E}.\vec{A} = EA\cos\theta$$

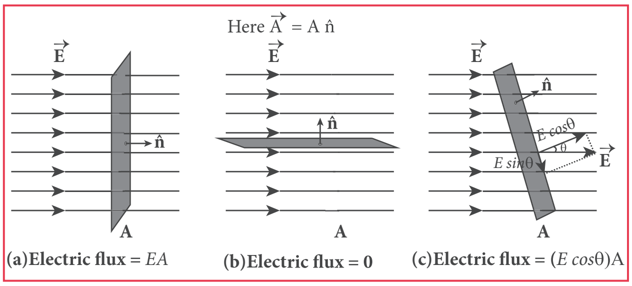
Here, note that $\vec{A}$ is the area vector $\vec{A} = A\hat{n}$

(v) Its magnitude is simply the area A and its direction is along the unit vector $\hat{n}$ perpendicular to the area as shown in Figure.

Using this definition for flux $\Phi_E = \vec{E}.\vec{A}$, equations (1) and (2) can be obtained as special cases.

In Figure (a), θ = 0° so $\Phi_E = \vec{E}.\vec{A} = EA$

In Figure (b), θ = 90° so $\Phi_E = \vec{E}.\vec{A} = 0$



The electric flux for Uniform electric field

Unit 1

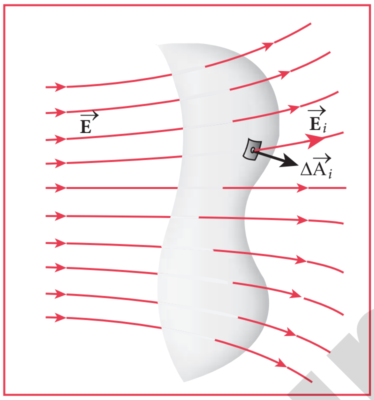
8. Derive an expression for electric flux in a non uniform electric field and an arbitrarily shaped area.

Ans. **(i)** Suppose the electric field is not uniform and the area A is not flat surface (Figure). Then the entire area is divided into n small area segments $\Delta \vec{A}_1, \Delta \vec{A}_2, \Delta \vec{A}_3 ......\Delta \vec{A}_n$, such that each area element is almost flat and the electric field over such area element can be considered uniform.

(ii) The electric flux for the entire area A is approximately written as

$$\Phi_E = \vec{E}_1 \cdot \Delta \vec{A}_1 + \vec{E}_2 \cdot \Delta \vec{A}_2 + \vec{E}_3 \cdot \Delta \vec{A}_3 ...... \vec{E}_n \cdot \Delta \vec{A}_n$$

$$= \sum_{i=1}^{n} \vec{E}_i \, \Delta \vec{A}_i \qquad ...(1)$$



Electric flux for non-uniform electric Field

(iii) By taking the limit $\Delta \vec{A}_i \to 0$ (for all i) the summation in equation (1) becomes integration. The total electric flux for the entire area is given by

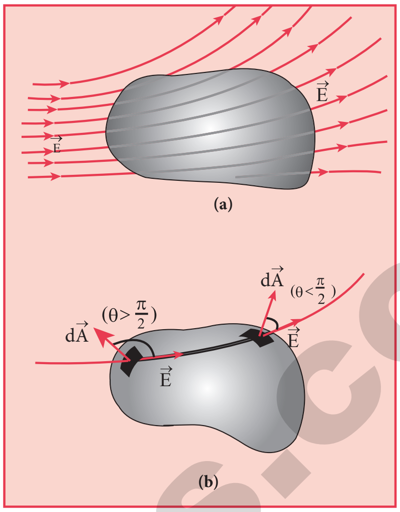
$$\Phi_E = \int \vec{E} . d\vec{A} \qquad ...(2)$$

(iv) From Equation (2), it is clear that the electric flux for a given surface depends on both the electric field pattern on the surface area and orientation of the surface with respect to the electric field.

9. Deduce electric flux for closed surfaces.

Ans. **(i)** A closed surface is present in the region of the non-uniform electric field as shown in Figure (a). The total electric flux over this closed surface is written as

$$\Phi_E = \oint \vec{E} \cdot d\vec{A} \qquad ...(1)$$



Electric flux over a closed surface

(ii) **Note** the difference between equations $\Phi_E = \int \vec{E} . d\vec{A}$ and (1). The integration in equation (1) is a closed surface integration and for each area element, the outward normal is the direction of $d\vec{A}$ as shown in the Figure (b).

(iii) The total electric flux over a closed surface can be negative, positive or zero. In the Figure (b), it is shown that in one area element, the angle between $d\vec{A}$ and $\vec{E}$ is less than 90°, then the electric flux is positive and in another area element, the angle between $d\vec{A}$ and $\vec{E}$ is greater than 90°, then the electric flux is negative.

(iv) In general, the electric flux is negative if the electric field lines enter the closed surface and positive if the electric field lines leave the closed surface.

10. Write the special features of Gauss law.

Ans. **(i)** The total electric flux through the closed surface depends only on the charges enclosed by the surface and the charges present outside the surface will not contribute to the flux and the shape of the closed surface can be chosen arbitrarily.

(ii) The total electric flux is independent of the location of the charges inside the closed surface.

(iii) To arrive at equation $\Phi_E = \oint \vec{E} \cdot d\vec{A} = \frac{Q_{encl}}{\varepsilon_0}$ a spherical surface is chosen. This imaginary

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surface is called a Gaussian surface. The shape of the Gaussian surface to be chosen depends on the type of charge configuration and the kind of symmetry existing in that charge configuration. The electric field is spherically symmetric for a point charge, therefore spherical Gaussian surface is chosen. Cylindrical and planar Gaussian surfaces can be chosen for other kinds of charge configurations.

(iv) In the L.H.S of equation $\Phi_E = \oint \vec{E}\cdot d\vec{A} = \frac{Q_{encl}}{\varepsilon_0}$ the electric field $\vec{E}$ is due to charges present inside and outside the Gaussian surface but the charge Q_{encl} denotes the charges which lie only inside the Gaussian surface.

Unit 1

11. What is dielectrics or insulators?

Ans. **(i)** A dielectric is a non-conducting material and has no free electrons. The electrons in a dielectric are bound within the atoms. Ebonite, glass and mica are some examples of dielectrics.

(ii) When an external electric field is applied, the electrons are not free to move anywhere but they are realigned in a specific way. A dielectric is made up of either polar molecules or non-polar molecules.

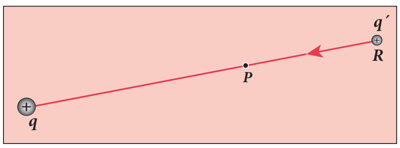
Long Answer Questions — 5 Marks

1. Explain in detail the Electrostatic Potential difference between the charges.

Ans. **(i)** Consider a positive charge q kept fixed at the origin which produces an electric field $\vec{E}$ around it.

(ii) A positive test charge q' is brought from point R to point P against the repulsive force between q and q' as shown in Figure. Work must be done to overcome this repulsion.

This work done is stored as potential energy.



(iii) The test charge q' is brought from R to P with constant velocity which means that external force used to bring the test charge q' from R to P must be equal and opposite to the coulomb force $\left(\vec{F}_{ext} = -\vec{F}_{coloumb}\right)$ The work done is

$$W = \int_R^P \vec{F}_{ext}\cdot d\vec{r} \quad ...(1)$$

(iv) Since coulomb force is conservative, work done is independent of the path and it depends only on the initial and final positions of the test charge. If potential energy associated with q' at P is U_P and that at R is U_R, then difference in potential energy is defined as the work done to bring a test charge q' from point R to P and is given as $U_P - U_R = \Delta U$.

$$\Delta U = \int_R^P \vec{F}_{ext}\cdot d\vec{r}$$

$$\text{Since } \vec{F}_{ext} = -\vec{F}_{coloumb} = -q'\vec{E}$$

$$\Delta U = \int_R^P \left(-q'\vec{E}\right)\cdot d\vec{r} = q'\int_R^P \left(-\vec{E}\right)\cdot d\vec{r}$$

Numerical Problems

1. It requires 50 µJ of work to carry a 2µC charge from point R to S. What is the potential difference between these points?

Sol.: $V_S - V_R = \frac{W}{q}$

Work W = 50 µJ = 50×10^{-6} J

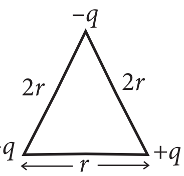
charge q = 2 µC = 2×10^{-6} C

$$V = V_S - V_R = \frac{W}{q} = \frac{50\times10^{-6}}{2\times10^{-6}} = 25 \text{ V}$$

V = 25 V.

2. Devise an arrangement of three point charges separated by finite distances that has zero electric potential energy.

Sol.:



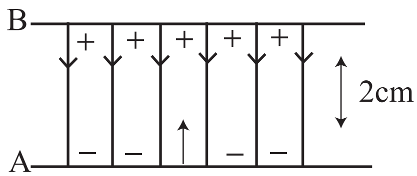
An arrangement of three point $-q, +q$ and $+q$ charges separated by finite distances, is as shown below.

Electric potential energy

$$V = \frac{kq(q)}{r} + \frac{kq(-q)}{2r} + \frac{k(-q)(+q)}{2r}$$

$$= \left(\frac{kq^2}{r}\right) - \left(\frac{kq^2}{2r}\right) - \left(\frac{kq^2}{2r}\right) = 0$$

3. An electron is released from the bottom plate A as shown in the figure (E = 10^4 NC^{-1}). Find the velocity of the electron when it reaches plate B. (e/m = 1.76×10^{11} Ckg^{-1}).



Sol.: **Given:** Electric field strength E = 10^4 NC^{-1} between the plates

Distance of separation between the plates = 2 cm
s = 2×10^{-2} m.

To find:

Velocity of the electron when it reaches B = v = ?

Formula:

According to equation of motion $v^2 = u^2 + 2as$

u - initial velocity = 0; $a = \frac{F}{m} = \frac{Ee}{m} = E\left(\frac{e}{m}\right)$

$v^2 = 0 + (2 \times E\frac{e}{m} \times s)$

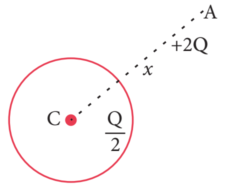
$v = \sqrt{2 \times 10^4 \times 1.76 \times 10^{11} \times 2 \times 10^{-2}}$

$v = \sqrt{7.04 \times 10^{13}} = \sqrt{0.704 \times 10^{14}}$

$v = 0.84 \times 10^7$ m s^{-1}

4. A thin metallic spherical shell of radius R carries a charge Q on its surface. A point charge $\frac{Q}{2}$ is placed at the centre C and another charge +2 Q is placed outside the shell at A at a distance x from the centre as shown in the figure.

(i) Find the electric flux through the shell.



(ii) Find the force on the charges at C and A.

Sol.:

(i) Electric flux $\phi = \frac{\text{Total enclosed charge}}{\varepsilon_0}$

Net charge enclosed inside the shell $q = 0$

$\therefore$ Electric flux through the shell $\frac{q}{\varepsilon_0} = 0$

(ii) The electric field or net charge inside the spherical conducting shell is zero.

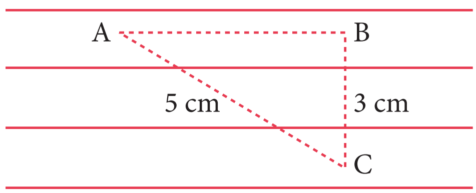
Hence the force on charge $\frac{Q}{2}$ at C is zero.

(i.e) $F_c = 0$

Force on charge at A, $F_A = \frac{1}{4\pi\varepsilon_0} \cdot \frac{2Q\left(Q + \frac{Q}{2}\right)}{x^2}$

$$= \frac{1}{4\pi\varepsilon_0} \frac{1}{x^2}\left[2Q^2 + \frac{\cancel{2}Q^2}{\cancel{2}}\right] = \frac{1}{4\pi\varepsilon_0} \cdot \frac{3Q^2}{x^2}$$

5. Three points A, B & C lie in a uniform electric field (E) of 5×10^3 NC^{-1}. Find the potential difference between A & C.



Sol.: The line joining B to C is perpendicular to electric field

So potential of B = potential of C

i.e. $V_B = V_C$

Distance AB = 4 cm = 4×10^{-2} m

[$AC^2 = AB^2 + BC^2$
$AB^2 = AC^2 - BC^2$
$= 25 - 9 = 16$
AB = 4cm]

Potential difference between A & C

$V_A - V_C = V_A - V_B = E.dx = E(AB)$

$= 5 \times 10^3 \times (4 \times 10^{-2})$

= 200 volt.

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6. A polythene piece rubbed with wool is found to have a negative charge of 3×10^{-7} C. Estimate the number of electrons transferred.

Sol.:

Here, $q = -3 \times 10^{-7}$ C

Charge of one electron, $e = -1.6 \times 10^{-19}$ C

Number of electrons transferred from wool to polythene piece, $n = \dfrac{q}{e} = \dfrac{-3\times10^{-7}\,\text{C}}{-1.6\times10^{-19}\,\text{C}}$

$= 1.875 \times 10^{12}$.

7. A copper Slab of mass 2g contains nearly 2×10^{22} atoms. The charge on the nucleus of each atom is 29e. What fraction of the electrons must be removed from the slab to give it a charge of +2μC?

Sol.: **Given:**

Total number of electrons in the Slab,

$N = 29 \times e = 29 \times 2 \times 10^{22}$

Number of electrons removed, $n = \dfrac{q}{e}$

$n = \dfrac{2\times10^{-6}}{1.6\times10^{-19}}$

$n = 1.25 \times 10^{13}$

∴ Fraction of electrons removed

$= \dfrac{\text{No.of electrons removed (n)}}{\text{Total No.of electrons(N)}}$

$= \dfrac{1.25\times10^{13}}{29\times2\times10^{22}} = 0.0216 \times 10^{-9}$

$= 2.16 \times 10^{-11}$.

8. A metal sphere has a charge of –6.5μC. When 5×10^{13} electrons are removed from the sphere, what would be net charge on it?

Sol.:

$q_1 = -6.5\mu C$

$q_2 = ne = 5 \times 10^{13} \times (1.6 \times 10^{-19})$

$q_2 = 8.0 \times 10^{-6}\text{ C} = 8\ \mu C$

Since electrons are removed from the sphere, q_2 is positive.

∴ Net charge on the sphere,

$q = q_1 + q_2$

$q = (-6.5 + 8)\times 10^{-6}\text{C}$

$q = 1.5 \times 10^{-6}\text{C} = 1.5\ \mu C$

9. How many electrons are there in one coulomb of negative charge?

Sol.:

Charge of an electron, $e = 1.6 \times 10^{-19}$C

$q = 1$C

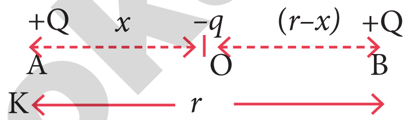
∴ No of electrons, $n = \dfrac{q}{e}$

$n = \dfrac{1}{1.6\times10^{-19}}$

$= 0.625 \times 10^{19}$

$n = 6.25 \times 10^{18}$ electrons

10. Two charges each of +Q units are placed along a line. A third charge $-q$ is placed between them. At what position and for what value of q will the system be in equilibrium?



Sol.:

Let the charge $-q$ be placed at O, So that its distance from charge at A = x and from charge B = r – x.

Now, the system is in equilibrium, it electrostatic force on q due to charge at A = electrostatic force on q due to charge at B (i.e),

i.e $\dfrac{1}{4\pi\varepsilon_0}\dfrac{Qq}{x^2} = \dfrac{1}{4\pi\varepsilon_0}\dfrac{Q.q}{(r-x)^2}$

$x^2 = (r-x)^2 ; x = r - x$

$x = \dfrac{r}{2}$

Three charges will be in equilibrium if not force on each is zero. (i.e)

$$\frac{1}{4\pi\varepsilon_0}\frac{qQ}{\left(\frac{r}{2}\right)^2} + \frac{1}{4\pi\varepsilon_0}\frac{Q\text{ - }Q}{r^2} = 0$$

(or) $q = -\dfrac{Q}{4}$

11. The dielectric constant of water is 80. What is its permittivity?

Sol.: $k = \dfrac{\varepsilon}{\varepsilon_0} = 80$; $\varepsilon_0 = 8.854 \times 10^{-12}$

$\varepsilon = 80 \times \varepsilon_0$

$= 80 \times 8.854 \times 10^{-12}$

$= 708.32 \times 10^{-12}\ C^2\ N^{-1}\ m^{-2}$.

12. What charge would be required to electrify a sphere of radius 25cm, so as to get a surface charge density of $\frac{3}{\pi}$ cm⁻²?

Sol.: r = 25cm = 0.25 m

$$\sigma = \frac{3}{\pi} \text{ cm}^{-2}$$

$$\text{As, } \sigma = \frac{q}{A} = \frac{q}{4\pi r^2} \quad \text{[A - surface area of the sphere]}$$

$$q = (4\pi r^2)\,\sigma = 4\pi \times (0.25)^2 \times \frac{3}{\pi}$$

$$= 0.75 \text{ C.}$$

13. The radius of gold nucleus (Z = 79) is about 7×10^{-15}m. Assume that the positive charge is distributed uniformly throughout the nuclear volume. Find the strength of the electric field at the surface of the nucleus.

Sol.: The total positive charge in the nucleus is,

$$q = +ze = 79 \times 1.6 \times 10^{-19} \text{ C.}$$

Since the surface encloses all the charges. We have,

$$\oint \vec{E}\,\vec{ds} = \frac{q}{\varepsilon_0} = \frac{79 \times 1.6 \times 10^{-19}}{8.85 \times 10^{-12}}$$

$$E = \frac{q}{\varepsilon_0} ds$$

$$= \frac{79 \times 1.6 \times 10^{-19}}{8.85 \times 10^{-12}} \times \frac{1}{4 \times 3.14 \times (7 \times 10^{-15})^2}$$

$$= 0.0232 \times 10^{23} \quad [\because \text{Area} = 4\pi r^2]$$

$$= 2.32 \times 10^{21} \text{ NC}^{-1}.$$

14. Two point charges having equal charges separated by 1m distance experience a force of 8N. What will be the force experienced by them, if they are held in water at the same distance? (Given = K_{water} = 80)

Sol.:
$$K_W = \frac{F_{air}}{F_{water}}$$

$$F_{water} = \frac{F_{air}}{K_W} = \frac{8}{80} = \frac{1}{10} \text{N}$$

$$\left[\begin{array}{l} \text{For air, } K = 1 \\ F = \dfrac{q_1 q_2}{4\pi\varepsilon_0 k r^2} \\ \quad = \dfrac{q_1 q_2}{4\pi\varepsilon_0 r^2} = 8\text{N} \end{array}\right]$$

$$\therefore F_{Water} = 0.1 \text{ N}$$

Note:

$$F = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}$$

$$F_{medium} = \frac{1}{4\pi\varepsilon_0\varepsilon_r}\frac{q_1 q_2}{r^2}$$

$$\frac{F}{F_{medium}} = \varepsilon_r \Rightarrow \left[\therefore \frac{F_{air}}{F_{water}} = K_{water}\right]$$

15. An infinite number of charges each equal to q are placed along X-axis at x = 1, x = 2, x = 4, x = 8 and so on. Find the electric field at the point x = 0 due to this set up of charges.

Sol.: $E_{Net} = E_1 + E_2 + E_3 + \ldots\ldots$

$$E_{Net} = \frac{1}{4\pi\varepsilon_0}\left[\frac{q}{(1)^2} + \frac{q}{(2)^2} + \frac{q}{(4)^2} + \frac{q}{(8)^2} + \ldots\right]$$

$$= \frac{q}{4\pi\varepsilon_0}\left[\frac{1}{1} + \frac{1}{4} + \frac{1}{16} + \frac{1}{64} + \ldots\ldots\right]$$

$$= \frac{q}{4\pi\varepsilon_0}\left[\frac{1}{1-\frac{1}{4}}\right] = \frac{4q}{12\pi\varepsilon_0} = \frac{q}{3\pi\varepsilon_0}$$

(sum of infinite series $= S_\infty = \dfrac{a}{1-r}$

Here a = 1, $r = \dfrac{1}{4}$)

16. Calculate the potential at a point P due to charge of 5×10^{-7}C located 10 cm away.

Sol.:
$$V = \frac{q}{4\pi\varepsilon_0 r}$$

$$= \frac{9 \times 10^9 \times 5 \times 10^{-7}}{10 \times 10^{-2}} = 4.5 \times 10^4 \text{ volt.}$$

17. A network of four 10µF capacitors is connected to a 500V supply as shown in the figure. Determine the equivalent capacitance of the network along AD.

Sol.:

$$\frac{1}{C_S} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} = 3 \times \frac{1}{10} = \frac{3}{10}$$

$$C_s = \frac{10}{3} = 3.33 \text{ µF}$$

$$C' = C_{eq} = C_S + C_4$$

$$= 3.33 + 10 = 13.33\text{µF.}$$

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18. A capacitor of capacity 10μF is subjected to charge by a battery of 10V. Calculate the energy stored in the capacitor.

Sol.: Capacitance, $C = 10\mu F = 10 \times 10^{-6} F$

Voltage, $V = 10V$

Energy, $E = ?$

Energy stored in the capacitor, $E = \frac{1}{2} CV^2$

$= \frac{1}{2} \times 10 \times 10^{-6} \times 10 \times 10 = 5 \times 10^{-4}$ J

19. A parallel plate capacitor has plate area, 25cm² and a separation of 2 mm between the plates. The capacitor is connected to a battery of 12V. Find the charge on the capacitor.

Sol.: Area of the plate, $A = 25 cm^2$

$= 25 \times 10^{-4} m^2$

Distance between the plates, $d = 2$ mm

$d = 2 \times 10^{-3} m$

Potential difference, $V = 12V$

Permittivity, $\varepsilon_0 = 8.85 \times 10^{-12}\ C^2 N^{-1} m^{-2}$

Charge, $q = CV$ $\quad \left[C = \frac{\varepsilon_0 A}{d}\right]$

$$q = \left(\frac{\varepsilon_0 A}{d}\right) V$$

$$= \frac{8.85 \times 10^{-12} \times 25 \times 10^{-4} \times 12}{2 \times 10^{-3}}$$

$q = 1327.5 \times 10^{-13}$

$q = 1.33 \times 10^{-10} C$

20. The electric potential in region is represented as $V = 2x + 3y - z$. Obtain an expression for electric field strength.

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

$$\frac{\partial V}{\partial x} = \frac{\partial}{\partial x}(2x + 3y - z) = 2$$

$$\frac{\partial V}{\partial y} = 3\ ; \quad \frac{\partial V}{\partial z} = -1$$

$\therefore$ Electric field, $E = -2\hat{i} - 3\hat{j} + 1\hat{k}$

21. An electric dipole of length 4cm, when placed with its axis making an angle of 60° with a uniform electric field, experiences a torque of $4\sqrt{3}$ Nm. Calculate the potential energy of the dipole, if it has charge ±8nC.

Sol.: Length, $l = 2a = 4cm = 4 \times 10^{-2} m$

Angle, $\theta = 60°$

torque $\tau = 4\sqrt{3}$ Nm

Charge, $Q = 8 \times 10^{-9}$ C

We know that, $\tau = pE \sin\theta$ $\quad$ [where $p = Q \times 2a$]

$\tau = (Q \times 2a) E \sin\theta$

$$\therefore E = \frac{\tau}{Q \times (2a) \sin\theta}$$

$$= \frac{4\sqrt{3}}{8 \times 10^{-9} \times 4 \times 10^{-2} \times \sin 60°}$$

$\therefore$ Potential energy, $U = -pE \cos\theta$

$= -Q(2a) \times E \times \cos\theta$

$= -8 \times 10^{-9} \times 4 \times 10^{-2}$

$$\times \frac{4\sqrt{3} \times \cos 60°}{8 \times 10^{-9} \times 4 \times 10^{-2} \times \sin 60°}$$

$$U = \frac{-4\sqrt{3}}{\sqrt{3}} = -4J$$

22. Three capacitors each of capacitance 9pF are connected in series

(i) What is the total capacitance of the combination?

(ii) What is the potential difference across each capacitor, if the combination is connected to a 120 V supply.

Sol.: Here, $C_1 = C_2 = C_3 = 9$ pF

Voltage, $V = 120V$

(i) Total capacitance in series combination,

$$\frac{1}{C_S} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} = \frac{1}{9} + \frac{1}{9} + \frac{1}{9}$$

$$\frac{1}{C_S} = \frac{3}{9}$$

$\Rightarrow C_S = 3\ pF$

(ii) Total charge, $q = V \times C_S$

where $V = 120$

$q = 120 \times 3 \times 10^{-12}$

$= 360\ pC$

∴ Potential difference across C_1 is $V_1 = \dfrac{q}{C_1}$

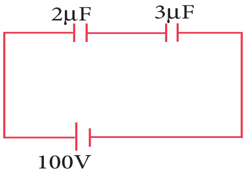
$$V_1 = \frac{360\times10^{-12}}{9\times10^{-12}} = 40V$$

$$V_2 = \frac{q}{C_2} = \frac{360}{9} = 40V$$

$$V_3 = \frac{q}{C_3} = \frac{360}{9} = 40V$$

∴ Potential difference across each capacitor is 40V.

23. In the circuit shown in figure, find
(i) the equivalent capacitance and
(ii) the charge stored in each capacitor.



Sol.:

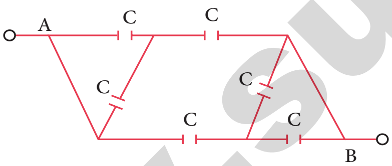
(i) The equivalent capacitance is,

$$C_s = \frac{C_1C_2}{C_1+C_2} = \frac{6}{5} = 1.2\mu F$$

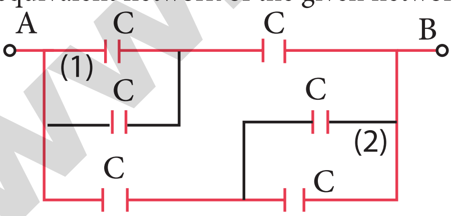
(ii) Charge in each capacitor

$$q = C_sV = 1.2 \times 100 = 120\mu C$$

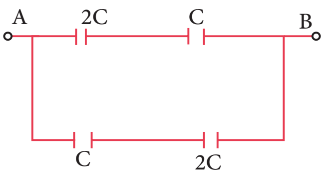
24. A network of six identical capacitors, each of value C is made as shown in the figure find the equivalent capacitance between the points A & B.



Sol.: The equivalent network of the given network is



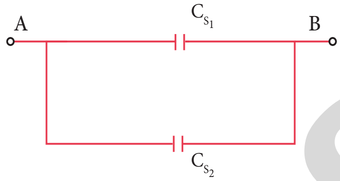
in (1) $Cp_1 = C + C = 2C$
in (2) $Cp_2 = C + C = 2C$



$$\Rightarrow \frac{1}{C_{S_1}} = \frac{1}{2C} + \frac{1}{C} = \frac{3}{2C}$$

$$C_{S_1} = \frac{2C}{3}$$

Also, $C_{S_2} = \dfrac{2C}{3}$



$$C_{P_3} = C_{eq} = C_{S_1} + C_{S_2} = \frac{2C}{3} + \frac{2C}{3} = \frac{4C}{3}$$

25. Two insulated charged copper sphere A and B have their centres separated by a distance of 50 cm.
(i) What is the mutual force of electrostatic repulsion, if the charge on each is 6.5×10^{-7}C and the radii of A and B are negligible compared to the distance of separation?
(ii) What is the mutual force of repulsion, if each sphere is charged double the above amount and the distance between them is halved?

Sol.:

(i) $q_1 = q_2 =$ **6.5×10^{-7}C**
$r = 50\text{ cm} = 0.5\text{m}$

Electrostatic force of repulsion,

$$F = \frac{1}{4\pi\varepsilon_0}\frac{q_1q_2}{r^2}$$

$$= \frac{9\times10^9\times(6.5\times10^{-7})^2}{(0.5)^2}$$

$$F = 1.521 \times 10^{-2}N$$

(ii) After doubling the charge, we get

$q_1 = 1.3 \times 10^{-6}$C
$q_2 = 1.3 \times 10^{-6}$C

The distance between the Sphere is halved so

$$r = \frac{0.5}{2} = 0.25\text{ m}$$

New force of repulsion $F' = \dfrac{1}{4\pi\varepsilon_0}\dfrac{q_1q_2}{r^2}$

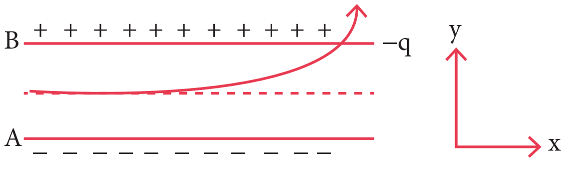
$$= \frac{9\times10^9\times(1.3\times10^{-6})^2}{(0.25)^2}$$

$$= 16 \times 1.52 \times 10^{-2}$$

$$= 0.243\text{ N.}$$

HOTS **2 MARKS**

1. A particle of mass m and charge (–q) enters the region between the two charged plates initially moving along X-axis with speed V_x as shown in figure. The length of plate is L and an uniform electric field E is maintained between the plates. Show that the vertical deflection of the particle at the far edge of the plate is $\frac{qEL^2}{2mV_x^2}$.



Ans. Force on particle towards upper plate B, $F_y = qE$

Vertical acceleration of particle $a_y = \frac{qE}{m}$

Initial vertical velocity $V_y = 0$

Time taken by particle between the plates $t = \frac{L}{V_x}$

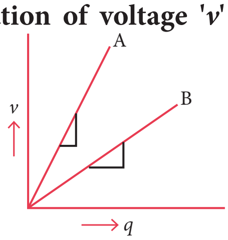
From equation of motion $s = V_y t + \frac{1}{2} a_y t^2$

Vertical deflection $y = 0 + \frac{1}{2} a_y t^2$

$$= 0 + \frac{1}{2}\left(\frac{qE}{m}\right)\left(\frac{L}{V_x}\right)^2$$

$y = \frac{qEL^2}{2mV_x^2}$ Hence proved.

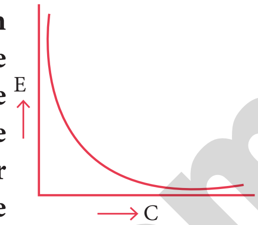
2. The graph shows the variation of voltage 'v' across the plates of two capacitors A & B versus increase of charge 'q' stored on them. Which of the capacitors has higher capacitance? Give reason.



Ans. $C = \frac{Q}{V} = \frac{1}{Slope\ of\ line}$

As slope of A is smaller, capacitance of A is higher. (i.e) $S_A < S_B \Rightarrow C_A > C_B$

3. The graph shown here shows the variation of total energy (E) stored in a capacitor against the value of the capacitance (C) itself. Which of the two is kept constant for this graph, whether the charge on capacitor or the potential used to charge it?



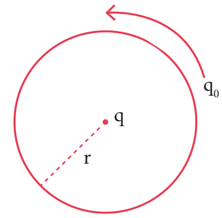
Ans. The given graph represents $E \propto \frac{1}{C}$

This is satisfied by the expression $E = \frac{q^2}{2C}$, $\alpha \frac{1}{C}$

for the constant q.

4. If a point charge is rotated in an arc of radius r around a charge q, what will be the work done? Explain.

Ans. All points of circle of radius r are at same potential hence work done is zero.



5. Gauss law is true for any closed surface, no matter what its shape or size is. Justify.

Ans. This is due to the fact that

(i) electric field is radial

(ii) electric field $E \propto \frac{1}{R^2}$

6. How does the energy stored in a capacitor change if

(i) after disconnecting the battery, the plates of charged capacitor are moved faster.

(ii) the battery remains connected.

Ans. (i) After disconnecting the battery, the charge on capacitor remains constant.

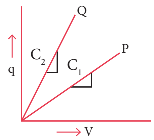
$\therefore$ Energy stored in a capacitor $\left(U = \frac{q^2}{2C}\right)$ increases.

(ii) As the battery remains connected, the potential difference remains constant.

Hence energy stored $U = \frac{1}{2} CV^2$ decreases.

Unit 1

7. The given graph shows the variation of charge *q* versus potential difference V for 2 capacitors C_1 & C_2. The two capacitors have same plate separation but the area of plate C_2 is twice that of C_1. Which of the two lines P & Q correspond to capacitors C_1 & C_2? Why?



Ans. Let, Q represents C_2 & P represents C_1

Reason :

From the graph, the slope $\frac{q}{v}$ =

Capacitance is greater FOR Q

Here, the slope of Q is greater than the slope of P. According to given conditions

$C = \frac{\varepsilon A}{d}$ (i.e) $C \propto A$. So, capacitance is larger for C_2 because the area of its plates is large and d for the two capacitor is same.

Hence Q represents C_2.

8. A parallel plate capacitor of capacitance C is charged to a potential V. It is connected to another uncharged capacitor having the same capacitance. Find the ratio of the energy stored in the combined system to that stored initially in the single capacitor.

Ans. Energy stored in the capacitor = $\frac{1}{2}CV^2 = \frac{q^2}{2C}$

Net capacitance of the parallel combination (when capacitors are connected together)

$= C + C = 2C$

Since the total charge Q remains same, initial energy,

$$U_i = \frac{q^2}{2C}$$

Final energy $U_f = \frac{q^2}{2(2C)}$

$$\frac{U_f}{U_i} = \frac{1}{2}$$

9. Two charged spherical conductors of radii R_1 & R_2 when connected by a conducting wire acquire charges q_1 & q_2 respectively. Find the ratio of their surface charge densities in terms of their radii.

Ans. The charges will flow between the two spherical conductors till their potential become equal.

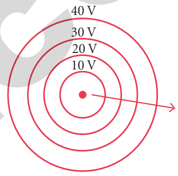
i.e. $\frac{Kq_1}{R_1} = \frac{Kq_2}{R_2}$ (or) $\frac{q_1}{q_2} = \frac{R_1}{R_2}$

The ratio of the surface charge densities on the two conductors will be

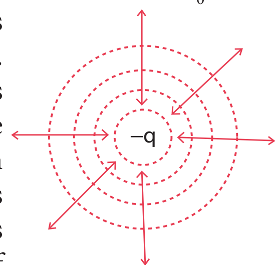
$$\frac{\sigma_1}{\sigma_2} = \frac{q_1 / 4\pi R_1^2}{q_2 / 4\pi R_2^2} = \frac{q_1}{q_2} \cdot \frac{R_2^2}{R_1^2} = \frac{R_1}{R_2} \times \frac{R_2^2}{R_1^2}$$

$\therefore \frac{\sigma_1}{\sigma_2} = \frac{R_2}{R_1} \Rightarrow$ Required ratio $= \frac{R_2}{R_1}$

10. Concentric equipotential surfaces due to a charged body placed at the centre are shown. Identify the polarity of the charge and draw the electric field lines due to it.



Ans. For a single charge the potential $V = \frac{q}{4\pi\varepsilon_0 r}$



This shows that V is constant if 'r' is constant. Greater the radius smaller will be the potential. In the given figure all the potential is increasing. This shows that the polarity of charge is negative ($-q$). The direction of electric field will be radially inward, the field lines are directed from higher to lower potential.

11. Will there be any effect on the potential at the point if the medium around this point is changed?

Ans. Yes, if the dielectric constant of the medium is increased, there will be a decrease of potential.

We know $V = \frac{1}{4\pi\varepsilon_0} \frac{q}{kr}$

$\Rightarrow V \propto \frac{1}{k} \rightarrow$ dielectric medium

12. Distinguish between the electric potential and potential energy and state the relation between them.

Ans. While electric potential is work done per unit charge whereas the potential energy is the total work done in bringing different charges from infinity to their respective positions.

$V = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q_1}{r}$ and $U = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q_1 q_2}{r}$

$$U = q_2 \left[\frac{1}{4\pi\varepsilon_0} . \frac{q_1}{r} \right] = q_2 V$$

$\therefore$ Electric potential energy

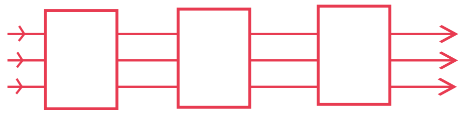
= charge $q_2 \times$ potential due to charge q_1 at the location of charge q_2

13. Draw equipotential surface

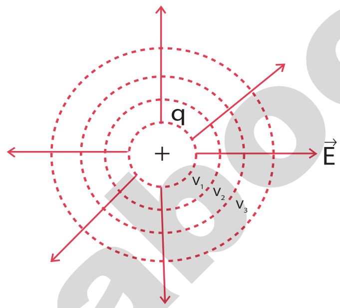
(i) in a uniform electric field and

(ii) for a point charge (Q < 0)

(i) For a uniform electric field $\vec{E}$, the equipotential surface is normal to its field lines



(ii) For a isolated point charge :



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