

# PHYSICS VOLUME - I & II

# 12th Standard

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  - Govt. Supplementary Exam. **Sept 2020** Question Paper is given.



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(II)



"The woods are lovely, dark and deep."

But I have promises to keep, and
miles to go before I sleep

Robert Frost

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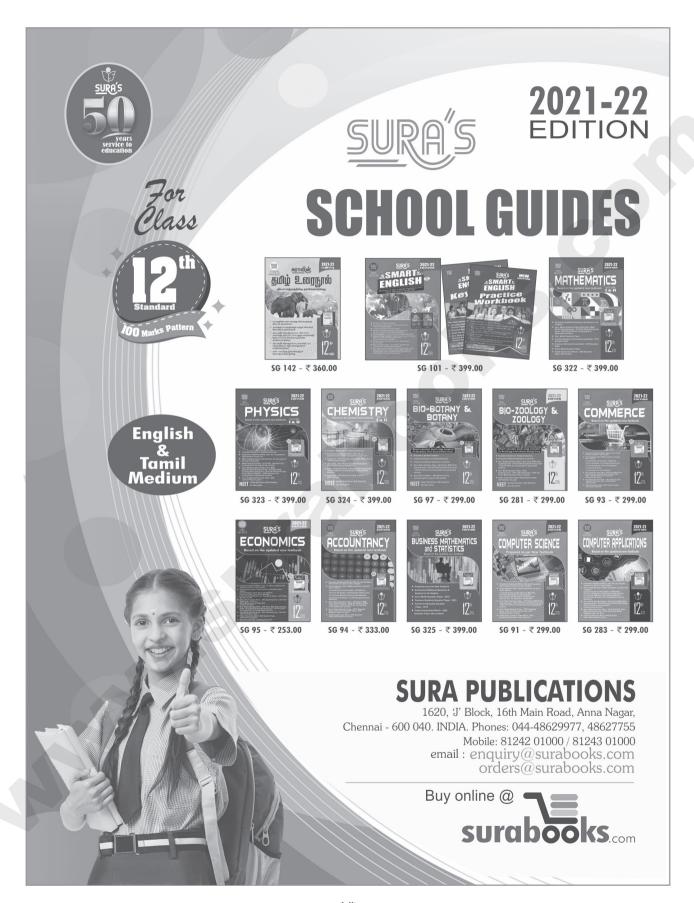
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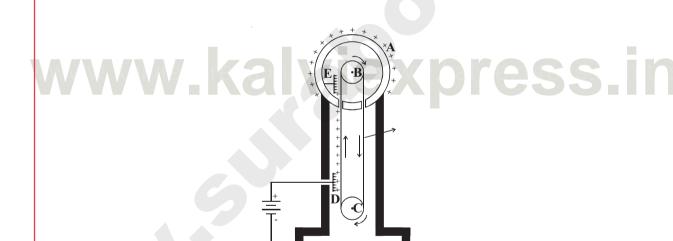
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# PHYSICS VOLUME - I

# 12th Standard



(VII)

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# UNIT 1

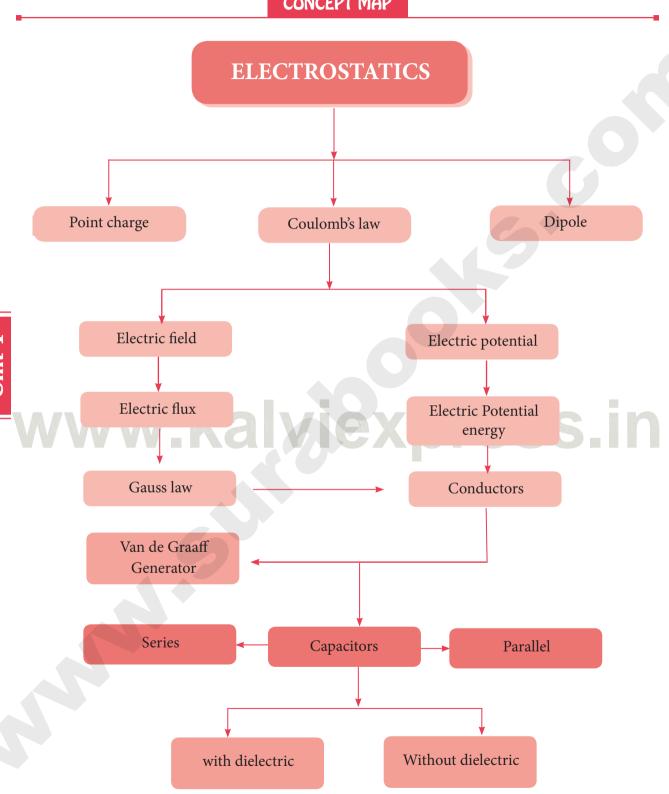
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  - **1.8.1** Capacitors
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  - **1.9.4** Van de Graaff Generator



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# **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.

$$\vec{F_1^{tot}} = k \left[ \frac{q_1 q_2}{r_{21}^2} \hat{r}_{21} + \frac{q_1 q_3}{r_{31}^2} \hat{r}_{31} + \dots + \frac{q_1 q_n}{r_{n1}^2} \hat{r}_{nl} \right]$$

**Properties of charges** 

Quantisation of charge q = ne  $[n = 0, \pm 1, \pm 2, \pm 3,...]$ Charges are additive  $Q = \Sigma Q_{u}$ Q = Constant

Conservation of charges

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

Electric field due to a point charge

A point charge

 $\begin{array}{ccc}
+q & +q_{\circ} \\
& & +q_{\circ}
\end{array}$   $\stackrel{+q}{\longrightarrow} E \quad \overrightarrow{E} = \frac{1}{4\pi\epsilon_{0}} \frac{q}{r^{2}} \hat{r}$ 

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  $9 \times 10^9$  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.

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_	CLLIC	111163	OI IUILE

: 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  $\frac{1}{\epsilon_{-}}$  lines of force in free

**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.

$$d\phi = \vec{E} \cdot \vec{ds} = E ds \cos \theta$$

Gauss' law

It states that the total flux of the electric field E over any closed surface is equal to  $\frac{1}{\varepsilon_0}$  times the net charge enclosed by the surface,

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<sub>2</sub>O, H<sub>2</sub>O, HCl, NH<sub>3</sub>. These molecules have a permanent dipole moment.

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Non-	no	lar	mo	lecul	les
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: 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 $C_3$	$q = q_1 + q_2 + q_3$ $q_1 = C_1 V ; q_2 = C_2 V$ $q_3 = C_3 V$
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	$\frac{1}{C_{s}} = \frac{1}{C_{1}} + \frac{1}{C_{2}} + \frac{1}{C_{3}}$	$C_p = C_1 + C_2 + C_3$

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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	Value of constant G is always fixed.
$[\varepsilon, \varepsilon_r, \varepsilon_0]$	,

# **FORMULAE**

- (1) Electrostatic force between charges  $q_1$  and  $q_2$ ,  $F = \overrightarrow{F}_{12} = \frac{1}{4\pi\epsilon_o} \frac{q_1 q_2}{r_{21}^2} \mathring{r}_{21}$
- (2) Value of  $k = \frac{1}{4\pi\epsilon_o} = 9 \times 10^9 \text{ Nm}^2\text{C}^{-2}$
- (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  $\varepsilon_r = \frac{\varepsilon}{\varepsilon_a}$
- (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  $E = \frac{1}{4\pi\epsilon_0} \frac{q}{r^2}$
- (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,  $\stackrel{\rightarrow}{E} = \frac{1}{4\pi\epsilon_0} \frac{2\stackrel{\rightarrow}{p}}{r^3} (r >> a)$ 
  - (ii) Electric field due to a dipole at a point on the equatorial line  $E = \vec{E}_{tot} = \frac{-1}{4\pi\epsilon_0} \frac{\vec{p}}{r^3}$  (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,  $V = \frac{1}{4\pi\epsilon_o} \frac{q}{r}$
- (15) Electric potential energy of dipole  $U = -pE \cos\theta = -\overrightarrow{p}$ .
- (16) Electric potential at a point due to an electric dipole  $V = \frac{p}{4\pi\epsilon_0} \frac{\cos\theta}{r^2}$
- (17) Electric flux =  $\frac{q}{\varepsilon_o} \Rightarrow \phi_E = \vec{E} \cdot \vec{A} = EA \cos\theta$
- (18) Electric field due to infinite long straight charged wire,  $E = \frac{\lambda}{2\pi\epsilon_0 r}$
- (19) Electric field due to plane sheet of charge  $E = \frac{\sigma}{2\epsilon_o} = \frac{q}{A} \frac{1}{2\epsilon_o}$  Vector form,  $\vec{E} = \frac{\sigma}{2\epsilon_o} \hat{n}$

ess.in

# **Electrostatics**

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- (20) Electric field at a point between two parallel sheets of charge  $E = \frac{\sigma}{\epsilon_{-}}$
- (21) Electric field due to a uniformly charged sphere
  - at a point on the surface of the sphere,  $E = \frac{1}{4\pi\epsilon} \frac{Q}{R^2} \hat{r}$ r = R
  - at a point outside the sphere  $E = \frac{1}{4\pi\varepsilon} \frac{Q}{r^2} \hat{r}$
  - (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,  $\sigma = \frac{q}{\Lambda}$
- (25) Capacitance of a parallel plate capacitor  $C = \frac{\varepsilon_0 A}{d}$ 
  - With a dielectric slab,  $C = \frac{\varepsilon_o A}{\left[ (d-t) + \frac{t}{\varepsilon_r} \right]}$
  - With the dielectric completely filled capacitor  $C^1 = \frac{\varepsilon_o \varepsilon_r A}{d} = C \times \varepsilon_o$
- (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  $C = \frac{A}{9 \times 10^9}$
- (28) Equivalent capacitance
  - (i)  $C_1$  and  $C_2$  in series  $C_s = \frac{C_1 C_2}{C_1 + C_2}$ ;  $C_s = \frac{1}{C_S} = \frac{1}{C_1} + \frac{1}{C_2}$ (ii)  $C_1$  and  $C_2$  in parallel  $C_p = C_1 + C_2$
- (29) Polarisation,  $\vec{p} = \chi_e E_{ext}$  ( $\chi_e$  electric susceptibility)

### **Values And Units**

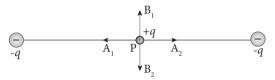
- (1) Permittivity of free space  $\varepsilon_0$  $8.854 \times 10^{-12} \text{ C}^2 \text{N}^{-1} \text{m}^{-2}$
- 9×109 Nm2C-2
- (3) Charge of an electron, e  $1.6 \times 10^{-19} \text{ C}$
- (4) 1 micro farad 10<sup>-6</sup> farad
- 10<sup>-12</sup> farad (5) 1 pico farad
- (6) Permittivity of medium, ε  $C^2N^{-1}m^{-2}$
- Coulomb (C) (7) Electric charge (q)
- (8) Electric field (E)  $NC^{-1}$  or V  $m^{-1}$
- (9) Electric potential (V) IC<sup>-1</sup> or volt
- (10) Electric dipole moment (*p*) Coulomb metre
- (11) Electric potential energy (U) =**Joule**
- (12) Capacitance (C) farad
- $Nm^2C^{-1}$ (13) Electric flux (14) Torque Nm
- (15) Relative permittivity of air 1 (no unit)

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# **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, and B,
- (c) both directions
- (d) No stable

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

- 2. Which charge configuration produces a uniform electric field? [HY-2019]
  - (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)  $\frac{23}{11}$
- (c) 5
- (d)  $\frac{11}{25}$

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

- 4. An electric dipole is placed at an alignment angle of  $30^{\circ}$  with an electric field of  $2 \times 10^{5}$  N C<sup>-1</sup>. It experiences a torque equal to 8 N m. The charge on the dipole if the dipole length is 1 cm is
  - (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)  $\frac{80q}{\varepsilon_{\circ}}$
- (b)  $\frac{q}{40\varepsilon}$
- (c)  $\frac{q}{80\varepsilon_{c}}$

d)  $\frac{q}{160\varepsilon_{\circ}}$ 

[Ans. (b)  $\frac{q}{40\varepsilon_0}$ ]

- 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  $(NSEP\ 04-05[Sep.-2020])$ 
  - (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) Q r Q
- (b) r Q
- (c) -Q r -2Q
- (d)  $Q = \frac{-2Q}{2r}$
- (a) 1 = 4 < 2 < 3
- (b) 2 = 4 < 3 < 1
- (c) 2 = 3 < 1 < 4
- (d) 3 < 1 < 2 < 4

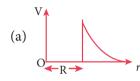
[Ans. (a) 1 = 4 < 2 < 3]

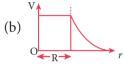
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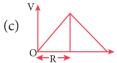
- An electric field  $E=10x \hat{i}$  exists in a certain region of space. Then the potential difference  $V = V_0 - V_A$ , where  $V_0$  is the potential at the origin and  $V_A$  is the potential at x = 2 m is:
  - (a) 10 V
- (b) -20 V
- (c) +20 V
- (d) -10 V

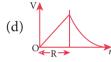
[Ans. (c) +20 V]

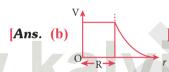
**10.** A thin conducting spherical shell of radius R has a charge Q which is uniformly distributed on its surface. The correct plot for electrostatic potential due to this spherical shell is











- 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
  - (a)  $8.80 \times 10^{-17}$  J
- (b)  $-8.80 \times 10^{-17} \text{ J}$
- (c)  $4.40 \times 10^{-17} \text{ J}$
- (d)  $5.80 \times 10^{-17} \text{ J}$

[Ans. (a)  $8.80 \times 10^{-17}$  J]

12. If voltage applied on a capacitor is increased from V to 2V, choose the correct conclusion.

[Govt. MOP-2019; Mar.-2020]

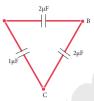
- (a) Q remains the same, C is doubled
- (b) Q is doubled, C doubled
- (c) C remains same, Q doubled
- (d) Both Q and C remain same

[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? [Sep.-2020; QY-2019]
  - (a) Capacitance
- (b) Charge
- (c) Voltage
- (d) Energy density

[Ans. (d) Energy density]

14. Three capacitors are connected in triangle as A shown in the figure. The equivalent capacitance between the points A and C is



- (a) 1µF
- (b) 2 µF
- (c) 3 µF
- (d)  $\frac{1}{4}\mu F$

[Ans. (b) 2 µF]

- 15. Two metallic spheres of radii 1 cm and 3 cm are given charges of  $-1 \times 10^{-2}$  C and  $5 \times 10^{-2}$  C respectively. If these are connected by a conducting wire, the final charge on the bigger sphere is (AIIPMT -2012)
  - (a)  $3 \times 10^{-2}$  C
- (b)  $4 \times 10^{-2}$  C
- (c)  $1 \times 10^{-2}$  C
- (d)  $2 \times 10^{-2}$  C

[Ans. (a)  $3 \times 10^{-2}$  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.

$$q = ne$$

- Where *n* is any integer  $(0, \pm 1, \pm 2, \pm 3,$ (ii) ±4.....). this is called Quantisation of electric charge.
- 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, 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  $k = \frac{1}{4\pi\epsilon_0}$  and its value is  $k = 9 \times 10^{-1}$  $10^9$  Nm<sup>2</sup>C<sup>-2</sup>. Here  $\varepsilon_0$  is the permittivity of free space or vacuum and the value of  $\frac{1}{4\pi k}$  = 8.85 × 10<sup>-12</sup> C<sup>2</sup> N<sup>-1</sup> m<sup>-2</sup>

	Coulomb	Gravitational
i)	It may be attractive	It is always
	or repulsive.	attractive in nature.
ii)	It depends upon	It does not depend
	medium	upon the medium
iii)	It is always greater	It is lesser than
	in magnitude	coulomb force
	because of high	because value of
	value of	G is
	$K = 9 \times 10^9 \text{ Nm}^2 \text{ C}^{-2}$	$6.62 \times 10^{-11} \mathrm{Nm^2kg^{-2}}$
iv)	The force between	It is always same
	the charges will	whether the two
	not be same during	masses are rest or
	motion or rest.	motion

Write a short note on superposition principle.

**Ans.** When a number of charges are interacting the total force of a given charge is the vector sum of the individual forces exerted on the given charge by all the other charges.

Define 'electric field'.

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

$$\vec{E} = \frac{\vec{F}}{q_0} = \frac{kq}{r^2} \hat{r} = \frac{1}{4\pi\epsilon_0} \frac{q}{r^2} \hat{r}$$

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

(iii) Vector quantity

(iv) SI unit is Newton per Coulomb (NC<sup>-1</sup>).

What is meant 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 represent the electric field in some region of space visually.

The electric field lines never intersect. Justify.

**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.

Define 'electric dipole'. Give the expression for the magnitude of its electric dipole moment and the direction.

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

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

and it is directed from -q to +q

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,  $\overrightarrow{P} = \sum_{i=1}^{n} q_i \overrightarrow{r}_i$ where  $\overrightarrow{r_i}$  is the position vector of charge  $q_i$  from the origin.

**10.** Define 'electrostatic potential'.

**Ans.** Work done by an external force to bring a unit positive charge with constant velocity from infinity to ones point in E scalar.

11. What is an equipotential surface?

**Ans.** A surface on which all the points are at the same 

12. What are the properties of an equipotential surface?

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

If the points A and B lie on the same equipotential surface, work done is zero because  $V_R = V_{\Delta}$ .

The electric field is always normal to an equipotential 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 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,

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

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

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# 14. Define 'electrostatic potential energy'.

**Ans.** Electric potential energy is defined as the work done in bringing the various charges to their respective positions from infinitely large mutual separation.

This is Only for Sample

# 15. Define 'electric flux'

- **Ans.** (i) The number of electric field lines crossing a given area kept normal to the electric field lines is called electric flux.
  - (ii) Scalar quantity
  - (iii)  $SI \Rightarrow Nm^2c^{-1}$

# 16. What is meant by electrostatic energy density?

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

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

- **Ans.** (i) The phenomenon of protecting a region of space from any external electric field is called electrostatic shielding.
  - (ii) Consider a cavity inside the conductor. Whatever the charges at the surfaces and whatever the electrical disturbances outside, the electric field inside the cavity is zero.

# 18. What is Polarisation?

**Ans.** (i) Total dipole moment per unit volume of the dielectric.

$$p = \chi_e \stackrel{\rightarrow}{\to} E_{ext}$$

(ii)  $\chi_e$  electric susceptibility.

# 19. What is dielectric strength?

**Ans.** The maximum electric field the dielectric can withstand before it gets breakdown is called dielectric strength.

### 20. Define 'capacitance'. Give its unit.

**Ans.** Ratio of the magnitude of charge to the potential difference between the conductors.  $C = \frac{Q}{V}$ 

# **21.** What is Corona discharge? [Mar. - 2020]

- **Ans.** (i) The electric field near the edge of conductor is very high and it ionizes the surrounding air.
  - (ii) The positive ions are repelled at the sharp edge.
  - (iii) Negative ions are attracted towards the sharper edge.

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

### III. Long Answer ouestions:

### 1. Discuss the basic properties of electric charges.

- **Ans.** (i) Electric charge: The electric charge is fundamental property of particles having mass and its unit is coulomb.
  - (ii) Conservation of charges: Charges are neither be created nor be destroyed but can only be transferred from one object to the other. This is called conservation of total charges.
  - (iii) Quantisation of charges: The charge q on any object is equal to an integral multiple of the fundamental unit of charge e. q = ne. Here n is any integer  $(0, \pm 1, \pm 2, \pm 3, \pm 4...)$ . This is called Quantisation of electric charge.

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

Ans. Various aspects of Coulomb's law:

- (i) Coulomb's law states that electrostatic force between 2 stationary point charges is directly proportional to the product of the magnitude of the charges and is inversely proportional to the square of the distance between them.
- (ii) The force on the charge  $q_2$  exerted by the  $q_1$  always lies along the line joining the two charges.  $\hat{r}_{12}$  is the unit vector from charge  $q_1$  to  $q_2$ .  $\overrightarrow{F}_{21} = k \frac{q_1 q_2}{r^2} \overrightarrow{r}_{12}$ . The force on the charge  $q_1$  exerted by  $q_2$  is along- $\hat{r}_{12}$  (i.e., in opposite direction).

$$\vec{F}_{12} = k \cdot \frac{q_1 q_2}{r^2} \cdot \hat{r}_{21}$$
 i.e.  $\vec{F}_{12} = -\vec{F}_{21}$ 

- (iii)  $k = \frac{1}{4\pi\epsilon_0} = 9 \times 10^9 \text{ Nm}^2\text{C}^{-2}\text{in SI units.}$   $\epsilon_0$ -permittivity of free space or vacuum  $\epsilon_0 = 8.85 \times 10^{-12} \text{ C}^2 \text{ N}^{-1} \text{ m}^{-2}$
- (iv) If  $q_1 = q_2 = 1C$ ; r = 1m, then  $|F| = \frac{9 \times 10^9 \times 1 \times 1}{1^2} = 9 \times 10^9 \text{ N}$
- (v) In vacuum  $\overrightarrow{F}_{21} = \frac{1}{4\pi\varepsilon_0} \frac{q_1 q_2}{r^2} \mathring{r}_{12}$ .

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In a medium  $\stackrel{\rightarrow}{F}_{21} = \frac{1}{4\pi\epsilon} \frac{q_1 q_2}{r^2} \stackrel{\wedge}{r}_{12} \quad \epsilon > \epsilon_0$ 

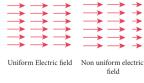
 $\therefore \varepsilon = \varepsilon_0 \cdot \varepsilon_r \ (\varepsilon_r \text{-relative permittivity})$  For air or vacuum  $\varepsilon_r = 1$  and for all other media  $\varepsilon > 1$ .

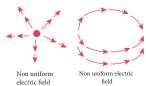
- (vi) It has same structure as Newton's law of gravitation, where  $F = G \frac{M_1 M_2}{r^2}$  and  $G = 6.626 \times 10^{11} \text{ Nm}^2 \text{ kg}^{-2}$
- (vii) The expression for Coulomb force is true only for point charges.
- (viii) Gravitational force is between 2 masses is independence of the medium but Coulomb force between 2 charges depends on the nature of the medium.
- 3. Define 'Electric field' and discuss its various aspects.
- Ans. Electric Field: Electric Field at the point P at a distance r from the point charge q is the

force experienced by a unit charge.  $\stackrel{\rightarrow}{E} = \frac{\stackrel{\rightarrow}{F}}{q_0}$  i.e.  $E = \frac{1}{4\pi\epsilon_0} \frac{q}{r^2} \stackrel{\wedge}{r}$  ...(1)

# Important aspects of the Electric field:

- (i) If *q* is positive, electric field points away from source charge *q*. If *q* is negative, electric field points towards the source charge *q*.
- (ii) Force experienced by the test charge  $q_0$  at P  $F = q_0 \stackrel{\rightarrow}{E}$
- (iii) From equation (1) electric field is independent of  $q_0$  (test charge) and 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.





(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.

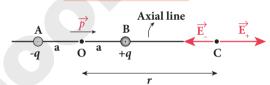
- 4. Calculate the electric field due to a dipole on its axial line and equatorial plane. [PTA-5]
- Ans. Electric field due to an electric dipole at points on the axial line:

AB - Electric dipole; 2a -dipole distance.

C - point along axial line.

r - Distance from mid point 'O' to point C. E at 'C' due to +q

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



E at 'C' due to −*q* 

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

$$\overset{\rightarrow}{\mathrm{E}}_{tot} = \overset{\rightarrow}{\mathrm{E}}_{+} + \overset{\rightarrow}{\mathrm{E}}_{-}$$

at 'C' using superpostion principle

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

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

But r >> a when 'C' is for away from the dipole and  $2aq \stackrel{\wedge}{p} = \stackrel{\rightarrow}{p}$ 

$$\vec{E}_{tot} = \frac{1}{4\pi\varepsilon_0} \cdot \frac{2\vec{p}}{r^3}$$

 $\vec{E}$  acts along  $\vec{p}$ 

Electric field to dipole at a point on equatorial line:

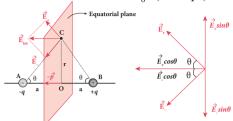
AB - dipole ; 2*a* - dipole distance.

P - dipole moment

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r-distance. E due to  $+q = |E_+| = \frac{1}{4\pi\epsilon_0} \cdot \frac{q}{(r^2 + q^2)}$ along BC along CA

E due to 
$$-q = |\mathbf{E}_{-}| = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q}{(r^2 + q^2)}$$



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

resolving into components, the perpendicular components are equal and opposite so they cancel each other. Total Electric Field at C is sum of parallel components.

$$\overrightarrow{E}_{tot} = -\left| \overrightarrow{E}_{+} \right| \cos \theta \, \widehat{p} - \left| \overrightarrow{E}_{-} \right| \cos \theta \, \widehat{p}$$

$$| E_{+} | = | E_{-} |$$
...(1)

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

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

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

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

r >> a and  $\overrightarrow{p} = 2qa \stackrel{\wedge}{p}$ 

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

 $\stackrel{\rightarrow}{\rm E}$  is opposite to  $\stackrel{\rightarrow}{p}$ 

**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:

AB - an electrical dipole;  $\overrightarrow{p}$  dipole moment.

 $\stackrel{\rightarrow}{\rm E}$  - uniform electric filed :  $\theta$ -angle made by  $\stackrel{\rightarrow}{p}$ with E τ - Torque

 $qE \rightarrow$  force experienced by +q;  $-qE \rightarrow$  force experienced by - q. Total force acting on dipole is zero.

Two unlike force acting at different points produces torque. Torque tends to set dipole in the direction of E.

Total torque on dipole

$$\overrightarrow{\tau} = \overrightarrow{OA} \times \Big|_{-q} \overrightarrow{E} \Big| + \overrightarrow{OB} \times q \overrightarrow{E}$$

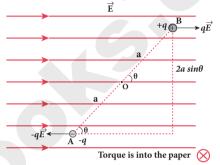
 $\tau = qE \cdot 2a \sin\theta$ ;  $\tau = p E \sin\theta$ 

p = 2aq

 $\tau = \vec{p} \times \vec{E}$ , in terms of vector product

When  $\theta = 90^{\circ} \tau$  is maximum. i.e.  $\tau = PE$ 

 $\theta = 0^{\circ} \tau = 0$  i.e. dipole align with the electric field E.



### Torque on dipole

- Derive an expression for electrostatic potential due to a point charge.
- Consider a positive charge q kept fixed at the origin. Let P be a point at distance rfrom the charge q. This is shown in Figure.



Electrostatic potential at a point P

(ii) The electric potential at the point P is

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

Electric field due to positive point charge q

$$\stackrel{\text{is}}{E} = \frac{1}{4\pi\epsilon_0} \frac{q}{r^2} \stackrel{\wedge}{r}$$

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

The infinitesimal displacement vector,

 $d\overrightarrow{r} = dr \stackrel{\wedge}{r}$  and using  $\stackrel{\wedge}{r} \stackrel{\wedge}{.} \stackrel{\wedge}{r} = 1$ , we have

$$V = -\frac{1}{4\pi\epsilon_0} \int_{\infty}^{r} \frac{q}{r^2} \hat{r} . dr \hat{r} = -\frac{1}{4\pi\epsilon_0} \int_{\infty}^{r} \frac{q}{r^2} dr$$

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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

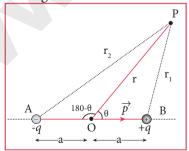
$$V = \frac{1}{4\pi\varepsilon_0} \frac{q}{r} \qquad ...(2)$$

# **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 lower electrostatic potential, 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  $q_1, q_2, q_3, \dots, q_n$  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]
- *Ans.* (i) > AB electric dipole.
  - 2a dipole distance.
  - ➤ 'r' be the distance between the point 'P' and mid point 'O' of AB.
  - > 'θ' angle between 'OP' and "AB'



# Potential due to electric dipole

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

Potential at P due 
$$+q = \frac{1}{4\pi\epsilon_0} \frac{q}{r_1}$$

Potential at P due 
$$-q = -\frac{1}{4\pi\epsilon_0} \frac{q}{r_2}$$

Total potential at P,

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

(iii) By the cosine law for triangle BOP,

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

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

Since a << r, 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.

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

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

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

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

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

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

(v) p = 2qa,

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

### Special cases

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

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

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

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

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

$$V = 0 \qquad \dots (6)$$

- 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

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

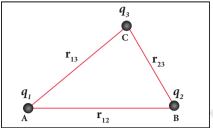
(ii) This potential V is the work done to bring a unit positive charge from infinity to the point. Now if the charge  $q_2$  is brought from infinity to that point at distance r from  $q_1$ , the work done is the product of  $q_2$  and the electric potential at that point. Thus we have

$$W = q_2 V$$

(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

$$U = q_2 V = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r}$$
 ...(1)

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



# **Electrostatic potential energy for Collection of point charges**

- (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 at B 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.

$$U = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r_{12}} \qquad ...(2)$$

(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 the 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 is

$$U = \frac{1}{4\pi\epsilon_0} \left( \frac{q_1 q_3}{r_{13}} + \frac{q_2 q_3}{r_{23}} \right) \qquad ...(3)$$

(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

$$U = \frac{1}{4\pi\epsilon_0} \left( \frac{q_1 q_2}{r_{12}} + \frac{q_1 q_3}{r_{13}} + \frac{q_2 q_3}{r_{23}} \right) \dots (4)$$

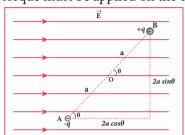
This stored potential energy U is equal to the total external work done to assemble the three charges at the given locations.

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

# en Ans. (i)

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- 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  $\stackrel{\rightarrow}{E}$ . This dipole experiences a torque which 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  $\theta'$  to another angle  $\theta$ , 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

$$W = \int_{0}^{\theta} \tau_{ext} d\theta \qquad ...(1)$$

(iii) Since  $\overrightarrow{\tau}_{ext}$  is equal and opposite to  $\overrightarrow{\tau}_{E} = \overrightarrow{p} \times \overrightarrow{E}$ 

We have

$$\left| \overrightarrow{\tau}_{ext} \right| = \left| \overrightarrow{\tau}_{E} \right| = \left| \overrightarrow{p} \times \overrightarrow{E} \right| \qquad \dots (2)$$

 $\Rightarrow p_{\rm E} \sin \theta = \tau_{\rm ext}$ 

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 n  $\theta'$  and  $\theta$ .  $\Delta U = -pE \cos\theta + pE \cos\theta'$ 

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

'U' also depends on the orientation '  $\theta$ ' other than  $\stackrel{\rightarrow}{p}$  and  $\stackrel{\rightarrow}{\rm E}$  .

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

(v) The potential energy is maximum when the dipole is aligned anti-parallel  $(\theta = \pi)$  and minimum when the dipole is aligned parallel  $(\theta = 0)$  to the external field.

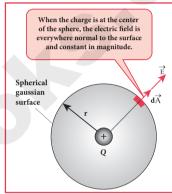
10. Obtain Gauss law from Coulomb's law.

[Sep.-2020]

**Ans.** (i) A positive point charge Q is surrounded by an imaginary sphere of radius *r* electric flux through the closed surface of the sphere

$$\Phi_{\rm E} = \oint \vec{E} \cdot d\vec{A} = \oint E dA \cos \theta \qquad ...(1)$$

(ii) Since the electric field of the point charge is directed radially outward both  $\overrightarrow{dA}$  and  $\overrightarrow{E}$  are along the same direction therefore  $\theta = 0^{\circ}$ .



 $\therefore \Phi_{E} = \oint E dA \text{ since } \cos 0^{\circ} = 1 \qquad ...(2)$ 

E is uniform on the surface of the sphere,

$$\therefore \oint d\mathbf{A} = 4\pi r^2$$

$$\therefore \varphi_{E} = 4\pi r^{2} E \text{ and } E = \frac{1}{4\pi \varepsilon_{0}} \cdot \frac{Q}{r^{2}}$$

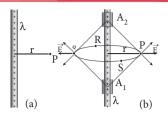
$$\Phi_{E} = \frac{1}{4\pi \varepsilon_{0}} \cdot \frac{Q}{r^{2}} \times 4\pi r^{2} = 4\pi \frac{1}{4\pi \varepsilon_{0}} Q$$

$$\Phi_{E} = \frac{Q}{\varepsilon_{0}} \qquad ...(3)$$

The equation (3) is called as Gauss's law and is true fro any 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]
- Ans. (i)  $> \lambda$  Linear charge density of an infinitily long, uniformly charged wire, r distance between wire and point 'P'
  - > A<sub>1</sub>, A<sub>2</sub> two charge elements.
  - ➤ The resultant 'E' due to A₁ and A₂, act radially outward and is same at all points.
  - > r & L radius & length of cylindrical Gaussian surface of radius 'r'.

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Electric field due to infinite long charged wire

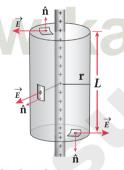
(ii) The total electric flux

$$\Phi_{\rm E} = \oint \stackrel{\rightarrow}{\rm E} \cdot d \stackrel{\rightarrow}{\rm A}$$

$$\oint \stackrel{\rightarrow}{\rm E} \cdot d \stackrel{\rightarrow}{\rm A} + \oint \stackrel{\rightarrow}{\rm E} \cdot d \stackrel{\rightarrow}{\rm A} + \oint \stackrel{\rightarrow}{\rm E} \cdot d \stackrel{\rightarrow}{\rm A}$$
Curved top surface bottom surface ...(

(iii) for the curved surface,  $\stackrel{.}{E} \parallel \stackrel{.}{A}$  and  $\stackrel{.}{E} \cdot d \stackrel{.}{A}$ = E dA. For the top and bottom surfaces,  $\stackrel{.}{E} \perp r \stackrel{.}{A}$  and  $\stackrel{.}{E} \cdot d \stackrel{.}{A} = 0$ Applying Gauss law to the cylindrical surface,

$$\phi_{\rm E} = \int \mathbf{E} \cdot d\mathbf{A} = \frac{\mathbf{Q}_{encl}}{\mathbf{Q}_{encl}} \qquad \dots (2)$$



### Cylindrical Gaussian surface

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

$$E \int_{\text{Curved}} dA = \frac{\lambda L}{\varepsilon_0} \qquad ...(3)$$

But  $\int dA = \text{Total}$  area of the curved surface  $= 2\pi \text{rl}$ .

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

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

In vector form  $\overrightarrow{E} = \frac{1}{2\pi\epsilon_0} \frac{\lambda}{r} \widehat{r}$  and is true for an infinitely long wire.

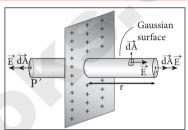
**12.** Obtain the expression for electric field due to a charged infinite plane sheet.

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

- (i)  $\sigma \rightarrow$  surface charge density of an infinite plane sheet.
- (ii)  $2r \& A \rightarrow length \& area of cylindrical Gaussian surface,$

$$\phi_{E} = \oint \overrightarrow{E} \cdot d\overrightarrow{A}$$

$$= \int_{\text{Curved}} \overrightarrow{E} \cdot d\overrightarrow{A} + \int_{P} \overrightarrow{E} \cdot d\overrightarrow{A} + \int_{P} \overrightarrow{E} \cdot d\overrightarrow{A} = \frac{Q_{encl}}{\varepsilon_{0}} \qquad ...(1)$$



Electric field due to charged infinite planar sheet

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

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

$$\phi_{E} = \int_{P} E \, dA + \int_{P'} E \, dA = \frac{Q_{encl}}{\varepsilon_{0}}$$
iv) 
$$\therefore Q_{encl} = \sigma A,$$

$$2E \int_{P} dA = \frac{\sigma A}{\varepsilon_{0}}$$

$$2E\int_{P} dA = \frac{\sigma A}{\varepsilon_{0}}$$
$$\int_{P} dA = A$$

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

or 
$$\stackrel{\rightarrow}{E} = \frac{\sigma}{2\varepsilon_0} \stackrel{\wedge}{n}$$
 ...(4)

 $\stackrel{\wedge}{n}$  Unit vector normal to the plane.

If  $\sigma > 0$ , E – outward perpendicular to plane.

 $\sigma$  < 0, E – inward perpendicular to plane.

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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.

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.</li>

Applying Gauss law

$$\oint_{\text{Gaussian}} \vec{E} \cdot \vec{dA} = \frac{Q}{\varepsilon_0} \qquad ...(1)$$

 $\stackrel{\rightarrow}{\rm E}$  and  $\stackrel{\rightarrow}{d\rm A}$  are in the same direction. at all point

Hence 
$$\mathbb{E} \oint d\mathbf{A} = \frac{\mathbf{Q}}{\varepsilon_0}$$

But  $\oint dA$  = total area of Gaussian surface

 $=4\pi r^2$ 

Substituting in (1)

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

In vector from 
$$\stackrel{\rightarrow}{E} = \frac{1}{4\pi\epsilon_0} \frac{Q}{r^2} \cdot \hat{r}$$

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

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

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

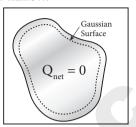
Consider a point P inside the shell at a distance r from the center.

$$\oint \vec{E} \cdot d\vec{A} = \frac{Q}{\epsilon_0}$$
Gaussian
surface
$$E \cdot 4\pi r^2 = \frac{Q}{\epsilon_0}$$

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

$$\therefore E = 0$$

- **14.** Discuss the various properties of conductors in electrostatic equilibrium.
- **Ans.** (i) The Electric Field is zero everywhere inside the conductors 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  $\sigma$  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.

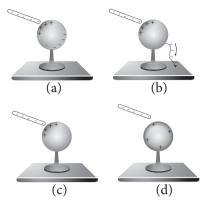
Before introducing the charged rod, the free electrons were distributed uniformly on the surface of the conductor and the net charge is zero.

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.

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### 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.

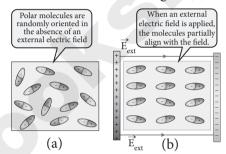
  Note that positive charges will not flow to
  - Note that positive charges will not flow to the ground because they are attracted by the negative charges of the rod (Figure (b)).
- (iii) When the grounding wire is removed from the conductor, the positive charges remain near the charged rod (Figure (c))
- (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. (i) When an external electric field is applied on a conductor, the charges are aligned in such a way that an internal electric field is created which cancels the external electric field. But in the case of a dielectric, which 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. Therefore the net electric field inside the dielectric is not zero but is parallel to an external electric field with magnitude less than that of the external electric field. Let us consider a rectangular dielectric slab placed between two oppositely charged plates (capacitor) as shown in the Figure (b).

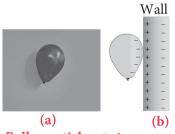
- (iii) The uniform electric field between the plates acts as an external electric field  $\overrightarrow{E}_{ext}$  which polarizes the dielectric placed between plates. The positive charges are induced on one side surface and negative charges are induced on the other side of surface.
- (iv) But inside the dielectric, the net charge is zero even in a small volume. So the dielectric in the external field is equivalent to two oppositely charged sheets with the surface charge densities  $+\sigma_b$  and  $-\sigma_b$ . These charges are called bound charges. They are not free to move like free electrons in conductors.

This is shown in the Figure (b).



### Induced electric field lines inside the dielectric

(v) For example, the charged balloon after rubbing sticks onto a wall. The reason is that the negatively charged balloon is brought near the wall, it polarizes (induces) opposite charges on the surface of the wall, which attracts the balloon.



Balloon sticks Polarisation of wall to the wall due to the electric field due to the balloon

- **17.** Obtain the expression for capacitance for a parallel plate capacitor. [PTA-2]
- Ans. Capacitance of a parallel plate capacitor

Consider a capacitor with two parallel plates,

- A Area of each plate
- d Distance between the plates
- $\sigma$  surface charge density on the plates  $\sigma = \frac{Q}{A}$

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The Electric Field between the plates is  $E = \frac{Q}{A\epsilon_0}$ Since the Electric Field is uniform, the electrical potential between the plates  $V = Ed = \frac{Qd}{A\epsilon_0}$ :. Capacitance of the capacitor

$$C = \frac{Q}{V} = \frac{Q}{\frac{Qd}{A\varepsilon_0}} = \frac{\varepsilon_0 A}{d}$$

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

**Ans.** The capacitor stores not only 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 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

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

The total work done to charge the capacitor

$$W = \int_{0}^{Q} \frac{Q}{C} \cdot dQ = \frac{Q^2}{2C}$$

This work done is stored as Electrostatic Potential Energy

$$U_{E} = \frac{Q^{2}}{2C} = \frac{1}{2}.CV^{2}$$

$$[:: Q = CV]$$

For parallel capacitor, capacitance  $C = \frac{\varepsilon_0 A}{d}$  and V = Ed

$$\mathbf{U}_{\mathrm{E}} = \frac{1}{2} \left( \frac{\varepsilon_{0} \mathbf{A}}{d} \right) (\mathbf{E}d)^{2} = \frac{1}{2} \cdot \varepsilon_{0} \cdot (\mathbf{A}d) \mathbf{E}^{2}$$

Ad - volume of the space between the capacitor plates.

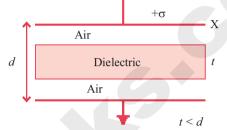
Energy density, 
$$u_{\rm E} = \frac{\rm U}{\rm Volume}$$
  
 $u_{\rm E} = \frac{1}{2} \, \varepsilon_{\rm o} E^2$ 

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

Ans. Capacitance of a parallel plate capacitor with a dielectric medium:

(i) X, Y - conducting plates ; A - area σ - charge density

- t Thickness of dielectric  $\varepsilon_{-}$  relative permittivity
- (ii) Thickness of air gap = (d t). Electric field at any point in the air between the plates as shown in figure,  $E' = \frac{\sigma}{\varepsilon_o}$
- (iii) Electric field at any point, in the dielectric slab  $E' = \frac{\sigma}{\epsilon}$



### Dielectric in capacitor

(v) 
$$V = E(d - t) + E't$$

$$V = \frac{\sigma}{\varepsilon_o} (d - t) + \frac{\sigma t}{\varepsilon_o \varepsilon_r}$$

$$= \frac{\sigma}{\varepsilon_o} \left[ (d - t) + \frac{t}{\varepsilon_r} \right]$$

(vi) The charge on the plate X,  $q = \sigma A$ Hence the capacitance of the capacitor is,

$$C = \frac{q}{V} = \frac{\sigma A}{\frac{\sigma}{\varepsilon_o} \left[ (d-t) + \frac{t}{\varepsilon_r} \right]} = \frac{\varepsilon_o A}{(d-t) + \frac{t}{\varepsilon_r}}$$

the capacitance increases, when dielectric is placed.

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

### Ans. Capacitors in series:

 $C_1$ ,  $C_2$ .  $C_3$  - capacitances of capacitors connected in series.

V - battery voltage

Q - charge on each capacitor is same.

 $V_1$ ,  $V_2$ ,  $V_3$  - potential difference across  $C_1$ ,  $C_2$ ,  $C_3$ .  $V = V_1 + V_2 + V_3$ .

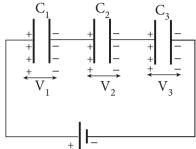
Since Q = CV; V = 
$$\frac{Q}{C_1} + \frac{Q}{C_2} + \frac{Q}{C_3}$$
  
 $\frac{Q}{C_s} = \frac{Q}{C_1} + \frac{Q}{C_2} + \frac{Q}{C_3}$   
 $\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_2}$ 

# Electrostatics

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The inverse of the equivalent capacitance in series is equal to the sum of the inverses of each capacitance.

 $C_s$  is always less than the smallest individual capacitance in series.



# (a) Capacitors connected in series

### Capacitor in parallel:

C<sub>1</sub>. C<sub>2</sub>, C<sub>3</sub> - capacitances of capacitors connected in parallel connection.

V - Applied parallel potential.

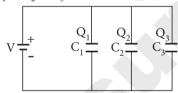
Potential difference across each capacitor is same.  $Q_1$ ,  $Q_2$ ,  $Q_3$  - charge stored in  $C_1$ ,  $C_2$ ,  $C_3$ . Total charge  $Q = Q_1 + Q_2 + Q_3$ 

$$Q = C_{p}V;$$

$$Q = C_{1}V + C_{2}V + C_{3}V$$

$$C_{p}V = (C_{1} + C_{2} + C_{3})V$$

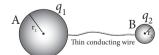
$$C_{p} = C_{1} + C_{2} + C_{3}$$



(a) Capacitors in parallel

The equivalent capacitance of capacitors connected in parallel is equal to the sum of the individual capacitance.  $C_p$  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) The radius of conductor spheres A & B =  $r_1$  &  $r_2$ . A & B are connected by thin wire.



Two conductors are connected through conducting wire

(ii) The distance between the spheres > radii of A & B. A- change given to A. This charge is redistributed into both A & B and Electrostatic potential becomes equal

$$q_1$$
 - charge on A  
 $q_2$  - charge on B  
 $\therefore$  Q =  $q_1 + q_2$ 

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

$$V_{A} = \frac{1}{4\pi\varepsilon_{0}} \frac{q_{1}}{r_{1}} \qquad ...(1)$$

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

$$V_{\rm B} = \frac{1}{4\pi\epsilon_0} \frac{q_2}{r_2} \qquad ...(2)$$

(iv) The spheres are connected by the conducting wire, the surfaces of both the spheres together form an equipotential surface.

$$V_{A} = V_{B}$$
or  $\frac{q_{1}}{r_{1}} = \frac{q_{2}}{r_{2}}$  ...(3)

(v) Let us take the charge density of  $A = \sigma_1$  charge density of  $B = \sigma_2$ 

$$\therefore q_1 = 4\pi r_1^2 \sigma_1$$
 and  $q_2 = 4\pi r_2^2 \sigma_2$  Substituting  $\sigma \frac{q}{A} = 4\pi r_2^2$  these values into equation (3), we get

$$\sigma_1 r_1 = \sigma_2 r_2 \qquad \dots (4)$$

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

$$\sigma \propto \frac{1}{r}$$

- (vi) For a smaller radius, the charge density will be larger and vice versa.
- **22.** Explain in detail the construction and working of a Van de Graaff generator. [QY-2019]
- **Ans.** It is a machine which produces large electrostatic potential difference of the order of 10<sup>7</sup> V.

### **Principle:**

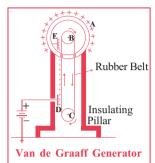
Electrostatic induction and action at points.

### **Construction:**

- (i) It consists of a hollow metallic sphere (A) mounted on insulating pillars.
- (ii) A pulley B is mounted at the centre of the sphere and another pulley C is mounted near the bottom.

The comb D is maintained at a positive potential of the order of 10<sup>4</sup> volt.

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



Working:

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

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 stuck to the belt moves up end and reaches near the comb E.

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

The acquired +ve charge is distributed on the outer surface of the sphere.

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

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

(viii) The high voltage can be used to accelerate positive ions for the purpose of nuclear disintegration.

Exercises:

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.

**Ans.** Given: Charge produced  $q = 50 \text{ nC} = 50 \times 10^{-9} \text{ C}$ ; To find:

No. of electrons n = ?

q = ne magnitude of electrons =  $1.6 \times 10^{-19}$  C

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

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.

Ans. Given:

Number of electrons in human body =  $10^{28}$ Charge appeared on my friend and me (ie)

C = 1% of charge on  $10^{28}$  electrons

$$= \frac{1}{100} \times 10^{28} \times 1.6 \times 10^{-19} \,\mathrm{C}$$

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

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

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

 $F = 23.04 \times 10^{23} \text{ N}$ 

Also mass of the person m = 60 kgweight = mg

 $= 60 \times 9.8$ 

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

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.

**Ans.** The forces acting on q, due to  $Q_1$  and  $Q_2$  are  $F_1$ and  $F_2$ .

Q2

$$F_{4}\sin\theta$$
 $F_{4}\sin\theta$ 
 $F_{4}\cos\theta$ 
 $F_{4}\cos\theta$ 
 $F_{5}\cos\theta$ 
 $F_{5}\sin\theta$ 
 $F_{5}\cos\theta$ 
 $F_{5}\cos\theta$ 
 $F_{5}\cos\theta$ 

These forces are equal and opposite.

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

 $F_1 \sin\theta$  and  $F_2 \sin\theta$  i.e  $F_1 \sin45^\circ$  and  $F_2 \sin45^\circ$  are equal and opposite. So they get cancel.

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Total force acting on q is due to  $Q_3$  (i.e  $F_3$ )  $F_4 \cos\theta$ ,  $F_2 \cos\theta$   $F = F_3 + F_2 \cos\theta + F_4 \cos\theta$ Total force F = k.  $\frac{qQ}{R^2}$  + k.  $\frac{qQ}{R^2}$ .  $\cos 45^\circ$  +  $\frac{kqQ}{R^2}$  $=\frac{kqQ}{R^2}\left[1+\frac{2}{\sqrt{2}}\right]$  $=\frac{kqQ}{R^2}\left[1+\sqrt{2}\right]\hat{i}$ Total F  $= \frac{1}{4\pi\epsilon_0} \frac{qQ}{R^2} \left[ 1 + \sqrt{2} \right] \hat{i}$   $\left[ \because k = \frac{1}{4\pi\epsilon_0} \right]$ 

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,  $m_{\rm M} = 7.9 \times 10^{22} \, \text{kg}$ 

### Ans. Given:

Mass of the earth  $m_E = 5.9 \times 10^{24} \text{ kg}$ Mass of the moon  $m_M = 7.9 \times 10^{22} \text{ kg}$ 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

Formula: 
$$\frac{1}{4\pi\epsilon_0} \cdot \frac{q \times q}{r^2} = G \cdot \frac{m_E \times m_M}{r^2}$$

$$\frac{1}{4\pi\epsilon_0} = 9 \times 10^9$$

$$G = 6.6 \times 10^{-11} \text{ Nm}^{-2} \text{ kg}^{-2}$$

$$4\pi\epsilon_0 = 0.11 \times 10^{-9}$$
(or)

$$q = \sqrt{4\pi\epsilon_0 \,\text{Gm}_{\text{E}} \cdot \text{m}_{\text{M}}}$$

$$= \sqrt{0.11 \times 10^{-9} \times 6.6 \times 10^{-11} \times 5.9 \times 10^{24} \times 7.9 \times 10^{22}}$$

$$q = \sqrt{33.84 \times 10^{26}}$$

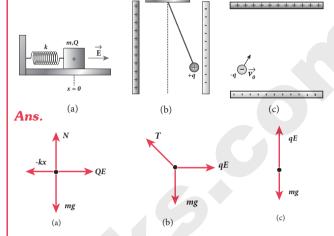
$$q = 5.82 \times 10^{13} \text{ C}.$$

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

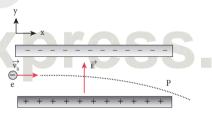
$$\frac{1}{4\pi\varepsilon_0} \cdot \frac{q_1 q_2}{\left(\frac{r}{2}\right)^2} = G \cdot \frac{m_E \cdot m_M}{\left(\frac{r}{2}\right)^2}$$

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).



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



**Ans.** The speed of the electrons Electric field strength

Acceleration of the electrons *a* 

Velocity of the electrons  $\nu$ 

Position of the electrons r=?

According to Newton's II law F = ma

The force on the electrons in an uniform electric field.

F = Ee

The e-s acceleration due to electric field

$$a = \frac{F}{m} = \frac{Ee}{m}$$

The acceleration of the electrons  $a = \frac{Ee}{m}$  is in the downward direction. The horizontal velocity remains  $v_0$  as there is no acceleration in this direction.

$$v = v_x \hat{i} + v_y \hat{j}$$

The horizontal component of the velocity remains  $v_x = v_0$ . The vertical component (downward) velocity as it emerges from the field region is

$$v_y = \stackrel{\rightarrow}{a} t = -\frac{eE}{m} t. \stackrel{\wedge}{j}$$

The velocity of the electron,  $\vec{v} = v_0 \hat{i} - \frac{eE}{t} \cdot \hat{j}$ 

The electrons starts with a velocity  $v_0$ .

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

The position of the electrons s = r = ?

Initial velocity of the electrons  $u = v_0$ 

Acceleration of the electrons  $\overrightarrow{a} = \left(-\frac{eE}{m}\right) \cdot \hat{j}$ 

$$\therefore \stackrel{\rightarrow}{r} = v_0 t \stackrel{\wedge}{i} + \frac{1}{2} \cdot \left( -\frac{\mathbf{E}e}{m} t^2 \right) \stackrel{\wedge}{.} \stackrel{\rightarrow}{j}$$

$$= v_0 t \hat{i} - \frac{1}{2} \cdot \frac{\text{E}e}{m} \cdot t^2 \hat{j}$$

$$\stackrel{\rightarrow}{r} = v_0 t \hat{i} - \frac{1}{2} \cdot \frac{\text{E}e}{m} \cdot t^2 \hat{j}$$

$$\vec{r} = v_0 t \hat{i} - \frac{1}{2} \cdot \frac{Ee}{m} \cdot t^2 \hat{j}$$

A closed triangular box is kept in an electric field of magnitude  $E = 2 \times 10^3 \text{ N C}^{-1}$  as shown in the figure.



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

Ans. Given:

The magnitude of electric field  $E = 2 \times 10^3 \text{ NC}^{-1}$ Area of the surface  $A = 0.15 \times 0.05$ 

From the diagram  $1 \alpha = 15 \text{ cm} = 0.15 \text{ m}, b = 5 \text{ cm}$ = 0.05m

To find:

The electric flux through

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

$$\phi_{\text{vertical surface}} = 2 \times 10^{3} \times 0.15 \times 0.05 \times \cos 0^{\circ} \\
= 0.015 \times 10^{3} = 15 \text{ Nm}^{2} \text{ C}^{-1}$$

Electric flux through slanted surface

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

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

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

$$5 \text{ cm} \begin{cases} 60^{\circ} & \sin 30 = \frac{\text{opposite}}{\text{hyp}} \\ \text{Opposite} = 5 \text{ cm. hyp} = \frac{\text{opposite}}{\sin 30^{\circ}} \end{cases}$$

hyp. = 
$$\frac{5 \times 10^{-2}}{\frac{1}{1}}$$
 = 2 × .05

$$= 0.10 \text{ m}$$

Area of the slanted surface

$$A = (0.10 \times 0.15) \text{ m}^2$$

$$\phi_{1} = EA \cos\theta$$

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

$$= 0.015 \times 10^3 = 15 \text{ Nm}^2 \text{ C}^{-1}$$

c) Entire surface 
$$\phi_{tot} = ?$$

$$\phi_{\text{tot}} = \phi_{\text{vs}} + \phi_{\text{s,s}} + \phi_{\text{ends}}$$

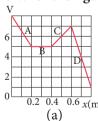
$$\phi_{\rm ends} = EA \cos \theta$$

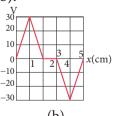
$$\phi_{\text{ends}} = \text{EA cos } \theta$$
$$\theta = 90^{\circ} \text{ ; cos } 90^{\circ} = 0$$

$$\phi_{\text{ends}} = 0$$

$$= -15 + 15 + 0$$
 
$$\varphi_{tot} = 0.$$

The electrostatic potential is given as a function of x in figure (a) and (b). 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).





Ans.

(a) 
$$E = -\frac{dV}{dx}$$

(i) Region A

$$\frac{dV}{dx} = \frac{-3}{0.2} = -15V_i, E = \frac{dV}{dx}$$

$$\therefore E = -(-15) = 15 \text{ Vm}^{-1}$$

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(ii) Region B

$$\frac{dV}{dx} = \frac{0}{0.2} = 0$$

(iii) Region C

$$\frac{dV}{dx} = \frac{2}{0.2} = 10$$

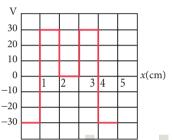
$$E = -\frac{dV}{dx} = (-10)Vm^{-1}$$

(iv) Region D

$$\frac{dV}{dx} = \frac{-6}{0.2} = -30$$

$$E = -\frac{dV}{dx} = -(-30) = 30Vm^{-1}.$$

**(b)** 



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 × 10<sup>6</sup> Vm<sup>-1</sup> 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.

Ans. Given:

(a) The distance between two electrodes d = 0.6mm  $= 0.6 \times 10^{-3} \text{ m}$ 

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

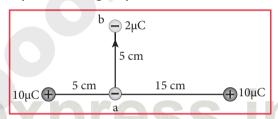
Potential difference need to produce spark V = ?

Formula: 
$$E = \frac{V}{d}$$
  
Solution:  $\therefore V = E \cdot d$   
 $= 0.6 \times 10^{-3} \times 3 \times 10^{6}$   
 $= 1800 \text{ V}.$ 

- From the above, we come to know when the gap is increased. potential also increase.
- The distance,  $d = 1 \text{ mm} = 1 \times 10^{-3} \text{ m}$ (c) 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  $+10 \mu C$  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.



**Ans.** Given: 
$$q_1 = 10 \times 10^{-6} \text{ C}$$
,  $q_2 = -2 \times 10^{-6} \text{ C}$ 

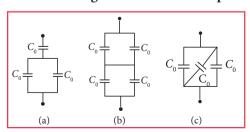
$$r = 5 \times 10^{-2} \text{ m}$$

**Solution:** Change in potential energy

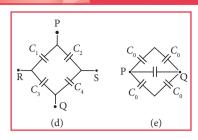
$$\Delta U = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r} = \frac{9 \times 10^9 \times (10)(-2) \times 10^{-12}}{5 \times 10^{-2}}$$
$$= \frac{-9 \times 10^9 \times 20 \times 10^{-12} \times 10^2}{5 \times 10^{-12} \times 10^2}$$

 $\Delta U = -3.6$  J, negative sign implies that to move the charge -2µC no external work is required. System spends its stored energy to move the charge from point a to point b.

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



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Ans.

a.



Capacitor 1 & 2 are connected in parallel  $C_p = C_0 + C_0 = 2C_0$ 

Capacitor  $C_p$  and  $C_3$  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<sub>0</sub>



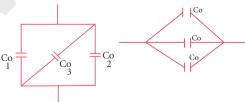
 $C_1 \& C_2$  are in series  $\frac{1}{Cs_1} = \frac{1}{C_0} + \frac{1}{C_0} = \frac{2}{C_0}$ 

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

Cs, & Cs, are in parallel

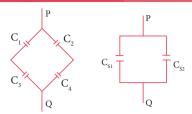
$$\therefore C_p = Cs_1 + Cs_2 = \frac{C_0}{2} + \frac{C_0}{2} = C_0$$

Resultant capacitance =  $C_0$ 



Resultant capacitance  $C_p = C_0 + C_0 + C_0$  $C_p = 3 C_0$ 

d.



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

$$Cs_1 = \frac{C_1 C_3}{C_1 + C_2}$$

C<sub>2</sub> and C<sub>4</sub> are in series

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

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

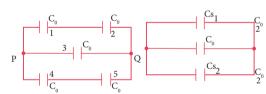
Now Cs, and Cs, are parallel

$$Cp = Cs_1 + Cs_2$$

$$= \frac{C_1 C_3}{C_1 + C_3} + \frac{C_2 C_4}{C_2 + C_4}$$

$$= \frac{(C_1 C_3)(C_2 + C_4) + (C_2 C_4)(C_1 + C_3)}{(C_1 + C_3)(C_2 + C_4)}$$
The resultant capacitance

$$= \frac{C_1C_2C_3 + C_1C_3C_4 + C_1C_2C_4 + C_3C_2C_4}{(C_1 + C_3)(C_2 + C_4)}$$



Capacitors 1 and 2 are in series

$$\frac{1}{Cs_{1}} = \frac{1}{C_{0}} + \frac{1}{C_{0}} = \frac{2}{C_{0}}$$

$$Cs_{1} = \frac{C_{0}}{2}$$

Parallerly 4 and 5 are in series

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

Cs<sub>1</sub>, Cs<sub>2</sub>, 3 are in parallel

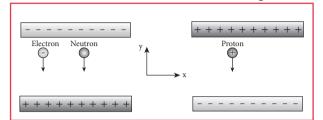
$$\therefore C_p = \frac{C_0}{2} + \frac{C_0}{2} + C_0$$
$$= C_0 + C_0$$

Resultant capacitance =  $2C_0$ .

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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 $^{-2})$ 

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

Distance between the plates of

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

Mass of proton m<sub>p</sub> =  $1.6 \times 10^{-27}$  kg Mass of electron m<sub>e</sub> =  $9.1 \times 10^{-31}$  kg Charge of proton, e =  $1.6 \times 10^{-19}$  C

To find:

a. Time of flight of an electron  $t_e = ?$  $s = ut + \frac{1}{2}at^2$ , initial velocity (u) = 0

**Solution:** 

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

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

F - force due to electric field

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

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

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

$$\therefore t_e^2 = \frac{2 \, h m_e}{\frac{\Delta V}{\Delta d} \cdot e}$$

$$t_{e}^{2} = \Delta dx \frac{2hm_{e}}{\Delta Ve} = \frac{2 \times 10^{-3} \times 9.1 \times 10^{-31} \times 10^{-3}}{5 \times 1.6 \times 10^{-19}}$$

$$t_e = \sqrt{\frac{2 \times 10^{-3} \times 9.1 \times 10^{-31} \times 10^{-3}}{5 \times 1.6 \times 10^{-19}}}$$
$$= \sqrt{2.275 \times 10^{-18}} = 1.5 \times 10^{-9} \text{ s (or) } 1.5 \text{ ns}$$

$$t_p = \sqrt{\frac{2 \times 10^{-3} \times 1.6 \times 10^{-27} \times 10^{-3}}{5 \times 1.6 \times 10^{-19}}}$$
$$= \sqrt{\frac{2}{5} \times 10^{-33} \times 10^{19}} = \sqrt{0.4 \times 10^{-14}}$$

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

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

$$t^2 = \frac{2h}{g}$$
 [i.e.  $t = \frac{2s}{a}$ ]  $a = g$ ,  $s = h$ 

$$t = \sqrt{\frac{2 \times 10^{-3}}{10}} = \sqrt{2 \times 10^{-4}}$$

$$t = 1.414 \times 10^{-2} \text{ sec.}$$

- c. Electron will reach first

  : 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<sup>6</sup> Vm<sup>-1</sup>), 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?

# Unit 1

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### Ans. Given:

**a.** Electric field between ground and cloud

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

Distance between ground and the cloud

d = 1000m

To find: Electric potential between ground

and the cloud V = ?

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

$$E = 3 \times 10^6 \times 10^3 = 3 \times 10^9 \text{ V}$$

**b.** The amount of electrons transferred from cloud to ground q = 25 C

Electrostatic P.E. transfered from cloud to ground U = ?

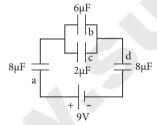
**Solution:** 

$$U = \frac{1}{2} CV^2$$

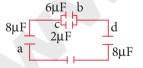
$$C = \frac{q}{V}$$
  $\therefore U = \frac{1}{2} q.V$ 

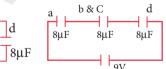
$$U = \frac{1}{2} \times 25 \times 3 \times 10^9 = \frac{75}{2} \times 10^9$$
$$= 37.5 \times 10^9 \text{ J.}$$

- 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



Ans.





B & C are parallel so  $C = (6 + 2) \mu F = 8\mu F$ Now all a, b & c, d are in series.

Effective capacitance  $\frac{1}{C_s} = \frac{1}{8} + \frac{1}{8} + \frac{1}{8} = \frac{3}{8}$   $\therefore C_s = \frac{8}{3}$ 

a. Charges on each capacitor:

Total charges on capacitor =  $q = C_s$ .

$$V = \frac{8}{3} \times 9 \times 10^{-6} = 24 \,\mu\text{C}$$

Charge on capacitor  $a = q_a = C.V.$ 

$$q_a = 24 \,\mu\text{C}$$

In case of capacitor in series the charge flowing through capacitor is same.

$$q_a = q_d = 24 \,\mu\text{C}$$

But across b & c, the charge is not same since they are in parallel.

Charge on b = 
$$q_b = \frac{6}{3} \times 9 \times 10^{-6}$$
  
= 18  $\mu$ C

Charge on c = 
$$q_c = \frac{2}{3} \times 9 \times 10^{-6}$$
  
=  $6 \,\mu\text{C}$ 

**b.** Potential difference across capacitor *a* 

$$V_a = \frac{q_a}{C_a} = \frac{24 \times 10^{-6}}{8 \times 10^{-6}} = 3V$$

Potential difference across capacitor b

$$V_b = \frac{q_b}{C_b} = \frac{18 \times 10^{-6}}{6 \times 10^{-6}} = 3V$$

Potential difference across capacitor c

$$V_c = \frac{q_c}{C_c} = \frac{6 \times 10^{-6}}{2 \times 10^{-6}} = 3V$$

Potential difference across capacitor d

$$V_d = \frac{q_d}{C_d} = \frac{24 \times 10^{-6}}{8 \times 10^{-6}} = 3V$$

c. Energy stored in  $a U_a = \frac{1}{2} CV^2$ 

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

Energy stored in b

$$U_b = \frac{1}{2} \times 6 \times 3 \times 3 \times 10^{-6} = 27 \,\mu\text{J}$$
[C<sub>b</sub> = 6 \mu F]

Energy stored in c

$$U_c = \frac{1}{2} \times 2 \times 3 \times 3 \times 10^{-6} = 9 \,\mu\text{J}$$
[C<sub>c</sub> = 2 \(\mu\mathrm{F}\)]

Energy stored in d

$$U_d = \frac{1}{2} \times 8 \times 10^{-6} \times 3 \times 3 = 36 \times 10^{-6} = 6 \text{ J}$$
  
= 36 \mu j

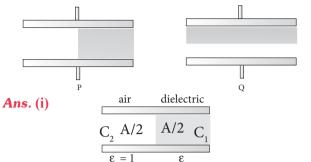
15. Capacitors P and Q have identical cross sectional areas A and separation d. The space between the capacitors is filled with a dielectric of dielectric constant  $\varepsilon$ , as shown in the figure.

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## Calculate the capacitance of capacitors P and Q.

[PTA-4]



The given arrangement is equivalent to parallel combination of the capacitor each plate of

areas = 
$$\frac{A}{2}$$

Plate of separation = d

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

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

The capacitance for  $K_1 = C_1$ 

The capacitance for  $K_2 = C_2$   $C = \frac{\varepsilon}{4}$ 

$$C_{1} = \frac{\varepsilon_{0} \frac{A}{2} \cdot K_{1}}{d} = \frac{\varepsilon_{0} K_{1} A}{2d}$$

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

If C is the capacitance of the capacitor. then

$$C = C_{1} + C_{2}$$

$$= \frac{\varepsilon_{0} K_{1}A}{2d} + \frac{\varepsilon_{0} K_{2} A}{2d} = \frac{\varepsilon_{0} (K_{1} + K_{2})A}{2d}$$

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

For capacitor Q.

(ii) dielectric 
$$C_1$$
  $C_2$   $C_3$   $C_4$   $C_5$   $C_7$   $C_8$   $C_7$   $C_8$   $C_9$   $C_9$ 

This is equivalent to a series combination of two capacitors

Plate of separation  $\frac{d}{2}$ Dielectric constant for first medium =  $K_1$ [air  $K_1 = \varepsilon$ .] Dielectric constant for second medium =  $K_2$  [direction  $K_2 = \varepsilon_r$ ]

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

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

If C is the capacitance of the capacitor

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

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

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

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

### 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]
[PTA-2]

- 2. The unit of permittivity is:
  - (b)  $N m^2 C^{-2}$
  - (a)  $C^2 N^{-1} m^{-2}$ (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 m<sup>2</sup> with 10 turns is in a plane which is parallel to a uniform electric field of 100 N/C. 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]

- Dimension and unit of Electric flux is [PTA-3]
  - (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)  $ML^3T^{-3}A^{-1}$ ,  $Nm^2C^{-1}$ ]

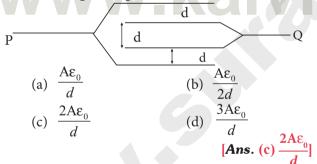
- At infinity, the electrostatic potential is [PTA-4]
  - (a) infinity
  - (b) maximum
  - (c) minimum
  - (d) zero

[Ans. (d) zero]

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

[Ans. (c) neutral]

The resultant capacitance of four plates, each is having an area A, arranged as shown above, will be (plate separation is d)



Hint:

$$C = C_1 + C_2 = 2C$$

$$\therefore C = \frac{2\varepsilon_0 A}{d}$$

- An electric dipole is placed at an angle 30° with an electric field intensity of  $2 \times 10^5$  N C<sup>-1</sup>. 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)  $7 \mu C$

[Ans. (2 mC)]

- VERY SHORT ANSWER OUESTIONS 2 MARKS
- The electric field outside a conductor is perpendicular to its surface. Justify.
- Ans. (i) The electric field outside the conductor is perpendicular to the surface of the conductor and has a magnitude of where  $\sigma$  is the surface charge density at that point.
  - If the electric field has components parallel (ii) 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.
- State the law of conservation of electric charges.

**Ans.** The total electric charge in the universe is constant and charge can neither be created nor be destroyed. In any physical process, the

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

net change in charge will always be zero.

- **Ans.** Unit of Electric flux is Vm or Nm<sup>2</sup>C<sup>-1</sup> It is a scalar quantity.
- Can two equipotential surfaces intersect? Give [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]
- Ans. Two equal and opposite charges separated by a very small vector distance.
- Define electric potential. [PTA-6]
- **Ans.** It is defined as the amount of work done in moving a unit positive charge from infinity to that point.

#### SHORT ANSWER QUESTIONS 3 MARKS

- 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

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- (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  $Q = (-q) \times \text{potential}$  at a point Q due to +q located at a point P.

$$W_{Q} = -q \times \frac{1}{4\pi\epsilon_{0}} \frac{q}{a} = \frac{1}{4\pi\epsilon_{0}} \frac{q^{2}}{a}$$

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

$$W_{R} = q \times \frac{1}{4\pi\epsilon_{0}} \left( -\frac{q}{a} + \frac{q}{\sqrt{2}a} \right) = \frac{1}{4\pi\epsilon_{0}} \frac{q^{2}}{a} \left( -1 + \frac{1}{\sqrt{2}} \right)$$

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

$$W_{S} = -q \times \frac{1}{4\pi\epsilon_{0}} \left( \frac{q}{a} + \frac{q}{a} + \frac{q}{\sqrt{2}a} \right) = \frac{1}{4\pi\epsilon_{0}} \frac{q}{a} \left( 2 - \frac{1}{\sqrt{2}} \right)$$

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

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

$$\text{Hence } C_s = \frac{C_1 C_2}{C_p} \Rightarrow 6 = \frac{C_1 C_2}{25}$$

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

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

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

$$\text{(or)}$$

$$C_1^2 - 25 C_1 + 150 = 0$$

$$C_1^2 - 10 C_1 - 15 C_1 + 150 = 0$$

$$C_1(C_1 - 10) - 15 (C_1 - 10) = 0$$

$$(C_1 - 10) (C_1 - 15) \text{ or } C_1 = 10 \text{ or } 15$$

$$\text{if } C_1 = 10 \mu \text{F}; C_2 = 15 \mu \text{F}$$

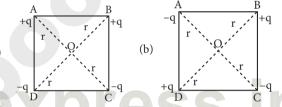
$$C_1 = 15 \mu \text{F}; C_2 = 10 \mu \text{F}$$

- 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

$$F_{e} = \frac{ke^{2}}{r^{2}} = \frac{9 \times 10^{9} \times (1.6 \times 10^{-19})^{2}}{(5.3 \times 10^{-11})^{2}}$$
$$= \frac{9 \times 2.56}{28.09} \times 10^{-7}$$
$$= 8.2 \times 10^{-8} \text{ N}$$

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]



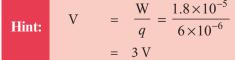
- Ans. (i) Electric field at the centre of fig (b) will be zero because same charges on the diagonally opposite corners of a square give zero electric field at the centre whereas it will be 'non zero' in fig (a).
  - (ii) Electric potential will be the same in case of fig(a) and (b) because there are 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  $1.8 \times 10^{-5}$  J. The potential difference between the two points is [Govt. MQP-2019]
  - (a) 1.08 V
- (b)  $1.08 \,\mu\text{V}$
- (c) 3 V

(d) 30 V **Ans.** (c) 3 V

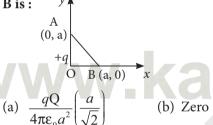


- 2. Two point charges A and B having charges +O and -O respectively, are placed at certain distance, apart and force acting between them is F. If 25% charge of A is transformed to B, then force between the charges becomes.

- (a)  $\frac{16}{9}$ F (b)  $\frac{4}{3}$ F (c) F (d)  $\frac{9}{16}$ F [Ans. (d)  $\frac{9}{16}$ F]
- 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 [OY-2019]
  - (a)  $2\pi R^2 E$
- (b)  $\frac{\pi}{E} R^2$
- (c)  $(\pi R^2 \pi R)/E$
- (d) Zero

[Ans. (d) Zero]

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]



- (c)  $\left[\frac{-qQ}{4\pi\varepsilon_0}\frac{1}{a^2}\right]\sqrt{2a}$  (d)  $\left[\frac{qQ}{4\pi\varepsilon_0}\frac{1}{a^2}\right]\sqrt{2a}$

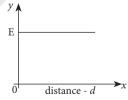
Ans. (b) Zerol

#### 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.



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.

[OY-2019]

**Ans.** The capacitance of the capacitor is

$$C = \frac{\varepsilon_0 A}{d} = \frac{8.85 \times 10^{-12} \times 25 \times 10^{-4}}{1 \times 10^{-3}}$$
$$= 221.2 \times 10^{-13} \text{ F}$$
$$C = 22.12 \times 10^{-12} \text{ F} = 22.12 \text{ pF}$$

#### 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

$$U_{E} = \frac{1}{2} CV^{2}$$
 ...(1)

This is rewritten as using  $C = \frac{\varepsilon_0 A}{J} \& V = Ed$ .

$$U_{E} = \frac{1}{2} \left( \frac{\varepsilon_0 A}{d} \right) (Ed)^2 = \frac{1}{2} \varepsilon_0 (Ad) E^2 \qquad \dots (2)$$

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

$$u_{\rm E} = \frac{\rm U}{\rm Volume}$$
 From equation (4),

We get 
$$u_{\rm E} = \frac{1}{2} \varepsilon_0 {\rm E}^2$$
 ...(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.

- **Ans.** The following rules are followed while drawing electric field lines for charges.
  - The electric field lines start from a positive charge and end at negative charges or at infinity.
  - 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.

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.

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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.

#### LONG ANSWER QUESTIONS

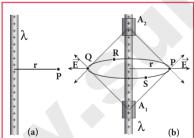
5 MARKS

- State Gauss Law in electrostatics. Obtain an expression for Electric field due to an infinitely long charged wire. [Mar.-2020]
- Gauss's law states that if a charge Q is Ans. (i) enclosed by an arbitrary closed surface, then the total electric flux  $\Phi E$  through the closed surface is

$$\Phi E = \oint \stackrel{\rightarrow}{E} \cdot d \stackrel{\rightarrow}{A} = \frac{Q_{encl}}{\varepsilon_0}$$

where Q<sub>encl</sub> denotes the charges within the closed surface.

- $\lambda$  Linear charge density of an infinitely long, uniformly charged wire, r - distance between wire and point 'P'
- A<sub>1</sub>, A<sub>2</sub> two charge elements.
- The resultant 'E' due to A, and A, act radially outward and is same at all points.
- r & L radius & length of cylindrical Gaussian surface of radius 'r'.



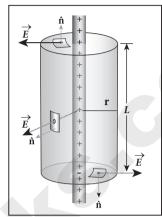
Electric field due to infinite long charged wire

The total electric flux

(iii) for the curved surface,  $\overrightarrow{E} \parallel \overrightarrow{A}$  and  $\overrightarrow{E} \cdot \overrightarrow{dA}$ = E dA. For the top and bottom surfaces,  $\stackrel{\rightarrow}{\mathrm{E}} \perp \mathbf{r} \stackrel{\rightarrow}{\mathrm{A}} \text{ and } \stackrel{\rightarrow}{\mathrm{E}} \cdot d \stackrel{\rightarrow}{\mathrm{A}} = 0$ 

Applying Gauss law to the cylindrical surface,

$$\phi_{\rm E} = \int_{\substack{\text{Curved} \\ \text{surface}}} E \cdot dA = \frac{Q_{encl}}{\varepsilon_0} \qquad ...(2)$$



**Cylindrical Gaussian surface** 

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

But  $\int dA = \text{Total}$  area of the curved surface =  $2\pi \text{rl}$ .  $\therefore E \cdot 2\pi r L = \frac{\lambda L}{\varepsilon_0}$   $E = \frac{1}{2\pi\varepsilon_0} \frac{\lambda}{r} \quad \text{(or)}$ 

In vector form  $\overrightarrow{E} = \frac{1}{2\pi\epsilon_0} \frac{\lambda}{r} \stackrel{\wedge}{r}$  and is true for an infinitely long wire.

#### **NUMERICAL PROBLEMS**

3 MARKS

Charges of +  $\frac{10}{3}$  × 10<sup>-9</sup> 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.

Ans. 
$$V = \frac{q}{4\pi\epsilon_0} \left( \frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3} + \frac{1}{r_4} \right)$$

$$[q = \frac{10}{3} \times 10^{-9} \text{C}]$$

$$= 9 \times 10^9 \times \frac{10}{3} \times 10^{-9}$$

$$\times q$$

$$\left( \frac{1}{4\sqrt{2} \times 10^{-2}} + \frac{1}{4\sqrt{2} \times 10^{-2}} + \frac{1}{4\sqrt{2} \times 10^{-2}} + \frac{1}{4\sqrt{2} \times 10^{-2}} \right)$$

$$V = 2.1216 \times 10^3 \text{ V}.$$

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- 2. A dipole is formed by two charges of 5  $\mu$ C and -5  $\mu$ C at a distance of 8 mm. Find the electric field at
  - 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]

Given:  $q = 5 \mu C$ , E along axial line at 25 cm = ?, E along equatorial line at 20 cm = ? **Solution**: a) dipole moment p

$$= 2qd = 2 \times 5 \times 10^{-6} \times 8 \times 10^{-3} = 80 \times 10^{-9} \text{ cm}$$

E along axial line at 25 cm

$$E = \frac{1}{4\pi\epsilon_0} \frac{2p}{r^3} = 9 \times 10^9 \times \frac{2 \times 80 \times 10^{-9}}{\left(25 \times 10^{-2}\right)^3}$$
$$= 0.09216 \times 10^6$$

$$= 0.09216 \times 10^{6}$$
$$= 9.2 \times 10^{4} \text{ NC}^{-1}$$

$$E = \frac{1}{4\pi\epsilon_0} \frac{p}{r^3} = 9 \times 10^9 \times \frac{80 \times 10^{-9}}{\left(20 \times 10^{-2}\right)^3} = 0.09 \times 10^6 = 9 \times 10^4 \text{ NC}^{-1}$$

### ADDITIONAL QUESTIONS AND ANSWERS

#### CHOOSE THE CORRECT ANSWER

1 MARK

- 1. Based on Franklin's convention amber rods
  - (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]

- In electrostatics if the charges are in motion, 3. 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]

- The value of constant 'K' in coulomb law is
  - (a)  $0.9 \times 10^9 \,\mathrm{Nm^2\,C^2}$
- (b)  $9 \times 10^{-9} \text{ Nm}^2\text{C}^2$
- (c)  $9 \times 10^9 \text{ Nm}^{-2} \text{ C}^{-2}$
- (d)  $9 \times 10^9 \text{ Nm}^2 \text{ C}^{-2}$

[Ans. (d)  $9 \times 10^9 \text{ Nm}^2 \text{ C}^{-2}$ ]

- The electrostatic force is always greater in magnitude than gravitational force for object
  - (a) bigger size
- (c) medium size
- (d) all the above

[Ans. (b) smaller size]

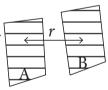
- 6. The relative permittivity of water is \_\_\_\_\_
  - (a)  $\varepsilon_r = 70$
- (b)  $\varepsilon_r = 75$  (d)  $\varepsilon_r = 85$
- (c)  $\varepsilon_r = 80$

[Ans. (c)  $\varepsilon$  = 80]

- **7**. 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]

The figure shows two parallel equipotential surface A and B kept at a small distance 'r' apart from each other. A point change of Q coulomb is taken from the surface A to B. The amount of net work done will be



- (a)  $W = \frac{-1}{4\pi\epsilon_0} \frac{q}{r}$  (b)  $W = \frac{1}{4\pi\epsilon_0} \frac{q}{r^2}$
- (c)  $W = \frac{-1}{4\pi\epsilon_0} \frac{q}{r^2}$
- (d) zero

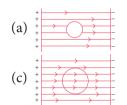
[Ans. (d) zero]

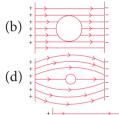
Hint:  $W = (V_A - V_B) q$ ∴  $V_A = V_B$  for equipotential surface  $W = O \times q = 0$ 

- 9. 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]

10. An uncharged metal sphere is placed between two equal and oppositely charged metal plates. The nature of lines of force will be





Ans. (b)

11. An isolated metal sphere of radius 'r' is given a charge 'q'. The potential energy of the sphere is

(a) 
$$\frac{q^2}{4\pi\epsilon_0 r}$$

(b) 
$$\frac{q}{4\pi\epsilon_0 r}$$

(c) 
$$\frac{q}{8\pi\epsilon_0 r}$$

(d) 
$$\frac{q^2}{8\pi\epsilon_0 r}$$

[Ans. (d)  $\frac{q^2}{8\pi\epsilon r}$ ]

Hint:

P.E = 
$$\frac{1}{2}$$
 CV<sup>2</sup> [::C =  $4\pi\epsilon_0 r$ ]

V =  $\frac{q}{4\pi\epsilon_0 r}$ 

P.E =  $\frac{1}{2} \times (4\pi\epsilon_0 r) \times \left(\frac{q}{4\pi\epsilon_0 r}\right)^2$ 

P.E =  $\frac{q^2}{8\pi\epsilon_0 r}$ 

- 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 nuleus is
  - (a) 6.8 V
- (b) 13.6 V
- (c) 54.4 V
- (d) 27.2 V

[Ans. (d) 27.2 V]

Hint:

$$V = \left(\frac{1}{4\pi\varepsilon_0}\right) \frac{q}{r}$$
$$= (9 \times 10^9) \times \frac{1.6 \times 10^{-19}}{0.53 \times 10^{-10}} = 27.2 \text{ V}$$

- 13. Which one of these is a vector quantity?
  - (a) Electric charge
- (b) Electric field
- (c) Electric flux
- (d) Electric potential

[Ans. (b) Electric field]

- **14.** 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]

- 15. 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:

$$8 \times \text{volume of one droplet of Hg} = \frac{4}{3} \pi R^3$$

$$8 \times \frac{\cancel{4}}{\cancel{3}} \cancel{\pi} r^3 = \frac{\cancel{4}}{\cancel{3}} \cancel{\pi} R^3$$
$$2^3 \times r^3 = R^3$$

$$(2r)^{3} = (R)^{3}$$

$$D - 2r$$

 $R = 2r \qquad [\because r = 1 \text{ mm}]$ 

$$R = 2 \times \frac{1}{q} \times 10^{-3} \,\mathrm{m} \,\mathrm{(or)} \,2 \,\mathrm{mm}$$

$$[\because q]$$

$$\therefore V = \frac{1}{4\pi\varepsilon_0} \times \frac{q}{R}$$

$$V = \frac{9 \times 10^{9} \times 0.066 \times 10^{-12} \times 8}{2 \times 10^{-3}}$$

$$V = 2.4 \text{ V}$$

$$V = 2.4 V$$

- 16. 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]

$$F_a = \frac{1}{4\pi\epsilon_0} \cdot \frac{q_1 q_2}{r^2}$$

$$F_g = \frac{1}{4\pi\epsilon_0 \epsilon_r} \cdot \frac{q_1 q_2}{r^2}$$

$$\frac{F_g}{F_g} = \frac{1}{\epsilon} = \frac{1}{8}$$

Hint:

$$F_a = \varepsilon_r = 8$$

$$F_a = \frac{F_a}{T_a} = \frac{40}{T_a} = 51$$

$$F_g = \frac{F_a}{8} = \frac{40}{8} = 5 \text{ N}$$

#### 17. The concept of 'Field' was introduced by

- (a) Faraday
- (b) Gauss
- (c) Maxwell
- (d) None

[Ans. (a) Faraday]

#### 18. 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]

#### 19. The expression for electric field in vector form is

- (a)  $\frac{1}{4\pi\epsilon_0} \frac{q}{r} \hat{r}$
- (b)  $\frac{-1}{4\pi\epsilon_0} \frac{q}{r} \hat{r}$
- (c)  $\frac{-1}{4\pi\epsilon_0} \frac{q}{r^2} \hat{r}$
- (d)  $\frac{1}{4\pi\epsilon_0} \frac{q}{r^2} \hat{r}$

[Ans. (d)  $\frac{1}{4\pi\epsilon} \frac{q}{r^2} \stackrel{\wedge}{r}$ ]

#### 20. 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<sup>-1</sup>
- (b) 6 Vm<sup>-1</sup>
- (c) 11 Vm<sup>-1</sup>
- (d)  $-23 \text{ Vm}^{-1}$

[Ans. (a)  $20 \text{ Vm}^{-1}$ ]

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,

 $\frac{dV}{dx} = 10(1) + 10$   $\therefore E = \frac{dV}{dx} = 20 \text{ Vm}^{-1}$ 

#### 21. Two condensers (capacitors) of capacity C<sub>1</sub> and C, are connected in parallel. A charge Q given to then is shared. The ratio of the charges Q is

- (c)  $C_1 \cdot C_2$
- (b)  $\frac{C_1}{C_2}$ (d)  $\frac{1}{C_1 \times C_2}$

[Ans. (b)  $\frac{C_1}{C}$ ]

Hint:

As they are in parallel, the potential is same across the two,

$$\therefore Q_1 = C_1 V \text{ and } Q_2 = C_2 V$$

$$\therefore \frac{Q_1}{Q_2} = \frac{C_1}{C_2}$$

$$\therefore \frac{Q_1}{Q_2} = \frac{C_1}{C_2}$$

#### 22. 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

This is in accordance with the law of Hint: conservation of charge.

- 23. 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, 
$$U = \frac{1}{2}CV^2$$
  

$$U = \frac{1}{2}(CV)V \ [\because q = CV]$$

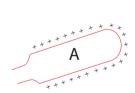
$$U = \frac{1}{2}qV = \frac{1}{2} \times 0.1 \times 200$$

$$U = 10 \text{ J}$$

- 24. Increasing the charge on the plates of a capacitor means
  - (a) increasing the capacitance
  - (b) increasing the potential difference between the plates
  - (c) both (a) and (b) above
  - (d) none of the above

[Ans. (b) increasing the potential difference between the plates]

25. 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

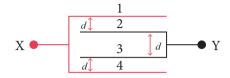




- (a) Zero (c) Positive
- (b) Negative (d) Infinite

[Ans. (c) Positive]

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)  $\frac{3 \, \varepsilon_0 A}{I}$
- (d)  $\frac{4 \, \varepsilon_0 A}{d}$

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

They constitute two parallel plate capacitors Hint: in parallel with each other.

- 27. Charge per unit volume is called
  - (a) Linear charge density  $(\lambda)$
  - (b) Surface charge density  $(\sigma)$
  - (c) Volume charge density (ρ)
  - (d) Electric flux

[Ans. (c) Volume charge density (p)]

- 28. The expression for the electric field due to a surface of total charge 'Q' is given by

  - (a)  $\vec{E} = \frac{1}{4\pi\epsilon_0} \int \frac{\sigma dA}{r^2} \hat{r}$  (b)  $\vec{E} = \frac{1}{4\pi\epsilon_0} \int \frac{\rho dA}{r^2} \hat{r}$
  - (c)  $\vec{E} = \frac{1}{4\pi\epsilon_0} \int \frac{\lambda dl}{r^2} \hat{r}$  (d)  $\vec{E} = \frac{1}{4\pi\epsilon_0} \int \frac{dq}{r^2} \hat{r}$

[Ans. (a) 
$$\vec{E} = \frac{1}{4\pi\epsilon_0} \int \frac{\sigma dA}{r^2} \hat{r}$$
]

- 29. The dipole is called point dipole when the distance
  - (a) 2a approaches infinity and q approaches zero
  - (b) 2a approaches zero and q approaches infinity
  - (c) 2a approaches zero and q approaches zero
  - (d) 2a approaches infinity and a approaches infinity.

[Ans. (b) 2a approaches zero and q approaches infinity]

- 30. The magnitude of torque on dipole is maximum if
  - (a)  $\theta = 0^{\circ}$
- (b)  $\theta = 90^{\circ}$
- (c)  $\theta = 180^{\circ}$
- (d)  $\theta = 180^{\circ}$

[Ans. (b)  $\theta = 90^{\circ}$ ]

- 31. The magnitude of electric dipole moment of water molecule is
  - (a)  $6 \times 10^{-30}$  Cm
- (b)  $6.2 \times 10^{-30}$  Cm
- (c)  $6.1 \times 10^{-30} \,\mathrm{Cm}$
- (d) 5.9 5 10<sup>-30</sup> Cm

[Ans. (c)  $6.1 \times 10^{-30}$  Cm]

- **32.** The expression for electric potential difference is

- (b)  $-\int_{\infty}^{1} \vec{E} . d\vec{r}$ (d)  $\int_{R}^{P} -\vec{E} . d\vec{r}$

- **33.** At Infinity (i.e  $r = \infty$ ), the electrostatic potential (V) is
  - (a) ∞

- (b) maximum
- (c) minimum
- (d) zero

[Ans. (d) zero]

- **34.** The potential due to a single point charge falls as

- **35.** The unit for electric flux is
  - (a)  $C^2 N^{-1}m^{-2}$
- (b) Nm<sup>2</sup> C<sup>-2</sup>
- (c) Nm<sup>2</sup> C<sup>-1</sup>
- (d)  $Nm^{-2}C^{-1}$

[Ans. (c) Nm<sup>2</sup> C<sup>-1</sup>]

- 36. The electric flux is negative, if the angle between  $\overline{dA}$  and  $\overline{E}$  is
  - (a) Less than 90°
- (b) greater than 90°
- (c) equal to 90°
- (d) equal to 0°

[Ans. (b) greater than 90°]

- 37. 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]

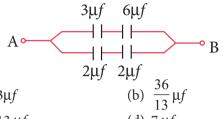
- **38.** A non-conducting material which has no free electrons is called
  - (a) capacitor
- (b) Dielectric
- (c) conductor
- (d) Inductor

[Ans. (b) Dielectric]

- **39.** The unit for electric susceptibility is
  - (a) Nm<sup>2</sup> C<sup>-2</sup>
- (b)  $C^2 N^{-1} m^{-2}$
- (c)  $C^{-2}Nm^2$
- (d)  $N^{-1} m^{-2}C^2$

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

40. In the given cricuit the effective capacitance between A and B will be



- (a)  $3\mu f$
- (c)  $13 \, \mu f$
- (d)  $7 \mu f$

[Ans. (a)  $3\mu f$ 

Hint:

$$C = \left(\frac{3 \times 6}{3+6}\right) + \left(\frac{2 \times 2}{2+2}\right)$$
$$= 2+1$$
$$C = 3\mu f$$

- 41. 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.]

- 42. The lower comb of van de graaff generator is maintained at a positive potential of
  - (a) 10 kV
- (b)  $10^7 \text{ V}$
- (c) 100 V
- (d) 10<sup>3</sup> V

[Ans. (a) 10 kV]

- 43. The negative gradient of potential is
  - (a) torque
- (b) electric current
- (c) electric field intensity (d) electric force

[Ans. (c) electric field intensity]

- 44. 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)  $\frac{1}{2}$

(b)  $\frac{1}{0.2}$ 

(c) 2

(d) 0.2 [Ans. (c) 2]

Hint:

$$\frac{F}{F_{m}} = \varepsilon_{r} \Rightarrow F_{m} = \frac{F}{2} \text{ (given)}$$

$$\frac{F}{\left(\frac{F}{2}\right)} = \varepsilon_{r} \Rightarrow \varepsilon_{r} = 2$$

- 45. An uniformly charged conducting shell of 2cm diameter has a surface charge density of 80μC / m<sup>2</sup>. The charge on the shell is
  - (a) 100.48 nC
- (b) 100.48 μC
- (c) 100.48 C
- (d)  $100.48 \times 10^{-12}$  C

[Ans. (a) 100.48 nC]

Hint:

$$\sigma = \frac{Q}{A} \Rightarrow Q = \sigma A$$

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

$$Q = (80 \times 10^{-6}) \times 4 \times 3.14 \times (1 \times 10^{-2})$$

$$= 100.48 \times 10^{-9} C = 100.48 \text{ nC}$$

- 46. In tuning radio we use,
  - (a) capacitors
- (b) transistors
- (c) diodes
- (d) LEDs

[Ans. (a) capacitors]

- 47. Dielectric constant for the metals is
  - (a) Zero
- (b) >1

(c) < 1

(d) Infinite

[Ans. (d) Infinite]

- 48. 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)  $C' = \frac{C}{\varepsilon_r}$
- (c)  $C' = \frac{\varepsilon_r}{C}$
- (d)  $C' = \varepsilon_0 \varepsilon_r C$

[Ans. (a)  $C' = \varepsilon C$ ]

- 49. The capacitance of a parallel plate capacitor increases from 5uf of 50uf when a dielectric is filled between the plates. The permitivity of the dielectric is
  - (a)  $8.854 \times 10^{-12} \,\mathrm{C}^2 \,\mathrm{N}^{-1} \,\mathrm{m}^{-2}$
  - (b)  $8.854 \times 10^{-11} \,\mathrm{C}^2 \,\mathrm{N}^{-1} \,\mathrm{m}^{-2}$
  - (c)  $10 \times 10^{-12} \text{ C}^2 \text{ N}^{-1} \text{ m}^{-2}$
  - (d)  $12 \times 10^{-12} \,\mathrm{C}^2 \,\mathrm{N}^{-1} \,\mathrm{m}^{-2}$

[Ans. (b)  $8.854 \times 10^{-11} \text{ C}^2 \text{ N}^{-1} \text{ m}^{-2}$ ]

Hint: 
$$\epsilon = \epsilon_0 \epsilon_r \qquad \left[ \epsilon_r = \frac{C_2}{C_1} \right]$$
$$= 8.854 \times 10^{-12} \times \left( \frac{C_2}{C_1} \right)$$
$$= 8.854 \times 10^{-12} \times \frac{50 \times 10^{-6}}{5 \times 10^{-6}}$$
$$= 8.854 \times 10^{-11} \, \text{C}^2 \, \text{N}^{-1} \, \text{m}^{-2}$$

- 50. An electric dipole placed at an angle in a nonuniform 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
- 51. 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]

- **52.** 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]

- **53.** Two conducting charged spheres x and yhaving 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]

- 54. Which of the following statement 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 sphericall
- 55. Two identical metal balls with charges +20 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)  $\frac{F}{12}$  (b)  $\frac{F}{8}$  (c) F

[Ans. (b)  $\frac{F}{Q}$ ]

- **56.** 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]

- 57. 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  $\frac{Q}{2}$
- (b) each  $\frac{Q}{5}$
- (c)  $\frac{Q}{3}$  and  $\frac{2Q}{3}$  (d)  $\frac{Q}{4}$  and  $\frac{3Q}{4}$

[Ans. (a) each  $\frac{Q}{2}$ ]

- **58.** 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]

- **59.** When 4V emf is applied across a 1F capacitor, it will store energy of
  - (a) 2J
- (b) 4J
- (c) 6I
- (d) 8J

[Ans. (d) 8J]

- **60.** 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]

- **61.** 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]
- **62.** Which of the following cannot be the units of electric field intensity?
  - (a) NC<sup>-1</sup>
- (b) Vm<sup>-1</sup>
- (c)  $IC^{-1}/m$
- (d) JC<sup>-1</sup>

[Ans. (d) JC<sup>-1</sup>]

- 63. The electric flux through a surface will be minimum when the angle between E and A is
  - (a) 90°
- (b) 60°
- (c)  $0^{\circ}$
- (d) 45°

[Ans. (a)  $90^{\circ}$ ]

- **64.** One Joule per Coulomb is called
  - (a) Gauss
- (b) ampere
- (c) farad
- (d) volt

[Ans. (d) volt]

- 65. 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
- 66. The concentric spheres of radii R and r have similar charges with equal surface densities  $(\sigma)$ . What is the electric potential at their common centre?
  - (a)  $\frac{\sigma}{\epsilon_o} (R-r)$
- (b)  $\frac{\sigma}{\varepsilon_o} (R + r)$

(d)  $\frac{\sigma}{\epsilon_o}$  [Ans. (b)  $\frac{\sigma}{\epsilon_o}$  (R+r)]

- 67. A charge Q μC is placed at the center of a cube. The flux coming out from any surface will be
  - (a)  $\frac{Q}{24\epsilon_a}$
- (c)  $\frac{Q}{6\epsilon} \times 10^{-6}$
- (d)  $\frac{Q}{6\epsilon_0} \times 10^{-3}$

[Ans. (c)  $\frac{Q}{6\epsilon} \times 10^{-6}$ ]

- 68. A charge Q is placed at the corner of a cube. The electric flux through all the six faces of the
- (a)  $\frac{Q}{3\varepsilon_o}$  (b)  $\frac{Q}{6\varepsilon_o}$  (c)  $\frac{Q}{8\varepsilon_o}$  (d)  $\frac{Q}{\varepsilon_o}$

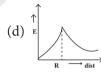
[Ans. (d)  $\frac{Q}{g}$ ]

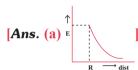
69. Which graph shows the variation of electric field E due to a hollow spherical conductor of radius R as a function of distance from the centre of the sphere?





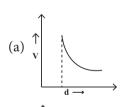


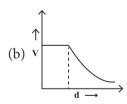


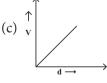


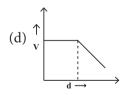
70. Which graph shows that in a hollow spherical shell potential (V) changes with respect to distance (r) from centre?

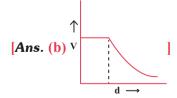
$$\left[V_{_{inside}} = \frac{Q}{4\pi\epsilon_{_{0}}R}r \le R, \ V_{_{outside}} = \frac{Q}{4\pi\epsilon_{_{0}}r}r \ge R, \ V\alpha\frac{1}{r}\right]$$



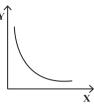








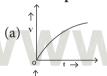
71. What physical quantities may X and Y represent? [Y represents the first mentioned quantity].



- (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

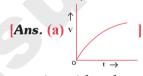
**72.** During charging a capacitor variation of potential V of the capacitor with time t is shown as



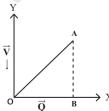








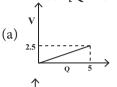
73. Charge Q on a capacitor varies with voltage V as shown in graph, where Q is along X-axis and V along Y-axis. The area of triangle OAB represents

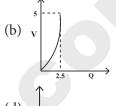


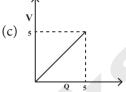
- (a) capacitance
- (b) capacitive reactance
- (c) magnetic field between the plates
- (d) energy stored in the capacitor

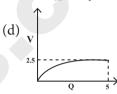
[Ans. (d) energy stored in the capacitor]

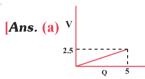
74. A condenser of 2µF capacitance is charged steadily from 0 to 5 coulomb. Which of the following graphs correctly represents the variation of potential difference across its plates with respect to the charge on the condenser  $[Q = C\overline{V}]$ 











75. 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) 
$$\frac{Q(R^2 + r^2)}{4\pi\epsilon_0(R + r)}$$

(b) 
$$\frac{QR}{R+r}$$

$$\begin{aligned} &(d)~\frac{Q\left(R+r\right)}{4\pi\epsilon_{_{0}}\left(R^{2}+r^{2}\right)}\\ &[\textit{Ans.}~(d)~\frac{Q\left(R+r\right)}{4\pi\epsilon_{_{0}}\left(R^{2}+r^{2}\right)} \end{aligned}$$

[Ans. (d) 
$$\frac{Q(R+1)}{4\pi\epsilon_0(R^2+r^2)}$$
]

**76.** A point charge q is placed at a distance  $\frac{a}{2}$ directly above the centre of a square of side 'a'. The electric flux through the square is

(a) 
$$\frac{q}{\varepsilon_0}$$

(b) 
$$\frac{q}{\pi \varepsilon}$$

(c) 
$$\frac{q}{4\epsilon_{o}}$$

(d) 
$$\frac{q}{6\varepsilon_{o}}$$

- (d)  $\frac{q}{6\varepsilon_0}$ [Ans. (d)  $\frac{q}{6\varepsilon_0}$ ]
- 77. A polythene piece rubbed with wool is found to have negative charge of  $3.2 \times 10^{-7}$  C. Estimate the number of electrons transferred from wool to polythene
  - (a)  $2 \times 10^{12}$
- (b)  $3 \times 10^{12}$
- (c)  $4 \times 10^{12}$
- (d)  $5 \times 10^{12}$

[Ans. (a)  $2 \times 10^{12}$ ]

- 78. 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
- (d) due to all
- [Ans. (d) due to all]
- 79. 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
- (c)  $\frac{q}{6\varepsilon_0}$

[Ans. (d)  $\frac{5q}{6\epsilon_0}$ ]

- 80. Electric field intensity at a point due to an infinite sheet of charge having surface charge density  $\sigma$  is E. If the sheet were conducting, electric intensity would be
- (b) E
- (c) 2E
- (d) 4E

[Ans. (c) 2E]

- 81. Surface density of charge on a sphere of radius R in terms of electric intensity E at a distance r in free space is
- (c)  $\varepsilon_{o} E \left(\frac{r}{R}\right)^{2}$
- 82. The electric flux over a sphere of radius 1m is **\$\phi\$**. If radius of the sphere were doubled without changing the charge enclosed, electric flux would become
  - (a) 2¢
- (b)  $\frac{\phi}{2}$  (c)  $\frac{\phi}{4}$  (d)  $\phi$  [Ans. (d)  $\phi$ ]
- 83. 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]

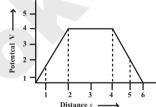
- 84. A charge q is enclosed as shown in fig. The electric flux is
  - q
- (ii)
- (iii)
- (a) maximum in (i)
- (b) maximum in (ii)
- (c) maximum in (iii)
- (d) equal in all

[Ans. (d) equal in all]

- **85.** A charge  $q_1$  exerts force on charge  $q_2$ . If another charge  $q_3$  is brought near, the force of  $q_1$ , exerted on  $q_2$ , will be
  - (a) decreased
- (b) increased
- (c) remains unchanged
- (d) increased if  $q_2$  is of same sign as  $q_1$  and decreased if  $q_2$  is of opposite sign.

[Ans. (c) remains unchanged]

**86.** Find the electric field at x = 5m 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]

#### MATCH THE FOLLOWING

- 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) (3)(4)(2)
  - (a) b d С
  - (b) c a
  - (c) d b
  - (d) b [Ans. (c) d c a b]

a

- 1. Amber (a) negatively charged 2. Rubber (b)  $\varepsilon = 1$ (c) a kind of resin 3. glass rod 4. Air (d) Positively charged
  - (1) (2)(3)(4)
  - (a) c b d a
  - (b) c d b
  - (c) b d
  - (d) d [Ans. (b) c a d b]

## Electrostatics

### 👣 Sura's 🖦 XII Std - Physics - Volume-I

<b>3</b> .	1.	D	ielectr	ic			(a)	Farada	ay cage	
	2.	С	apacito	or			(b)	Insula		
	3.	E	Electrostatic shielding			(c)	Van de genera	e graaff ator		
	4. Electrostatic Induction						(d)	Conde	enser	
(1) (2)					(3)	(4	4)			_
	(	(a)	b	d	a	С				
	(	(b)	С	d	a	b				
	(	(c)	d	a	b	С				
	(	(d)	d	С	a	b	[,	Ans. (	(a) b d a c	]
4.	1.		ermitti ace	vity of	free	(a)	Nev	vton's I	II law	
	2.	Electros		static force		(b)	Inve	erse law	V	
	3.	С	oulom	b law		(c)	Con	ıservati	ive force	
	4.	С	oulom	b force		(d)	8.85	$4 \times 10^{-1}$	$^{2}$ C $^{2}$ N $^{-1}$ m $^{-2}$	
			(1)	(2)	(3)	(4	4)			
	(	(a)	b	d	a	c				
		(b)		b	C	a				
		(c)		a	С	d				
_	(	(d)	d	a	b	С	[,	Ans. (	d) dabc	
<b>5</b> .	1.	El	ectric	flux	1	(a)	Ma: field	ximum d	electric	
	2.	El	ectric	field		(b)	Sca	lar qua	ntity	
	3.		ectric oment	-		(c)	Vec	tor qua	antity	
	4.	4. Dielectric strength		(d)	acts	from -	−q to +q			
	(1) (2) (3)			(4	4)					
	(	(a)	a	d	b	c				
		(b)		c	d	a				
		(c)		d	b	a				
	(	(d)	b	a	d	c	[4	Ans. (	b) b c d a	]
F	ILI	IN	THE R	LANKS						

1.	Van de Graaff generator pr	oduces an electrostatio
	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
- (a) bigger radius(b) Smaller r(c) maximum radius(d) less bent

[Ans. (b) Smaller radius]

- 5. Relative permittivity  $(\epsilon_r)$  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 diclectric is \_\_\_\_\_.
  - (a) induction
  - (b) charge distribution
    - (c) polarisation
  - (d) quantisation
- [Ans. (c) polarisation]
- 9. An example for a Non-polar molecule is
  - (a) H<sub>2</sub>O
- (b) N<sub>2</sub>O
- (c) CO<sub>2</sub>
- (d) NH,

[Ans. (c) CO<sub>2</sub>]

- **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)  $4 \times 10^2 \,\mu\text{C} / \text{m}^2$
- (b)  $4 \times 10^2 \,\text{C} / \text{m}^2$
- (c)  $4 \times 10^3 \,\mu\text{C} / \text{m}^2$
- (d)  $4 \times 10^3 \,\text{C} / \text{m}^2$

[Ans. (a)  $4 \times 10^2 \,\mu\text{C} / \text{m}^2$ ]

Hint:

$$\sigma = \frac{Q}{6 \times A} = \frac{6 \times 10^{-6}}{6 \times 5 \times 10^{-2} \times 5 \times 10^{-2}}$$
Where, [A = (side)<sup>2</sup>]

$$\sigma = \frac{10^{-6} \times 10^{4}}{25} = 0.04 \times 10^{-2} \text{ C/m}^{2}$$
$$= 4 \times 10^{-4} \text{ C/m}^{2} \text{ (or) } 400 \text{ }\mu\text{C/m}^{2}.$$

- **13.** The electric flux is if the electric field lines enter the closed surface.
  - (a) positive
- (b) negative
- (c) zero
- (d) maximum

[Ans. (b) negative]

- 14. Electrostatic force is stronger than gravitational force by \_\_
  - (a)  $2.23 \times 10^{39}$  times
- (b)  $2.25 \times 10^{39}$  times
- (c)  $2.41 \times 10^{39}$  times
- (d)  $2.29 \times 10^{39}$  times

[Ans. (c)  $2.41 \times 10^{39}$  times]

- **15.** 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]

- **16.** Capacitors use the principle of
  - (a) self induction
- (b) mutual induction
- (c) electrostatic induction
- (d) dielectric polarisation

[Ans. (c) electrostatic induction]

- 17. Electrostatics deals with the ...
  - (a) charges in motion
  - (b) static electric charges
  - (c) charges through conductors
  - (d) accelerated charges

[Ans. (b) static electric charges]

- 18. 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

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[Ans. (b) Thales]

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- **19.** The force between like charges is \_
  - (a) attraction
- (b) repulsion
- (c) no force
- (d) none

[Ans. (b) repulsion]

- **20.** The charge of an electron is \_
  - (a)  $1.6 \times 10^{-19}$  C
- (b)  $1.6 \times 10^{-91}$  C
- (c)  $16 \times 10^{-20}$  C
- (d)  $6.1 \times 10^{-19}$  C

[Ans. (a)  $1.6 \times 10^{-19}$  C]

- **21.** Device used for storing charges is \_\_\_\_
  - (a) resistor
- (b) capacitor
- (c) inductor
- (d) insulator

[Ans. (b) capacitor]

- 22. 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]

- 23. 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]

- 24. The repulsive force between two like charges of 1 coulomb each separated by a distance of 1 m in vacuum is equal to:
  - (a)  $9 \times 10^9 \text{ N}$
- (b)  $10^9 \text{ N}$
- (c)  $9 \times 10^{-9} \text{ N}$
- (d) 9 N

[Ans. (a)  $9 \times 10^9$  N]

- 25. 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]

- **26**. 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]

- 27. The value of relative permittivity of air is
  - (a)  $8.854 \times 10^{-12} \,\mathrm{C}^2 \,\mathrm{N}^{-1} \mathrm{m}^{-2}$
  - (b)  $9 \times 10^9 \,\mathrm{C}^2 \,\mathrm{N}^{-1} \,\mathrm{m}^{-2}$
  - (c) 1
  - (d)  $8.854 \times 10^{12}$

[Ans. (c) 1]

- 28. By using law of conservation of electric charge balance the following equations:  $_{92}^{238} U^{238} \rightarrow _{90}^{234} H^{234} +$ (a)  $_{2}^{2}He^{4}$  (b)  $_{1}^{1}H^{3}$  (c)  $_{1}^{1}H^{2}$  (d)  $_{1}^{1}H^{1}$

[Ans. (a)  $He^4$ ]

- **29.** The value of  $\frac{1}{4\pi\epsilon_0}$  is \_\_\_\_\_.
  - (a)  $9 \times 10^{9} \text{ N m}^{2} \text{ C}^{-2}$
  - (b)  $8.85 \times 10^{-12} \text{ N m}^2 \text{ C}^{-2}$
  - (c)  $9 \times 10^{-9} \text{ N m}^2 \text{ C}^{-2}$
  - (d)  $8.85 \times 10^{9} \text{ N m}^{2} \text{ C}^{-2}$

[Ans. (a)  $9 \times 10^{9} \text{ N m}^{2} \text{ C}^{-2}$ ]

- 30. Torque on a dipole in a uniform electric field is maximum when the angle between  $\overrightarrow{P}$  and
  - $\overline{E}$  is
  - (a) 0°

- (b) 90°
- (c) 45°
- (d) 180°

[Ans. (b) 90°]

- **31.** The unit of electric field intensity is
  - (a) NC<sup>-1</sup>
- (b)  $NC^{-1}C^2m^{-1}$
- (c) Cm

(d) JC<sup>-1</sup>

[Ans. (a) NC<sup>-1</sup>]

- 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)  $E = -\frac{dV}{dx}$ ]

- 33. 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]

- **34.** Which one of the following relation is correct?
  - (a)  $V = \frac{q}{C}$
- (b)  $C = q \tan q$
- (c) V = qC
- (d)  $q = \frac{1}{2} C^2 V$

[Ans. (a)  $V = \frac{q}{C}$ ]

- 35. 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  $\frac{1}{2}$
  - (c) proportional to  $\frac{1}{r^2}$
  - (d) independent of *r*

[Ans. (d) independent of r]

- **36.** 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

- 37. The intensity of the electric field that produces a force of 10<sup>-5</sup> N on a charge of 5 µC is
  - (a)  $5 \times 10^{-11} \,\mathrm{NC^{-1}}$
- (b) 50 NC<sup>-1</sup> ■
- (c)  $2 NC^{-1}$
- (d) 0.5 NC<sup>-1</sup>

Ans. (c) 2 NC

- 38. 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]

- 39. The number of electric lines of forces moving outwards from 1C charge is \_\_\_\_\_
  - (a) 1.13×10<sup>11</sup>
- (b)  $8.85 \times 10^{-11}$
- (c)  $9 \times 10^9$
- (d) infinite

[Ans. (c)  $9 \times 10^9$ ]

- **40.** Electric lines of force \_\_\_
  - (a) intersect each other
  - (b) never intersect
  - (c) intersect at infinity
  - (d) are always parallel

[Ans. (b) never intersect]

- 41. The force between two charges in vacuum is 0.1N. What is the force if the vacuum is replaced by medium whose permittivity is 10 times greater than that of vacuum?
  - (a) 0.1 N
- (b) 0.01 N
- (c) 0.001 N
- (d) 0.0001 N

[Ans. (b) 0.01 N]

- **42.** The unit of electric dipole moment is
  - (a) volt/metre  $\left| \frac{V}{m} \right|$
  - (b) coulomb/metre  $\left| \frac{C}{m} \right|$
  - (c) volt. metre [Vm]
  - (d) Coulomb.metre (Cm)

[Ans. (d) Coulomb.metre (Cm)]

- 43. The torque  $(\tau)$  experienced by an electric dipole placed in a uniform electric field (E) at an angle  $\theta$  with the field is
  - (a)  $pE \cos\theta$
- (b)  $pE \cos\theta$
- (c)  $pE \sin\theta$
- (d)  $2pE \sin\theta$

[Ans. (c)  $pE \sin\theta$ ]

- An electric dipole of moment p is placed in a uniform electric field of intensity E at an angle  $\theta$  with respect to the field. The direction of the torque is
  - (a) along the direction of p
  - (b) along direction of  $\vec{F}$
  - (c) opposite to the direction of p
  - (d) perpendicular to plane containing p and  $\vec{E}$

[Ans. (b) along direction of  $\overline{\mathbf{E}}$ ]

- 45. The tangent to line of force at any point gives the direction of the \_\_\_\_ \_\_\_ at that point.
  - (a) electric potential
- (b) electric field
- (c) electric flux
- (d) electric field energy [Ans. (b) electric field]
- **46.** When an electric dipole of dipole moment pis aligned parallel to the electric field E then the potential energy of the dipole is given as
  - (a) *p*E
- (b) zero
- (c) pE

[Ans. (c) -pE]

- 47. Near a charged object A another earthed object B is placed. Charges are induced on B. If B is removed after some time, then the charge on A
  - (a) remain the same
- (b) decrease
- (c) increase
- (d) become zero [Ans. (a) remain the same]

48. When an electric dipole is placed in a uniform external electric field parallel to the field, it

- will experience \_ (a) a torque but no force
- (b) a force but no torque
- (c) a torque as well as a force
- (d) neither a force nor a torque

[Ans. (b) a force but no torque]

#### FIND THE ODD ONE OUT

- (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.

- (a) Mica
- (b) Ebonite
- (c) Aluminium
- (d) Oil

[Ans. (c) Aluminium]

(a), (b), (d) are dielectrics, (c) is a conductor. Hint:

- 3. (a) O,
- (b) HCl
- (c) CO<sub>2</sub>
- (d) H<sub>2</sub>

[Ans. (b) Hcl]

- (a), (c), (d) are Non-polar molecules, but Hint: (b) is a polar molecule.
- 4. (a)  $\alpha$  - particle
- (b) electron
- (c) proton
- (d) deutron

[Ans. (b) electron]

electron cannot be accelerated using van Hint: 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]

(a), (c) and (d) are the applications of Hint: 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]

<b>2</b> .	(a)	Corona discharge	-	Lightning arrester
	(b)	Electrostatic induction	-	Van de graaff generator
	(c)	$\varepsilon_{r}$ of any medium		Less than one
	(d)	(d) Charge per unit area		Surface charge density

[Ans. (c)  $\varepsilon_{i}$  of any medium - Less than one]

#### **CHOOSE THE CORRECT PAIR**

1.	(a)	NH <sub>3</sub>	-	Non - polar molecule		
	(b)	$O_2$	-	Polar molecule		
	(c)	Mica	-	Conductor		
	(d)	Ceramic	-	Capacitor		

#### [Ans. (d) Ceramic - Capacitor]

<b>2</b> .	(a) Volt		-	electric current
	(b)	C/m	- /	electric dipole moment
V	(c)	$NC^{-1}$	V	electric field intensity
	(d)	$C^2Nm^2$	-	electric flux

[Ans. (c) NC<sup>-1</sup> - 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  $(\sigma)$  is inversely proportional to the radius of the sphere i.e  $\sigma \propto \frac{1}{r}$ . [If radius is smaller,  $\sigma$  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 statment?

- (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) (a) Have mass, (b) Inherent | (c) Intrinsic & fundamental
  - (ii) Conservation and
  - (iii) Quantization of charge

#### 2. What is meant by quantization of charges?

**Ans.** Charge *q* on any object is an integral multiple of fundamental unit of charge.

$$q = ne$$
  $n = 1, 2, 3 ...$ 

3. 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.

$$\vec{F} = k \cdot \frac{q_1 q_2}{r^2} \cdot \hat{r}$$

#### 4. What is electric field?

**Ans.** Force experienced by unit positive charge

$$\left|\stackrel{\rightarrow}{\mathbf{E}}\right| = \frac{\stackrel{\rightarrow}{k}}{q} \text{ Vector Ne}^{-1}.$$

## **5.** Give a comparison of electrical and gravitational forces?

**Ans.** (i) Both forces obey inverse square law, F  $\alpha \frac{1}{2}$ 

- (ii) Both forces are proportional to product of masses or charges.
- (iii) Both forces are conservative forces.
- (iv) Both forces can operate in vacuum.

#### 6. 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.  $H_2$ ,  $O_2$ ,  $Co_2$ .

#### 7. 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.

#### 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<sub>2</sub>O, N<sub>2</sub>O, HCl, NH<sub>3</sub>.

#### 9. 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.

#### 10. What are induced dipoles?

Ans. When an external electric field is applied, the dipoles inside the polar molecule 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.

#### 11. 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.

#### **12.** 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.

## **13.** When we rotate the blades, it starts to rotate as usual. Why it is 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.

#### 14. State the law of conservation of charges.

**Ans.** (i) Total electric charge is constant.

- (ii) Charge can either be created nor be destroyed.
- (iii) Net charge change is zero in any physical process.

## 15. (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 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  $\frac{q_A + (2q_B)}{4}$ 

$$\frac{q_{A}}{2} + q_{B} = \frac{q_{A}}{4} + \frac{q_{B}}{2} = \frac{q_{A} + 2q_{B}}{4}$$

$$q_{B} = -3q_{A}$$

∴ 
$$q_{\rm B} = -3q_{\rm A}$$
  
∴ New charge on B<sub>1</sub> is  $\frac{q_{\rm A} - 6q_{\rm A}}{4}$ 

New charge on B = 
$$-\frac{5}{4} q_A$$

## **16.** 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.

17. A charge Q \(\mu\)c 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 =  $\frac{Q}{\varepsilon_0}$ 

- Electric flux through one face =  $\frac{1}{6} \cdot \frac{Q}{\epsilon_{\rm o}} \mu V_{\rm m}$ Ans. (i)
  - By symmetry the flux through each of the six faces of cube will be same when charge is placed at the centre.

$$\therefore \varphi_{E} = \frac{1}{6} \cdot \frac{Q}{\epsilon_{0}}$$

Thus electric flux passing through two opposite faces of the cube

$$= 2 \cdot \frac{1}{6} \cdot \frac{Q}{\epsilon_0}$$

$$\varphi = \frac{1}{3} \cdot \frac{Q}{\varepsilon_0}$$

- 18. 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.  $\theta = 0$ .
  - In unstable equilibrium, P.E. is max., so  $\theta = \pi$ . i.e. dipole moment is antiparallel to electric field.
  - (iii)  $\theta = 0^{\circ} \overrightarrow{P}$  is parallel to  $\overrightarrow{E}$  stable equilibrium (b) unstable,  $\theta = 180^{\circ}$ .  $\overrightarrow{P}$  is antiparallel



- 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.
- Electric field line is the path of movement Ans. (i) of a charge. A moving charge experiences a continuous force in an electric field, so field line is always continuous
  - 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.

- 20. 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°
- The dipole moment of dipole  $|\overrightarrow{P}| = q \times 2a$ Ans. (i) Force on -q at  $A = -q \stackrel{\rightarrow}{E}$ Force on + q at  $B = +q \stackrel{\rightarrow}{E}$ Net force on the dipole =  $q \to -q \to = 0$ 
  - Work done on dipole when it is rotated through 180°

$$W = \Delta U = pE (\cos \theta_1 - \cos \theta_2)$$

$$= pE (\cos 0^\circ - \cos 180^\circ)$$

$$= pE (1 - (-1))$$

$$W = 2 pE$$

- 21. 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
  - decreasing velocity & decreasing acceleration.
  - b. decreasing velocity & increasing acceleration.
  - decreasing velocity & constant acceleration
  - increasing velocity & decreasing acceleration
  - increasing velocity increasing acceleration

Which of the above statement is correct? Explain.

At a distance r, the force on the small sphere Ans. (i) due to large sphere

$$F = \frac{1}{4\pi\epsilon_0} \cdot \frac{Qq}{mr^2}$$

(ii) If m is the mass of small sphere then its acceleration

$$a = \frac{F}{m} = \frac{1}{4\pi\varepsilon_0} \cdot \frac{Qq}{mr^2}$$

- (iii) As the small sphere is pushed away (i.e. rincreased) 'a' decreases.
- As 'a' is always +ve the speed of the small sphere goes on increasing.
- **(v)** ∴increasing velocity and decreasing acceleration.
  - (d) is correct.

22. 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.

23. 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 rabout 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.  $\therefore$  Work done W = V ×q = 0 × 1 = 0.

**24.** 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  $\theta$ . This work done in rotating dipole gets stored in the dipole in the form of potential energy.

Two concentric metallic spherical shells of radii R and 2 R are given charges Q, & Q, 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  $\sigma$  is same ∴ charge  $Q_1 = 4\pi R^2 \sigma$ charge  $Q_2 = 4\pi (2R^2)\sigma$  $\frac{Q_1}{Q_2} = \frac{4\pi R^2 \sigma}{4\pi (4R^2) \sigma} = \frac{1}{4}$ 

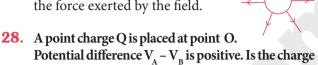


26. Two isolated metal spheres A & B have radii R & 2R respectively and same charge q. Find which of the two spheres have greater energy density just outside the surface of the sphere.

**Ans.** Energy density  $U = \frac{1}{2} \varepsilon_0 E^2$ But E =  $\frac{\sigma}{\epsilon_0} = \frac{Q}{A\epsilon_0}$  $:: U = \frac{1}{2} \cdot \frac{\epsilon_0 Q^2}{A^2 \epsilon_0} \Longrightarrow U = \frac{Q^2}{2A^2}$  $U \propto \frac{1}{\Delta^2} \implies U_A > U_B$ 

27. 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.



**Ans.** The electric potential  $V = \frac{1}{4\pi\epsilon_0} \cdot \frac{Q}{r}$ 

Q negative or positive?

$$V = \frac{1}{r}$$

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.

29. The electric field due to a point charge depends on the distance r as parallelly indicate how each of the following quantities depends on r?

Intensity of light from a point source.

- Electrical potential due to a point charge.
- Electrical potential at a distance r from centre of a charged metallic sphere

Given r < radius of the sphere.

Ans. (a)

- V does not depend on *r*.
- **30.** What are the factors on which the capacity of a parallel plate capacitor with dielectric depend?

Area of the plates Ans. (i)

- Separation between the plates. (ii)
- 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.
- **31.** 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<sub>0</sub> - energy stored, before the dielectric slab is inserted.

# **Electrostatics**

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(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  $\varepsilon_r$  is the dielectric constant.
- (ii) The electrostatic potential difference is reduced and the charge  $Q_0$  will remain constant, after the battery is disconnected.
  - ... 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.

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

#### 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.  $\Delta q_{1,} \rightarrow 1^{\rm st} \text{ charge element; } r_{\rm 1p} \text{ - distance of the point P from I}^{\rm st} \text{ charge element; } r_{\rm 2p} \text{ - distance of the point P from 2}^{\rm st} \text{ charge}$ 

 $\Delta q_{\rm n,} \rightarrow n^{\rm th}$  charge element;  $r_{\rm np}$  - distance of the point P from  $n^{\rm th}$  charge

Then. electric filed at point P due to all charge elements is given by

$$\overrightarrow{E} \approx \frac{1}{4\pi\varepsilon_0} \left( \frac{\Delta q_1}{r_{1P}} \stackrel{\wedge}{r_{1P}} + \frac{\Delta q_2}{r_{2P}} \stackrel{\wedge}{r_{2P}} + \dots + \frac{\Delta q_n}{r_{nP}} \stackrel{\wedge}{r_{nP}} \right)$$

$$\approx \frac{1}{4\pi\varepsilon_0} \sum_{t=1}^{n} \frac{\Delta q_i}{r_{iP}} \stackrel{\wedge}{r_{iP}}$$
(1)

For continuous distribution of charge,

Lt 
$$\Delta q \rightarrow 0 (= dq)$$

$$\therefore \vec{E} = \frac{1}{4\pi\epsilon_0} \cdot \int \frac{dq}{r^2} \hat{r}$$

- r→ 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. whe
  - 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 :

$$\sigma = \frac{Q}{A} C m^{-2}.$$

- σ → surface charge density (charge per unit area)
- $Q \rightarrow$  uniformly distributed charge on surface of area A.

For infinitesimal area,  $dq = \sigma dA$ .

(iii) Volume charge distribution :

$$\rho = \frac{Q}{V} \ C \ m^{\text{-3}}.$$

- $\rho \rightarrow \text{Volume charge density (charge per unit volume)}$
- $Q \rightarrow$  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 due to a collection of point charges at an arbitrary point 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

$$\overrightarrow{E}_{tot} = \overrightarrow{E}_1 + \overrightarrow{E}_2 + \overrightarrow{E}_3 + \dots + \overrightarrow{E}_n \qquad \dots (1)$$

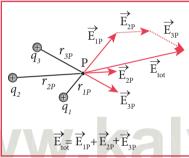
$$\vec{E}_{tot} = \frac{1}{4\pi\epsilon_0} \left\{ \frac{q_1}{r_{1P}^2} \hat{r}_{1P}^{\hat{}} + \frac{q_2}{r_{2P}^2} \hat{r}_{2P}^{\hat{}} + \frac{q_3}{r_{3P}^2} \hat{r}_{3P}^{\hat{}} + \dots + \frac{q_n}{r_{nP}^2} \hat{r}_{nP}^{\hat{}} \right\}$$
(2)

(iv) Here  $r_{1P}$ ,  $r_{2P}$ ,  $r_{3P}$ ...... $r_{nP}$  are the distances between the point P and the charges  $q_1$ ,  $q_2$ ,  $q_3$ ....... $q_n$  respectively. Also  $r_{1P}$ ,  $r_{2P}$ ,  $r_{3P}$ ..... $r_{nP}$  are the unit vectors directed from  $q_1$ ,  $q_2$ ,  $q_3$ ....... $q_n$  respectively 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.

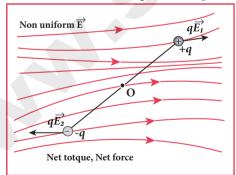
**Note** that the relative lengths of the electric field vectors for the charges depend on relative distances of the charges to the point P.



#### **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

$$\frac{\Delta U}{q'} = \frac{q' \int_{R}^{P} \left(-\stackrel{\rightarrow}{E}\right) . d\overrightarrow{r}}{q'} = -\int_{R}^{P} \stackrel{\rightarrow}{E} . d\overrightarrow{r} \qquad \dots (1)$$

- (ii) The above equation (1) is independent of  $q \otimes$ . The quantity  $\frac{\Delta U}{q'} = -\int_{R}^{P} \vec{E} \cdot d\vec{r}$  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.

$$V_P - V_R = \Delta V = \int_R^P - \stackrel{\rightarrow}{E} \cdot d\overrightarrow{r}$$

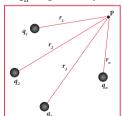
(iv) The electric potential energy difference can be written as  $\Delta U = q \otimes \Delta V$ .

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.

$$V_{\text{tot}} = \frac{kq_1}{r_1} + \frac{kq_2}{r_2} + \frac{kq_3}{r_3} + \dots + \frac{kq_n}{r_n}$$
$$= \frac{1}{4\pi\epsilon_0} \sum_{i=1}^{n} \frac{q_i}{r_i}$$

(ii) where  $r_1, r_2, r_3, \dots, r_n$  are the distances of  $q_1, q_2, q_3, \dots, q_n$  respectively from P (Figure).



Electrostatic potential due to collection of charges

## Electrostatics

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#### 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

$$\Phi_{E} = EA \qquad ...(1)$$

(ii) Suppose the same area A is kept parallel to the uniform electric field, then no electric field lines pierce through the area A, as shown in Figure (b). The electric flux for this case is zero.

$$\Phi_{\rm f} = 0 \qquad \qquad \dots (2)$$

(iii) If the area is inclined at an angle  $\theta$  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

$$\Phi_{E} = (E \cos \theta) A \qquad ...(3)$$

(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

$$\Phi_{\rm E} = \vec{\rm E} \cdot \vec{\rm A} = {\rm EA} \cos \theta$$

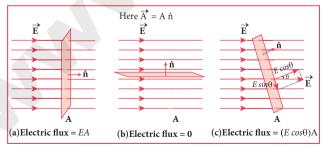
Here, note that A is the area vector  $A = A \hat{n}$ 

(v) Its magnitude is simply the area A and the direction is along the unit vector  $\hat{n}$  perpendicular to the area as shown in Figure.

Using this definition for flux  $\phi_E = E.A$ , equations (1) and (2) can be obtained as

In Figure (a), 
$$\theta = 0^{\circ}$$
 so  $\phi_E = \overrightarrow{E} \cdot \overrightarrow{A} = EA$ 

In Figure (b), 
$$\theta = 90^{\circ}$$
 so  $\phi_E = E \cdot A = 0$ 

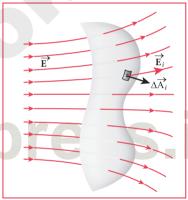


The electric flux for Uniform electric field

- 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 (Figure), then the entire area is divided into n small area segments  $\Delta A_1, \Delta A_2, \Delta A_3, \ldots, \Delta A_n$ , such that each area element is almost flat and the electric field through each area element is considered to be uniform.
  - (ii) The electric flux for the entire area A is approximately written as

$$\phi_{E} = \overrightarrow{E}_{1} \cdot \Delta \overrightarrow{A}_{1} + \overrightarrow{E}_{2} \cdot \Delta \overrightarrow{A}_{2} + \overrightarrow{E}_{3} \cdot \Delta \overrightarrow{A}_{3} \dots \overrightarrow{E}_{n} \cdot \Delta \overrightarrow{A}_{n}$$

$$= \sum_{i=1}^{n} \overrightarrow{E}_{1} \cdot \Delta \overrightarrow{A}_{1} \qquad \dots (1)$$



Electric flux for non-uniform electric Field

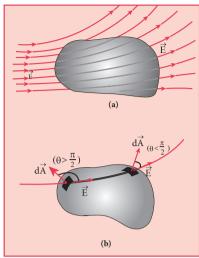
(iii) By taking the limit  $\Delta A_i \rightarrow 0$  (for all i) the summation in equation (1) becomes integration. The total electric flux for the entire area is given by

$$\phi_{\rm E} = \int \vec{\rm E} . d \vec{\rm A} \qquad ...(2)$$

- (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

$$\phi_{\rm E} = \oint \stackrel{\rightarrow}{\rm E} \cdot d\stackrel{\rightarrow}{\rm A} \qquad ...(1)$$

special cases.



Electric flux over a closed surface

- (ii) Note the difference between equations  $\phi_E = \int E \cdot dA$  and (1). The integration in equation (1) is a closed surface integration and for each area element, the outward normal is the direction of dA 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 dA and E is less than 90°, then the electric flux is positive and in another area element, the angle between dA and 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  $\phi_E = \oint \vec{E} \cdot d \stackrel{\rightarrow}{A} = \frac{Q_{\it{encl}}}{\epsilon_0}$  a spherical surface is chosen. This imaginary 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  $\phi_{E} = \oint \stackrel{\rightarrow}{E} \cdot d \stackrel{\rightarrow}{A} = \frac{Q_{encl}}{\epsilon_{0}} \text{ the electric field } \stackrel{\rightarrow}{E}$ 

is due to charges present inside and outside the Gaussian surface but the charge  $Q_{\rm encl}$  denotes the charges which lie only inside the Gaussian surface.

- (v) The Gaussian surface cannot pass through any discrete charge but it can pass through continuous charge distributions. It is because, very close to the discrete charges, the electric field is not well defined.
- (vi) Gauss law is another form of Coulomb's law and it is also applicable to the charges in motion. Because of this reason, Gauss law is treated as much more general law than Coulomb's law.

#### 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.

## **12.** Explain the Lightning arrester or lightning conductor.

**Ans.** Principle : action of points :

- (i) 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 as shown in Figure (a) and (b).
- (ii) The lower end of the rod is connected to the 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.