UNIT - 1 ELECTROSTATICS STUDY MATERIAL

I. One marks (Book inside)

1. The unit of electric flux is
   a) $Nm^2 C^{-1}$  
   b) $Nm^2 C^{-1}$  
   c) $Nm^2 C$  
   d) $Nm^{-2} C$

2. An electric dipole is placed in a uniform electric field with its axis parallel to the field. It experiences
   a) only a net force  
   b) neither a net force nor a torque  
   c) both a net force and torque  
   d) only a torque

3. The work done in moving $4 \mu C$ charge from one point to another in an electric field is $0.012 J$. The potential difference between them is
   a) $3000 \text{ V}$  
   b) $6000 \text{ V}$  
   c) $30 \text{ V}$  
   d) $48 \times 10^3 \text{ V}$

4. The electric field outside the two oppositely charged place sheets each of charge density $\sigma$ is
   a) $\frac{\sigma}{2 \varepsilon_0}$  
   b) $\frac{\sigma}{\varepsilon_0}$  
   c) $\frac{\sigma}{\varepsilon_0}$  
   d) zero

5. Which of the following quantities is a scalar?
   a) Electric force  
   b) Electric field  
   c) Dipole moment  
   d) Electric potential

6. Torque on a dipole in a uniform electric field is maximum when angle between $P$ and $E$ is
   a) $0^\circ$  
   b) $90^\circ$  
   c) $45^\circ$  
   d) $180^\circ$

7. Potential energy of two equal negative point charges of magnitude $2 \mu C$ placed 1 m apart in air is
   a) $2 J$  
   b) $0.36 J$  
   c) $4 J$  
   d) $0.036 J$

8. A hollow metallic spherical shell carrying an electric charge produces no electric field at points
   a) on the surface of the sphere  
   b) inside the sphere  
   c) at infinite distance from the centre of the sphere  
   d) outside the sphere

9. The unit of electric field intensity is
   a) NC$^{-2}$  
   b) NC  
   c) Vm$^{-1}$  
   d) Vm

10. Four charges $+q$, $+q$, $-q$ and $-q$ respectively are placed at the corners A, B, C and D of a square of side $a$. The electric potential at the centre $O$ of the square is
    a) $\frac{1}{4 \pi \varepsilon_0} (q/a)$  
    b) $\frac{1}{4 \pi \varepsilon_0} (2q/a)$  
    c) $\frac{1}{4 \pi \varepsilon_0} (4q/a)$  
    d) zero

11. The value of permittivity of free space is
    a) $8.854 \times 10^{12} \text{ C}^2 \text{N}^{-1} \text{ m}^{-2}$  
    b) $9 \times 10^9 \text{ C}^2 \text{N}^{-1} \text{ m}^{-2}$  
    c) $1/9 \times 10^9 \text{ C}^2 \text{N}^{-1} \text{ m}^{-2}$  
    d) $1/4 \pi \times 9 \times 10^9 \text{ C}^2 \text{N}^{-1} \text{ m}^{-2}$

12. The principle use in lightning conductors is
    a) corona discharge  
    b) mutual induction  
    c) self-induction  
    d) electromagnetic induction

13. The unit of electric dipole moment is
    a) volt / metre (V/m)  
    b) coulomb / metre (C/m)  
    c) volt. metre (Vm)  
    d) coulomb. metre (Cm)

14. Electric potential energy of an electric dipole in an electric field is given as
    a) $pE \sin \theta$  
    b) $-pE \sin \theta$  
    c) $-pE \cos \theta$  
    d) $pE \cos \theta$
30. The magnitude of the force acting on a charge of 2 x 10^{-10} C placed in a uniform electric field of 10 \text{V/m} is
a) 2 x 10^{-9} N       b) 4 x 10^{-9} N       c) 2 x 10^{-10} N       d) 4 x 10^{-10} N

31. Electric potential energy (U) of two point charges is
a) \frac{q_1 q_2}{4 \pi \varepsilon_0 r^2}       b) \frac{q_1 q_2}{4 \pi \varepsilon_0 r}       c) pE \cos \theta       d) pE \sin \theta

32. The torque 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

33. The capacitance of a parallel plate capacitor increases from 5 \mu F to 50 \mu F when a dielectric is filled between the plates. The permittivity of the dielectric is
a) 8.854 \times 10^{-12} \text{C}^2 \text{N}^{-1} \text{m}^{-2}       b) 8.854 \times 10^{-11} \text{C}^2 \text{N}^{-1} \text{m}^{-2}       c) 12       d) 10

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

35. When a point charge of 6 \mu C is moved between two points in an electric field, the work done is 1.8 \times 10^{-5} \text{J}. The potential difference between the two points is
a) 1.08 \text{V}       b) 1.08 \text{mV}       c) 3 \text{V}       d) 30 \text{V}

36. Three capacitors of capacitances 1 \mu F, 2 \mu F and 3 \mu F are connected in series. The effective capacitance of the capacitors is
a) 6 \mu F       b) 11 / 6 \mu F       c) 6 / 11 \mu F       d) 1 / 6 \mu F

37. 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) opposite to the direction of P       c) along the direction of E       d) perpendicular to the plane containing P and E

38. The electric field intensity at a distance r due to infinitely long straight charged wire is directly proportional to
a) r       b) 1/r       c) r^2       d) 1 / r^2

39. The ratio of electric potential at points 10 cm and 20 cm from the centre of an electric dipole along its axial line is
a) 1 : 2       b) 2 : 1       c) 1 : 4       d) 4 : 1

40. The intensity of electric field at a point is equal to
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

41. The capacitance of a capacitor is
a) directly proportional to the charge q given to it
   b) inversely proportional to its potential V
   c) directly proportional to the charge q and inversely proportional to the potential V
   d) independent of both the charge q and potential V

42. The intensity of the electric field that produces a force of 10^{-5} \text{N} on a charge of 5 \mu C is
a) 5 \times 10^{-11} \text{NC}^{-1}       b) 50 \text{NC}^{-1}       c) 2 \text{NC}^{-1}       d) 0.5 \text{NC}^{-1}

43. The unit of the number of electric lines of force passing through a given area is
a) no unit       b) \text{NC}^{-1}       c) \text{Nm}^2\text{C}^{-1}       d) \text{Nm}
59. The unit of molecular polarisability is
(a) $C^2 N^{-1}$ m $^{-1}$ (b) $Nm^2 C^{-1}$ (c) $N^{-1} m^{-2} C^2$ (d) $C^{-1} m^2 V$

60. Two point charges $+q_1$ and $+q_2$ are placed in air at a distance of 2m apart, one of the charges is moved towards the other through a distance of 1m. The work done is.
a) $q_1 q_2 / 4 \pi \varepsilon_0$ b) $q_1 q_2 / \pi \varepsilon_0$ c) $q_1 q_2 / 8 \pi \varepsilon_0$ d) $q_1 q_2 / 16 \pi \varepsilon_0$

61. Two capacitances 0.5μF and 0.75 μF are connected in parallel, Calculate the effective capacitance of the capacitor.
(a) 0.8μF (b) 0.7 μF (c) 0.25 μF (d) 1.25 μF

62. For which of the following medium, the value of relative permittivity is 1
(a) Mica (b) Air (c) Glass (d) Water

63. Van de Graff generator works on the principle of:
(a) electromagnetic induction and action of points
(b) electrostatic induction and action of points
(c) electrostatic induction only
(d) action of points only
UNIT 1

ONE MARK ANSWER WITH SOLUTIONS

1. (a) \( \text{Nm}^2 \text{C}^{-1} \)
2. (b) neither a net force nor a torque.
3. (a) 3000V.
4. (c) 0.
5. (b) Electric potential.
6. (b) 90°
7. (d) 0.036 J
8. (b) inside the sphere.
9. (a) \( \text{V/m}^{-1} \)
10. (d) \( c^2 \text{ N}^{-1} \text{ m}^{-2} \)
11. (c) \( \frac{1}{19 \times 10^9} \)
12. (a) Corona discharge.
13. (d) Coulomb's law.
14. (c) \( \rho \epsilon_0 \)
15. (c) 4 \( \mu \text{F} \).
16. (d) Guld.
17. (a) Zen.
18. (a) 3 \( \mu \text{F} \).
19. (c) Parallel to the axis of the dipole and opposite to the direction of dipole moment.
20. (a) \( 1.129 \times 10^5 \)
21. (b) 2.4 \( \mu \text{F} \)
22. (c) Coulomb's law.
23. (b) both a force and torque
24. (c) 0.03 J
25. \( \frac{1}{2} \text{ EV}^2 = \frac{1}{2} \times 6.1 \times (100)^2 \)

\( E = 0.03 \text{ J} \)
5. If

The force exerted by an electric field \( E \) on a charge \( q \) is given by
\[
F = Eq.
\]

3. The unit of electric dipole moment is \( \text{C m} \).

4. The electric field at any point on the axial line of an electric dipole is given by
\[
E = \frac{1}{4\pi e_0} \frac{2p}{r^3}
\]

6. The torque experienced by an electric dipole in an electric field is given by
\[
\tau = pE \sin \theta
\]

8. The net force on an electric dipole in an electric field is zero.

9. The relation between the electric field and the electric potential is given by
\[
E = -\frac{dV}{dr}
\]

10. The total number of electric lines of forces passing through the given area is called electric flux.

11. The unit of electric potential difference is volt.

12. The unit of electric field intensity is \( \text{V m}^{-1} \).

13. The equation of electric potential at any point due to an electric dipole is
\[
V = \frac{1}{4\pi e_0} \frac{p \cos \theta}{r^3}
\]

14. The work done in bringing each charge from infinite distance is called electric potential energy.
15. The unit of electric flux is \( \text{N m}^2 \text{ C}^{-1} \)
16. The electric field due to an infinite long straight charged wire is \( E = \frac{\lambda}{2\pi \varepsilon_0 r} \)
17. The electric field due to an infinite long charged plane sheet is \( E = \frac{\sigma}{2 \varepsilon_0} \)
18. Electric field at any point in between two parallel sheets of equal and opposite charges is 
\( E = \frac{1}{4\pi \varepsilon_0} \frac{q}{r^2} \)
19. The electric field at any point on the surface of a uniformly charged spherical shell is 
\( E = \frac{1}{4\pi \varepsilon_0} \frac{q}{r^2} \)
20. Electrostatic shielding is based on the fact that the electric field inside a conductor is 
zero
21. The phenomenon of obtaining charges without any contact with another charge is called 
**electrostatic induction**
22. The unit of capacitance is **farad**
23. A capacitor is a device to store **charges**
24. The number of electric lines of force originating from 1 coulomb charge is \( 1.129 \times 10^{11} \)
25. Non polar molecule is \( \text{O}_2, \text{N}_2, \text{H}_2 \)
26. Polar molecule is \( \text{N}_2 \text{O}, \text{H}_2 \text{O}, \text{HCl}, \text{NH}_3 \)
27. The magnitude of the induced dipole moment \( p \) is directly proportional to \( E \)
28. Greater the radius of a conductor, **smaller** is the charge density.
29. The permittivity of a medium is \( \varepsilon_0 \varepsilon_r \)
30. Direction of \( E \) – outward for \( +q \) and inward for \( -q \)
31. Gaussian Surface – Closed imaginary surface over an enclosed net charge
32. Capacitance of a capacitor \( C = \frac{Q}{V} \)
33. Electric dipole moment \( p = 2qa \)
34. Electric potential energy of dipole \( U = -pE\cos\Theta \)
35. Electric flux \( \Phi_E = \frac{q}{\varepsilon_0} \)
36. Electric field due to a uniformly charged sphere
   i) Outside the sphere \( E = \frac{1}{4\pi \varepsilon_0} \frac{q}{r^2} \) i) On the sphere \( E = \frac{1}{4\pi \varepsilon_0} \frac{q}{R^2} \) iii) Inside
   sphere – **Zero**
37. Work done by a charge \( W = qV \)
38. Charge density \( \sigma = \frac{Q}{A} \)
39. Linear charge density \( \lambda = \frac{Q}{L} \)
40. Polarization \( p = \kappa E \)
41. Capacitance of a parallel plate capacitor \( C = \frac{Q}{\varepsilon_0} \frac{d}{A} = \frac{\varepsilon_0 A}{d} \)
42. Capacitance in series \( C_s = \frac{1}{C_1} + \frac{1}{C_2} \) In parallel \( C_P = C_1 + C_2 \)
43. 1 micro (\( \mu \)) farad = \( 10^{-6} \) 1 pico farad = \( 10^{-12} \)
44. Unit of Charge = **Coulomb** (C).

Electric field (E) = \( \text{NC}^{-1} \) or \( \text{V} \text{m}^{-1} \).
Electric potential (V) = **Volt** or **J.C^{-1}**.

Dipole moment (p) = \( \text{Cm}^2 \) Torque (\( \tau \)) = \( \text{Nm} \).
Charge density \( \sigma = \text{Cm}^{-2} \). Linear charge density \( \lambda = \text{Cm}^{-1} \).
molecular polarisability = \( \text{C}^2 \text{N}^{-1} \text{m} \).
Dielectric strength = \( \text{V} \text{m}^{-1} \).
Two marks (Book Back)

1. What is Quantisation of charges?
   The charge \( q \) on any object is equal to an integral multiple of this fundamental unit of charge \( e \).
   \[ q = ne \]  
   \( n \) is any integer (0, \( \pm 1 \), \( \pm 2 \), \( \pm 3 \), \( \pm 4 \)………..).
   This is called quantisation of electric charge.

2. Write down coulomb’s law in vector form & mention what each term represents
   According to Coulomb, the force on the point charge \( q_2 \) exerted by another point charge \( q_1 \) is
   \[ \vec{F}_{12} = k \frac{q_1 q_2 \hat{r}_{21}}{r^2} \]
   \( \hat{r}_{21} \) is the unit vector directed from charge \( q_1 \) to charge \( q_2 \)
   \( k \) is the proportionality constant.

3. Difference between electrostatic force and gravitational force

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4. Define Superposition principle
   The total force acting on a given charge is equal to the vector sum of forces exerted on it by all the other charges.

5. 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
   \[ \vec{E} = \frac{\vec{F}}{q_0} = \frac{1}{4\pi\varepsilon_0} \frac{q}{r^2} \hat{r} \]
   Quantity: vector quantity  
   Unit: \( \text{NC}^{-1} \)
6. What is meant by Electric field lines

Electric field vector 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.

7. The electric field never intersect. Justify

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

8. Define electric dipole.

Two equal and opposite charges separated by a small distance constitute an electric dipole.

Ex: water, chloroform

9. Define dipole moment

It is product of any one of charges of dipole and distance(2d) between them

\[ P = 2qd \]

Quantity: vector quantity

Unit: Cm

10. Define electrostatic potential

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

Unit: V or JC⁻¹

11. Define equipotential surface

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

12. Write about Properties of equipotential surfaces

(i) The work done to move a charge q between any two points A and B is zero.

(ii) The electric field is normal to an equipotential surface.

13. Give the relation between Electric field and electric potential

\[ dV = -E \, dx \]

\[ E = -\frac{dV}{dx} \] Electric field is negative gradient of electric potential.

14. Define electrostatic potential energy

It is defined as work done in bringing the various charges to their respective positions from infinitely large mutual separation.

Unit: Joule

15. Define Electric Flux

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

Unit: \( Nm^2C^{-1} \)

\[ \Phi_E = EA \cos \theta \] Quantity: scalar

16. What is called energy density

The energy stored per unit volume of space is defined as energy density.

\[ u_E = \frac{U}{VOLUME} \]
7. Define Gauss’s law
Gauss’s law states that if a charge $Q$ is enclosed by an arbitrary closed surface, then the total electric flux $\Phi_E$ through the closed surface is
$$\Phi_E = \frac{Q_{enc}}{\varepsilon_0}$$

8. What are two kind of electric field
- **Uniform electric field** will have the same direction and constant magnitude at all points in space. **Non-uniform electric field** will have different directions or different magnitudes or both at different points in space.

9. Define one coulomb
One coulomb is a quantity of charge which when placed at a distance of one metre in air from equal and opposite charge experiences a repulsive force of $9\times10^9$ N
$$r = 1m \quad F = 9\times10^9N \quad q_1 = q_2 = 1C$$

10. State Coulomb’s law.
Coulomb’s law states that the electrostatic force is directly proportional to the product of the magnitude of the two point charges and is inversely proportional to the square of the distance between the two point charges.
$$F \alpha \frac{q_1q_2}{r^2}$$

11. What is called triboelectric charging?
Charging the objects through rubbing is called triboelectric charging.
1. Discuss the basic properties of electric charge

(i) Electric charge
   a. Electric charge is intrinsic and fundamental property of particles.
   b. The SI unit of charge is coulomb.

(ii) Conservation of charges
   a. Charges are neither created or nor destroyed but can only be transferred from one object to other.
   b. This is called conservation of total charges and is one of the fundamental conservation laws in physics.

   The total electric charge in the universe is constant and charge can neither be created nor be destroyed.

(iii) Quantisation of charges
   The charge \( q \) on any object is equal to an integral multiple of this fundamental unit of charge \( e \).
   \[ q = ne \]
   where \( n \) is any integer \((0, \pm1, \pm2, \pm3, \pm4 \ldots \ldots)\).

2. Explain in detail about Coulomb’s law & its various aspects

   It states that the electrostatic force is directly proportional to the product of the magnitude of the two point charges and is inversely proportional to the square of the distance between the two point charges.

   \[ F \propto \frac{q_1q_2}{r^2} \]

   The direction of forces is along the line joining two charges.

   \[ F = \frac{kq_1q_2}{r^2} \]

   where \( k = \frac{1}{4\pi\varepsilon_0} \)

   \( k = 9 \times 10^9 \text{ Nm}^2\text{C}^{-2} \)

   \( \varepsilon_0 \) – Permittivity of free space and its value is \( 8.854 \times 10^{-12} \text{ C}^2\text{N}^{-1}\text{m}^{-2} \)

   ➢ One coulomb is defined as quantity of charges which when placed at a distance of 1m in air or vacuum from an equal and similar charge experiences a repulsive force of \( 9 \times 10^9 \text{ N} \) in vacuum.

   \[ F = \frac{1}{4\pi\varepsilon_0} \frac{q_1q_2}{r^2} \]

   In medium of permittivity

   \[ F_m = \frac{1}{4\pi\varepsilon} \frac{q_1q_2}{r^2} \]

   \( \varepsilon > \varepsilon_0 \)

   Force between two point charges in a medium other than vacuum is always less than that in vacuum.

   \[ \varepsilon_r = \frac{\varepsilon}{\varepsilon_0} \]
### Gravitational force vs Electrostatic force

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### Define Electric field and its various aspect

**a.** According to Faraday, every charge in the universe creates an electric field in the surrounding space, and if another charge is brought into its field, it will interact with the electric field at that point and will experience a force. Consider a source point charge \( q \) located at a point in space. Another point charge \( q_0 \) (test charge) is placed at some point \( P \) which is at a distance \( r \) from the charge \( q \).

**b.** Force experienced by the charge \( q_0 \) due to \( q \) is \[ F = \frac{kqq_0}{r^2} \]

**c.** The charge \( q \) creates an electric field in the surrounding space. 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

\[ E = \frac{F}{q_0} = \frac{kq}{r^2} \]

**Unit** : NC\(^{-1}\)  **Quantity** : vector

**Important aspects of Electric field**

- charge \( q \) is positive - electric field points away from the source charge
- \( q \) is negative - electric field points towards the source charge \( q \).

✔ Force experienced by test charge placed at point \( P \) is \( E q_0 \)
  - From equation of electric field, it is depends only on the source charge \( q \) & independent on charge \( q_0 \)
a) If the charge $Q$ is uniformly distributed along the wire of length $L$, then linear charge density 
\[ \lambda = \frac{Q}{L} \text{ Unit : Cm}^{-1} \]

The charge present in the infinitesimal length $dl$ is $dq = \lambda dl$.

The electric field due to line of total charge $Q$ is given by
\[ \vec{E} = \frac{\lambda}{4\pi\varepsilon_0} \int \frac{dl}{r^2} \hat{r} \]

b) If the charge $Q$ is uniformly distributed on a surface of area $A$, then surface charge density (charge per unit area) is $\sigma = \frac{Q}{A}$ Unit ; Cm$^{-2}$

The electric field due to total charge $Q$ is given by
\[ \vec{E} = \frac{\sigma}{4\pi\varepsilon_0} \int \frac{da}{r^2} \hat{r} \]

c) If the charge $Q$ is uniformly distributed in a volume $V$, then volume charge density is given by $\rho = \frac{Q}{V}$ Unit; Cm$^{-3}$

The electric field due to total charge $Q$ is given by
\[ \vec{E} = \frac{\rho}{4\pi\varepsilon_0} \int \frac{dV}{r^2} \hat{r} \]

5. Calculate the electric field due to a dipole on axial and equatorial plane

1. AB is an electric dipole of two point charges $-q$ and $+q$ separated by a small distance $2d$. P is a point along the axial line of the dipole at a distance $r$ from the midpoint O of the electric dipole.

2. [Diagram of a dipole with electric field lines]

3. The electric field due to $+q$ 
\[ E_1 = \frac{1}{4\pi\varepsilon_0} \frac{q}{(r-d)^2} \text{ (along BP)} \]

4. The electric field due to $-q$ 
\[ E_2 = \frac{1}{4\pi\varepsilon_0} \frac{q}{(r+d)^2} \text{ (along PA)} \]
5. \[ E = E_1 + (-E_2) \]

6. \[
E = \left[ \frac{1}{4\pi\varepsilon_0} \frac{q}{(r-d)^2} - \frac{1}{4\pi\varepsilon_0} \frac{q}{(r+d)^2} \right] \text{along BP.}
\]

\[
E = \frac{q}{4\pi\varepsilon_0} \left[ \frac{1}{(r-d)^2} - \frac{1}{(r+d)^2} \right] \text{along BP}
\]

\[
E = \frac{q}{4\pi\varepsilon_0} \left[ \frac{4rd}{(r^2-d^2)^2} \right] \text{along BP.}
\]

7. \( d \ll r \) and \( p = 2dq \)

8. \[
E = \frac{q}{4\pi\varepsilon_0} \frac{4rd}{r^4} = \frac{q}{4\pi\varepsilon_0} \frac{4d}{r^3}
\]

9. \[
E = \frac{1}{4\pi\varepsilon_0} \frac{2p}{r^3} \text{ along BP.}
\]

10. \( E \) acts in the direction of dipole moment.
Equatorial plane

1. Consider an electric dipole AB. Let 2d be the dipole distance and p be the dipole moment. P is a point on the equatorial line at a distance r from the midpoint O of the dipole.

2. Electric field at a point P due to the charge +q
   \[ E_1 = \frac{1}{4\pi\varepsilon_0} \frac{q}{r^2 + d^2} \] along BP

3. Electric field at a point P due to the charge -q
   \[ E_2 = \frac{1}{4\pi\varepsilon_0} \frac{q}{r^2 + d^2} \] along PA

4. The magnitudes of \( E_1 \) and \( E_2 \) are equal. The vertical components \( E_1 \sin \theta \) and \( E_2 \sin \theta \) cancel each other. The horizontal components \( E_1 \cos \theta \) and \( E_2 \cos \theta \) will get added along PR.

5. Resultant electric field \( E = E_1 \cos \theta + E_2 \cos \theta \) (along PR)

6. \[ E = 2 \cdot \frac{1}{4\pi\varepsilon_0} \frac{q}{r^2 + d^2} \frac{d}{\sqrt{r^2 + d^2}} \]

7. \[ E = \frac{1}{4\pi\varepsilon_0} \frac{p}{(r^2 + d^2)^{3/2}} \]

8. \( d \ll r \) and \( p = 2dq \)

9. \[ E = \frac{1}{4\pi\varepsilon_0} \frac{p}{r^3} \]

10. The direction of \( E \) is opposite to the direction of dipole moment.
8. Derive an expression for electrostatic potential due to an electric dipole

1. Consider an electric dipole AB. Let p be the point at a distance r from the midpoint of the dipole and $\theta$ be the angle between PO and the axis of the dipole OB.

2. Potential at P due to charge (+q) = \[ \frac{1}{4\pi \varepsilon_0} \frac{q}{r_1} \]

Potential at P due to charge (-q) = \[ \frac{1}{4\pi \varepsilon_0} \left( -\frac{q}{r_2} \right) \]

Total potential at P due to dipole is. \[ V = \frac{1}{4\pi \varepsilon_0} \left( \frac{q}{r_1} - \frac{q}{r_2} \right) \] ...(1)

3. Applying cosine law, \[ r_1^2 = r^2 + d^2 - 2rd \cos \theta \]

Using the Binomial theorem and neglecting higher powers,

\[ \frac{1}{r_1} = \frac{1}{r} \left( 1 + \frac{d}{r} \cos \theta \right) \] ...(2)

4. Similarly, \[ r_2^2 = r^2 + d^2 - 2rd \cos (180 - \theta) = r^2 + d^2 + 2rd \cos \theta \]

5. \[ \frac{1}{r_2} = \frac{1}{r} \left( 1 - \frac{d}{r} \cos \theta \right) \] ...(3)

6. Substituting equation (2) and (3) in equation (1) and simplifying

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

\[ \therefore V = \frac{q}{4\pi \varepsilon_0} \frac{2d \cos \theta}{r^2} = \frac{1}{4\pi \varepsilon_0} \frac{p \cos \theta}{r^2} \] ...(4)

7. Special cases:

(i) If $\theta = 0^\circ$; \[ V = \frac{p}{4\pi \varepsilon_0 r^2} \]

(ii) If $\theta = 180^\circ$; \[ V = -\frac{p}{4\pi \varepsilon_0 r^2} \]

(iii) If $\theta = 90^\circ$; \[ V = 0 \]

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

The electric potential at a point at a distance $r$ from point charge $q_1$ is given by
10. Derive an expression for electrostatic potential energy of the dipole in a uniform electric field

- Consider a dipole placed in the uniform electric field \( \vec{E} \). A dipole experiences a torque when kept in an uniform electric field \( \vec{E} \).
- This torque rotates the dipole to align it with the direction of the electric field.
- To rotate the dipole (at constant angular velocity) from its initial angle \( \theta' \) to another angle \( \theta \) against the torque exerted by the electric field, an equal and opposite external torque must be applied on the dipole. The work done by the external torque to rotate the dipole from angle \( \theta' \) to \( \theta \) at constant angular velocity
  \[
  W = \int_{\theta'}^{\theta} \tau_{\text{ext}} \, d\theta
  \]
  \( \tau = pE\sin\Theta \)

Substituting \( \tau \) in above equation

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

\[
W = pE (\cos\theta' - \cos\theta)
\]

If \( \theta' = 90^\circ \)

The potential energy stored in the system of dipole kept in the uniform electric field is given by

\[
U = -pE\cos\theta = -\vec{p} \cdot \vec{E}
\]

\( \Theta = 180^\circ \) dipole aligned **antiparallel** to field \( U \) is maximum

\( \theta = 0^\circ \) dipole aligned **parallel** to field \( U \) is minimum

11. Obtain Gauss law from Coulomb’s law

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

\[
\Phi_E = \oint \vec{E} \cdot d\vec{A} \cos\theta
\]

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

\[
\Phi_E = \oint \vec{E} \cdot dA
\]

\( E \) is uniform on the surface of the sphere.
12. Obtain expression for electric field due to an infinitely long charged wire

- Consider an infinitely long straight wire having uniform linear charge density \( \lambda \). Let \( P \) be a point located at a perpendicular distance \( r \) from the wire.

- The electric field at the point \( P \) can be found using Gauss law. We choose two small charge elements \( A_1 \) and \( A_2 \) on the wire which are at equal distances from the point \( P \).

- The resultant electric field due to these two charge elements points radially away from the charged wire and the magnitude of electric field is same at all points on the circle of radius \( r \).

- Charged wire possesses a cylindrical symmetry of radius \( r \) and length \( L \).

\[
\Phi_E = \oint \vec{E} \cdot dA
\]

\[
= \oint \vec{E} \cdot dA + \oint \vec{E} \cdot dA + \oint \vec{E} \cdot dA
\]

Curved top bottom
Surface surface surface

Since \( \vec{E} \) and \( dA \) are right angles to each other, the electric flux through the place caps = 0

Flux through the curved surface = \( \oint \vec{E} \cdot dA \cos \theta \)

\( \theta = 0 \cos 0 = 1 \Phi_E = \oint \vec{E} \cdot dA = E(2\pi r) \) ……(1)

The net charge enclosed by Gaussian surface is

\( Q = \lambda l \)

By Gauss law \( \Phi_E = \frac{Q}{\varepsilon_0} \) ………..(2)

Equating (1) & (2)

\( E(2\pi rl) = \frac{Q}{\varepsilon_0} \)

\( E(2\pi rl) = \frac{\lambda l}{\varepsilon_0} \)
14. Obtain expression for electric field due to uniformly charged spherical shell

**Case (i) At a point outside the shell.**

1. Consider a charged shell of radius \( R \). Let \( P \) be a point outside the shell, at a distance \( r \) from the centre \( O \).
2. Let us construct a Gaussian surface with \( r \) as radius. The electric field \( E \) is normal to the surface.
3. The flux crossing the Gaussian sphere normally in an outward direction is,
   \[
   \phi = \int \vec{E} \cdot d\vec{s} = \int E \, ds = E \left( 4\pi r^2 \right)
   \]
   (Since angle between \( \vec{E} \) and \( ds \) is zero)
4. By Gauss's law,
   \[
   E \cdot \left( 4\pi r^2 \right) = \frac{q}{\varepsilon_0}
   \]
5. \[
   E = \frac{1}{4\pi\varepsilon_0} \frac{q}{r^2}
   \]
6. The electric field at a point outside the shell will be the same as if the total charge on the shell is concentrated at its centre.

**Case (ii) At a point on the surface.**

7. The electric field \( E \) for the points on the surface of charged spherical shell is,
   \[
   E = \frac{1}{4\pi\varepsilon_0} \frac{q}{R^2} \quad (r = R)
   \]

**Case (iii) At a point inside the shell.**

8. Consider a point \( P' \) inside the shell at a distance \( r' \) from the centre of the shell. Let us construct a Gaussian surface with radius \( r' \).
9. The total flux crossing the Gaussian sphere normally in an outward direction is:
   \[
   \phi = \int \vec{E} \cdot d\vec{s} = \int Eds = E \times \left( 4\pi r'^2 \right)
   \]
10. According to Gauss's law
    \[
    E \times 4\pi r'^2 = \frac{q}{\varepsilon_0} = 0
    \]
    The field due to a uniformly charged thin shell is zero at all points inside the shell.
18. Obtain the expression for capacitance for a parallel plate capacitor

Consider a capacitor with two parallel plates each of cross-sectional area \( A \) and separated by a distance \( d \).

The electric field between two infinite parallel plates is uniform and is given by

\[
E = \frac{\sigma}{\varepsilon_0}
\]

\( \sigma \) – Surface charge density on the plates (\( \sigma = \frac{Q}{A} \))

The electric field between the plates is

\[
E = \frac{Q}{A \varepsilon_0}
\]

Since the electric field is uniform, the electric potential between the plates having separation \( d \) is

\[
V = Ed = \frac{Qd}{A \varepsilon_0}
\]

Capacitance of the capacitor is given by

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

\( C \propto A \quad C \propto \frac{1}{d} \)
21. Derive the expression for resultant capacitance when capacitors are connected in series and in parallel

<table>
<thead>
<tr>
<th>Capacitors in series</th>
<th>Capacitors in parallel</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. ( C_1, C_2, C_3 ), capacitors are connected in series. ( C_s ) is the effective capacitances.</td>
<td>1. ( C_1, C_2, C_3 ), capacitors are connected in parallel. ( C_p ) is the effective capacitances.</td>
</tr>
<tr>
<td><img src="image" alt="Series Capacitors Diagram" /></td>
<td><img src="image" alt="Parallel Capacitors Diagram" /></td>
</tr>
<tr>
<td>3. Charge in each capacitor is same.</td>
<td>3. Potential in each capacitor is same.</td>
</tr>
<tr>
<td>4. ( V = V_1 + V_2 + V_3 )</td>
<td>4. ( q = q_1 + q_2 + q_3 )</td>
</tr>
<tr>
<td>5. ( V = \frac{q}{C_1} + \frac{q}{C_2} + \frac{q}{C_3} = \frac{q}{C_s} )</td>
<td>6. ( q = C_p V )</td>
</tr>
<tr>
<td>6. ( \frac{1}{C_s} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} )</td>
<td>7. ( C_p = C_1 + C_2 + C_3 )</td>
</tr>
<tr>
<td>8. The reciprocal of the effective capacitance is equal to the sum of reciprocal of the capacitance of the individual capacitors.</td>
<td>8. The effective capacitance of the capacitors connected in parallel is the sum of the capacitances of the individual capacitors.</td>
</tr>
</tbody>
</table>
Hence the new potential difference is

\[ V = Ed = \frac{E_0 d}{\varepsilon_r} = V_0 / \varepsilon_r \]

We know that capacitance is inversely proportional to the potential difference. Therefore as V decreases, C increases. Thus new capacitance in the presence of a dielectric is

\[ C = \frac{Q_0}{V} = \varepsilon_r \frac{Q_0}{V} = \varepsilon_r C_0 \]

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

\[ C = \varepsilon_r \varepsilon_0 \frac{A}{d} = \varepsilon A /d \]

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

\[ U_0 = \frac{Q_0^2}{2C_0} \]

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

\[ U = \frac{Q_0^2}{2C} = \frac{Q_0^2}{2\varepsilon_r C_0} = \frac{U_0}{2\varepsilon_r} \]

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

ii) When the battery remains connected to the capacitor

refer text book

22. Explain in detail how charges are distributed in a conductor & the principle behind lightning conductor

Consider two conducting spheres A and B of radii \( r_1 \) and \( r_2 \) respectively connected to each other by a thin conducting wire.

The distance between the spheres is much greater than the radii of either spheres.

If a charge Q is introduced into any one of the spheres, this charge Q is redistributed into both the spheres such that the electrostatic potential is same in both the spheres.
Due to the high electric field near comb D, air between the belt and comb D gets ionized. The positive charges are pushed towards the belt and negative charges are attracted towards the comb D. The positive charges stick to the belt and move up. When the positive charges reach the comb E, a large amount of negative and positive charges are induced on either side of comb E due to electrostatic induction. As a result, the positive charges are pushed away from the comb E and they reach the outer surface of the sphere. Since the sphere is a conductor, the positive charges are distributed uniformly on the outer surface of the hollow sphere. At the same time, the negative charges nullify the positive charges in the belt due to corona discharge before it passes over the pulley.

When the belt descends, it has almost no net charge. At the bottom, it again gains a large positive charge. The belt goes up and delivers the positive charges to the outer surface of the sphere. This process continues until the outer surface produces the potential difference of the order of $10^7$ which is the limiting value. We cannot store charges beyond this limit since the extra charge starts leaking to the surroundings due to ionization of air. The leakage of charges can be reduced by enclosing the machine in a gas filled steel chamber at very high pressure.

**Book inside questions**

1. Write the applications of capacitors
2. Write about microwave oven
3. How is electric flux is related to electric field
4. Derive an electric flux in a non uniform electric field and an arbitarly shaped area
5. Write the special features of gauss law
6. Explain about lightning arrester or lightning conductor
7. Derive an expression for energy density in parallel plate capacitor