PHYSICS

Class XII

Chapter 2- ELECTROSTATIC POTENTIAL AND CAPACITANCE

1 Mark Questions

Question 1.
A 500 μC charge is at the centre of a square of side 10 cm. Find the work done in moving a charge of 10 μC between two diagonally opposite points on the square.
Answer:
The work done in moving a charge of 10 μC between two diagonally opposite points on the square will be zero because these two points will be at equipotential.

Question 2.
What is the electrostatic potential due to an electric dipole at an equatorial point?
Answer:
Electric potential at any point in the equatorial plane of dipole is Zero.

Question 3.
What is the work done in moving a test charge q through a distance of 1 cm along the equatorial axis of an electric dipole?
Answer:
Since potential for equatorial axis
V = 0
∴ W = qV = 0

Question 4.
Define the term 'potential energy' of charge 'q' at a distance V in an external electric field.
Answer:
It is defined as the amount of work done in bringing the charge from infinity to its position in the system in the electric field of another charge without acceleration.
V = Er.

Question 5.
A point charge Q is placed at point O as shown in the figure. Is the potential difference V_A – V_B positive, negative or zero, if Q is
(i) positive
(ii) negative?

Answer:
Clearly,

$$V_A - V_B = \left(\frac{1}{4\pi\varepsilon_0}\cdot\frac{q}{OA}\right) - \left(\frac{1}{4\pi\varepsilon_0}\cdot\frac{q}{OB}\right)$$
$$= \frac{q}{4\pi\varepsilon_0}\cdot\left[\frac{1}{OA} - \frac{1}{OB}\right]$$

As OA < OB, so the quantity within bracket is negative.
(i) If q is positive charge, $V_A - V_B$ = negative
(ii) If q is negative charge, $V_A - V_B$ = positive

Question 6.
A hollow metal sphere of radius 5 cm is charged such that the potential on its surface is 10 V. What is the potential at the centre of the sphere?
Answer:
The electric field inside the shell is zero. This implies that potential is constant inside the shell (as no work is done in moving a charge inside the shell) and, therefore, equals its value at the surface, which is 10 V.

Question 7.
A hollow metal sphere of radius 10 cm is charged such that the potential on its surface is 5 V. What is the potential at the centre of the sphere?
Answer:
Hollow metal sphere behaves as an equipotential surface, so the potential at its centre will be 5 V.

Question 8.
Why is electrostatic potential constant throughout the volume of the conductor and has the same value (as inside) on its surface?
Answer:
Electric field inside the conductor = 0

$$E = -\frac{dV}{dr} \Rightarrow \frac{dV}{dr} = 0 \quad \therefore \mathbf{V = constant}$$

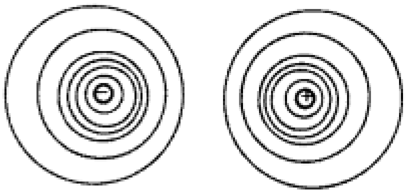
Question 9.
Distinguish between tor. dielectric and a conductor
Answer:

Dielectric	Conductor
Dielectrics are the insulating materials which transmit electric effects without conducting.	Conductors are the substances which can be used to carry or conduct electric charge from one place to the other.

Question 10.
Why must the electrostatic potential inside a hollow charged conductor be the same at every point?
Answer:
Inside the hollow charged conductor, electric field is zero therefore no work is done in moving a small test charge within the conductor. Hence electrostatic potential inside a hollow charged conductor is same at every point.

Question 11.
What is the geometrical shape of equipotential surfaces due to a single isolated charge?
Answer:
Concentric spheres with a gap between them not being uniform as $V \propto 1r$

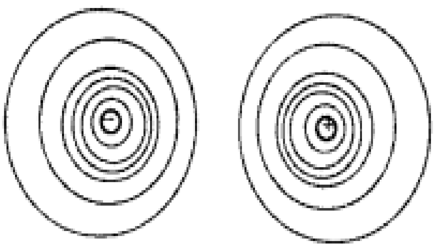
Question 12.
Two charges 2μC and – 2μC are placed at points A and B 5 cm apart. Depict an equipotential surface of the system.
Answer:



Equipotential surfaces of the system

Question 13.
What is the amount of work done in moving a point charge around a circular arc of radius r at the centre of which another point charge is located?
Answer:
Being an equipotential surface, work done will be zero.

Question 14.
Two charges 4μC and -4μC are placed at points A and B 3 cm apart. Depict an equipotential surface of the system.
Answer:



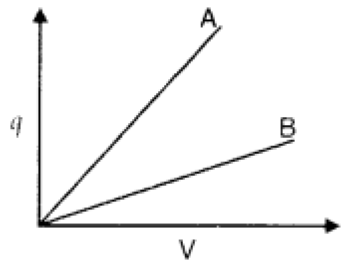
Equipotential surfaces of the system

Question 15.
"For any charge configuration, equipotential surface through a point is normal to the electric field." Justify.
Answer:
Work done in moving a charge over an equipotential surface is zero, hence a point on it will be normal to the electric field.
$W = FS \cos\theta \therefore \cos\theta = 0$ or $\theta = 90o$

Question 16.
Two equal balls having equal positive charge 'q' coulumbs are suspended by two insulating strings of equal length. What would be the effect on the force when a plastic sheet is inserted between the two ?
Answer:
The force would be reduced by a factor 'K' (equal to the value of dielectric constant of plastic sheet)

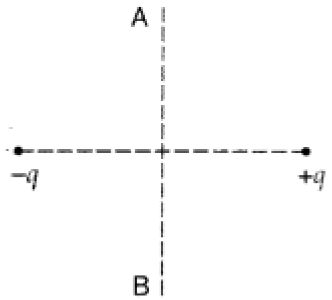
$$F_K = \frac{F_{Air}}{K}$$

Question 17.
The given graph shows variation of charge 'q' versus potential difference 'V' for two capacitors C_1 and C_2. Both the capacitors have same plate seperation but plate area of C_2 is greater than that of C_1. Which line (A or B) corresponds to C_1 and why?



Answer:
Line B corresponds to C_1
Reason: Since slope (qv) of 'B' is less than that of 'A'

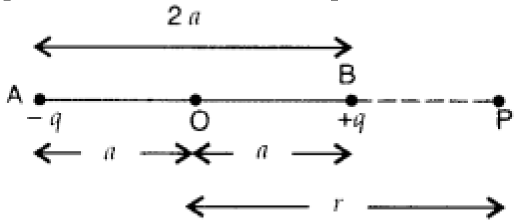
Question 18.
A charge 'q' is moved from a point A above a dipole of dipole movement 'p' to a point B below the dipole in equitorial plane without acceleration. Find the work done in the process.



Answer:
No work is done.

2 Mark Questions

Question 1.
Derive the expression for the electric potential at any point along the axial line of an electric dipole .
Answer:
Consider an electric dipole consisting of two points charged -q and +q and seperated by distance 2a. Let P be a point on the axis of the dipole at a distance r from its centre O.



Electric potential at point P due to dipole is,
$V = V_1 + V_2$

$$\text{or } V = \frac{1}{4\pi\varepsilon_0}\frac{-q}{AP} + \frac{1}{4\pi\varepsilon_0}\cdot\frac{q}{BP}$$

$$\text{or } V = -\frac{1}{4\pi\varepsilon_0}\cdot\frac{q}{r+a} + \frac{1}{4\pi\varepsilon_0}\cdot\frac{q}{r-a}$$

$$\text{or } V = \frac{q}{4\pi\varepsilon_0}\left[\frac{1}{r-a} - \frac{1}{r+a}\right]$$

$$\text{or } V = \frac{q}{4\pi\varepsilon_0}\left[\frac{(r+a)-(r-a)}{r^2-a^2}\right]$$

$$\text{or } V = \frac{1}{4\pi\varepsilon_0}\cdot\frac{q\times 2a}{r^2-a^2}$$

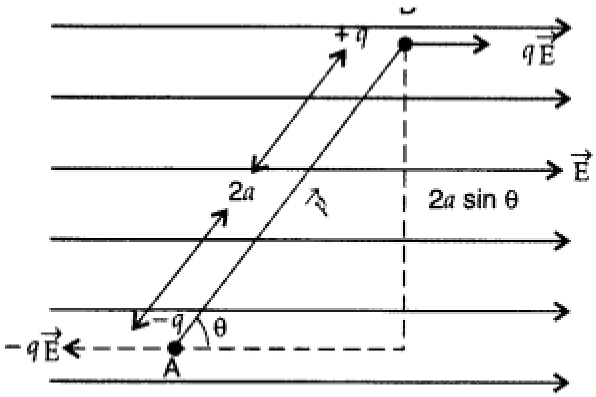
$$\text{or } V = \frac{1}{4\pi\varepsilon_0}\cdot\frac{p}{r^2-a^2}$$

...where [p is dipole moment [$p = q \times 2a$]

For ideal dipole : $a << r$

So $a^2 << r^2$ $\quad\quad \therefore V = \frac{1}{4\pi\varepsilon_0}\cdot\frac{p}{r^2}$

Question 2.
Derive an expression for the potential energy of an electric dipole of dipole movement $\vec{p}$ in the electric field $\vec{E}$
Answer:
Consider a dipole with charges +q and -q placed in a uniform electric field E→ such that AB = 2a as shown in the figure



Since the dipole experiences no net force in a uniform electric field but experiences a torque (τ) is given by

$\vec{\tau} = \vec{p} \times \vec{E}$ $\therefore\ \tau = pE \sin\theta$

It tends to rotate the dipole in clockwise direction. To rotate the dipole anti-clock wise has to be done on the dipole.

$$W = \int_{\theta_1}^{\theta_2} \tau d\theta \qquad \text{or } W = \int_{\theta_1}^{\theta_2} pE \sin\theta \, d\theta$$

$$\text{or} \quad W = pE\left[-\cos\theta\right]_{\theta_1}^{\theta_2}$$

$$\therefore \quad \mathbf{W = -pE[\cos\theta_2 - \cos\theta_1]}$$

Question 3.

Two point charges, $q_1 = 10 \times 10^{-8}$C, $q_2 = -2 \times 10^{-8}$C are seperated by a distance of 60 cm in air.

(i) Find at what distance from the 1st charge, q_1 would the electric potential be zero.

(ii) Also calculate the electrostatic potential energy of the system.

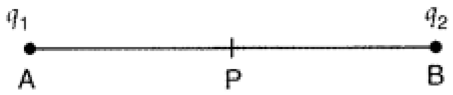
Answer:

(i) Given : $q_1 = 10 \times 10^{-8}$C, $q_2 = -2 \times 10^{-8}$C

AB = 60 cm = 0.60 = 0.6m

Let AP = x

Let AP = x then PB = $0.6 - x$



Potential P due to charge $q_1 = \frac{Kq_1}{AP}$

Potential P due to charge $q_2 = \frac{Kq_2}{BP}$

$\because$ Potential at P = 0

$\Rightarrow \frac{Kq_1}{AP} + \frac{Kq_2}{BP} = 0 \quad \Rightarrow \quad \frac{q_1}{AP} = \frac{-q_2}{PB}$

$\therefore \quad \frac{10 \times 10^{-8}}{x} = \frac{-(-2 \times 10^{-8})}{0.6 - x}$

$\Rightarrow 2x + 10x = 6 \quad \Rightarrow \quad 12x = 6$

$\therefore \quad x = \frac{1}{2} = 0.5\text{m}$

$\therefore$ Distance from first charge = 0.5 m = 50 cm.

(ii) Electrostatic energy of the system is

$$E_n = \frac{Kq_1q_2}{r} = \frac{-9 \times 10^9 \times 10^{-7} \times 2 \times 10^{-8}}{60 \times 10^{-2}}$$

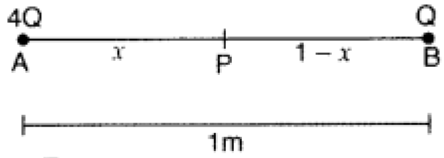
$$= \frac{-18 \times 10^{-6}}{60 \times 10^{-2}}$$

$$= \frac{-3}{10} \times 10^{-4} = -3 \times 10^{-5} \text{ Joule}$$

$\therefore$ U or $E_n = \mathbf{-3 \times 10^{-5}}$ **Joule**

Question 4.
Two point charges 4Q, Q are separated by lm in air. At what point on the line joining the charges is the electric field intensity zero?
Also calculate the electrostatic potential energy of the system of charges, taking the value of charge, Q = 2 × 10^{-7}C
Answer:

(*i*) **Given :** $r = 1\text{m}, \quad q_1 = 4Q, \quad q_2 = Q$



$$E_{PA} = E_{PB}$$

$$\frac{K(4Q)}{x^2} = \frac{KQ}{(1-x)^2} \quad \Rightarrow \quad \frac{4}{x^2} = \frac{1}{(1-x)^2}$$

$$\Rightarrow \quad \frac{2}{x} = \frac{1}{1-x} \quad \Rightarrow \quad 2 - 2x = x$$

$$\Rightarrow \quad 3x = 2 \quad \therefore \quad x = \frac{2}{3}\,\mathbf{m}$$

(ii) Electrostatic potential energy of the system is

$$U = K\frac{q_1 q_2}{r} = \frac{9 \times 10^9 \times 4Q \times Q}{1}$$

$$= 36 \times 10^9 \times (2 \times 10^{-7})^2 = \mathbf{1.44 \times 10^{-3}\ J}$$

Question 5.

Two point charges 20 x 10-6 C and -4 X 10-6 C are separated by a distance of 50 cm in air.

(i) Find the point on the line joining the charges, where the electric potential is zero.

(ii) Also find the electrostatic potential energy of the system.

Answer:

(i) Here $q_1 = 20 \times 10^{-6}$C, $q_2 = -4 \times 10^{-6}$C

and AB = 50 cm = 0.50 m = 0.5 m Let AP = x then PB = 0.5 – x

Potential at P due to charge q_1 = Kq1AP

Potential at P due to charge q_2 = Kq2PB

Potential at P = 0 ⇒Kq1AP+Kq2PB=0

$$\frac{Kq_1}{AP} = -\frac{Kq_2}{PB} \quad \Rightarrow \quad \frac{q_1}{AP} = -\frac{q_2}{PB}$$

$$\frac{20 \times 10^{-6}}{x} = -\frac{(-4 \times 10^{-6})}{0.5 - x}$$

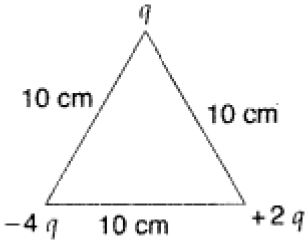
$$\Rightarrow \quad \frac{20}{x} = \frac{4}{0.5 - x}$$

$$14x = 5 \quad \Rightarrow x = \frac{5}{14}\text{m}$$

$$(ii)\ U = \frac{Kq_1q_2}{r} = \frac{9 \times 10^9 (20 \times 10^{-6})(4 \times 10^{-6})}{50 \times 10^{-2}}$$

$$= \mathbf{1.45\ J}$$

Question 6.
Calculate the work done to dissociate the system of three charges placed on the vertices of a triangle as shown.



Answer:
Initial P.E. of the three charges

$$u_i = \frac{1}{4\pi\varepsilon_0}\left[\frac{q_1q_2}{r} + \frac{q_2q_3}{r} + \frac{q_1q_3}{r}\right]$$

$$= \frac{1}{4\pi\varepsilon_0}\left[\frac{q(-4q)}{r} + \frac{(-4q)\times 2q}{r} + \frac{q\times 2q}{r}\right]$$

$$= -\frac{1}{4\pi\varepsilon_0}\cdot\frac{10q^2}{r} = \frac{-9\times 10^9\times 10\times(1.6\times 10^{-10})^2\,\text{J}}{0.10}$$

$$= \frac{-9\times 10^9\times 10\times 2.56\times 10^{-20}\times 100}{10}$$

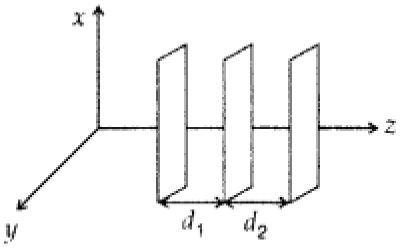
$$= -23.04\times 10^{-9} = -2.304\times 10^{-8}\ \text{J}$$

Final P.E, $u_f = 0$
∴ Work required to dissociate the system of three charges,
$W = u_f - u_i = -2.304 \times 10^{-8}$ J

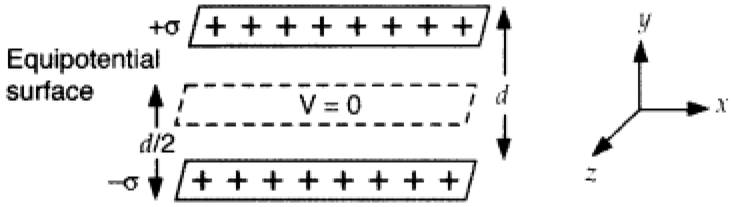
Question 7.
(i) Can two equipotential surfaces intersect each other? Give reasons.
(ii) Two charges -q and + q are located at points A (0, 0, – a) and B (0, 0, +a) respectively. How much work is done in moving a test charge from point P (7, 0, 0) to Q (-3,0,0)?
Answer:
(i) No, if they intersect, there will be two different directions of electric field at that point which is not correct. If they intersect, then at the same point of intersection, there will be two values of potential. This is not possible and hence two equipotential surfaces cannot intersect.
(ii) Since both the points P and Q are on the equatorial line of the dipole and V = 0 at every point on it, work done will be zero. Also the force on any charge is perpendicular to the equatorial line, so work done is zero.

Question 8.
Draw 3 equipotential surfaces corresponding to a field that uniformly increases in magnitude but remains constant along Z-direction. How are these surfaces different from that of a constant electric field along Z-direction?
Answer:
$d_2 < d_1$ for increasing field

and $d_2 = d_1$ for uniform field.

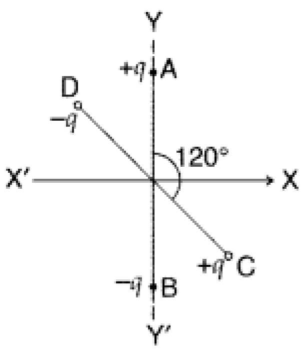


Question 9.
Two uniformly large parallel thin plates having charge densities + σ and – σ are kept in the X-Z plane at a distance 'd' apart. Sketch an equipotential surface due to electric field between the plates. If a particle of mass m and charge q' remains stationary between the plates, what is the magnitude and direction of this field?
Answer:
The equipotential surface is at a distance d/2 from either plate in X-Z plane. For a particle of charge (- q) at rest between the plates, then



(i) weight mg acts, vertically downward
(ii) electric force qE acts vertically upward
so mg = qE
E = mgq vertically downward,
i.e., along (-) Y-axis.

Question 10.
Two small identical electrical dipoles AB and CD, each of dipole moment 'p' are kept at an angle of 120° as shown in the figure. What X' is the resultant dipole moment of this combination? If this system is subjected to electric field (E→) directed along + X direction, what will be the magnitude and direction of the torque acting on this?



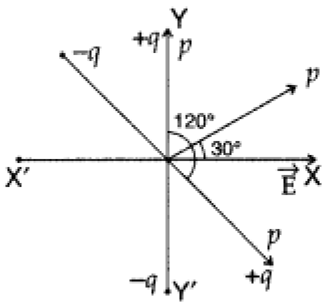
Answer:
Resultant dipole moment of both dipoles is

$$= \sqrt{p^2 + p^2 + 2p^2 \cos\theta}$$

$$= \sqrt{2p^2 + 2p^2 \cos 120°}$$

$$= \sqrt{2p^2 + 2p^2\left(-\frac{1}{2}\right)}$$

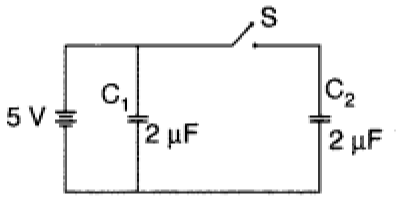
$$= \sqrt{p^2} = p$$



Resultant dipole moment (p) makes an angle of 60° with each dipole and 30° with x-axis as shown in the figure.

$$\text{Now } \tau = pE \sin 30° = pE\left(\frac{1}{2}\right) \Rightarrow \boxed{\tau = \frac{pE}{2}}$$

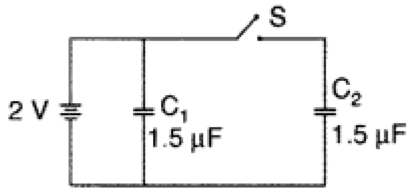
Question 11.
Figure shows two identical capacitors C_1 and C_2, each of 2 μF capacitance, connected to a battery of 5 V. Initially switch 'S' is left open and dielectric slabs of dielectric constant K = 5 are inserted to fill completely the space between the plates of the two capacitors. How will the charge and



(ii) potential difference between the plates of the capacitors be affected after the slabs are inserted?
Answer:
(i) When switch S is open and dielectric is introduced, charge on each capacitor will be $q_1 = C_1 V$, $q_2 = C_2V$
$q_1 = 5CV$
$= 5 \times 2 \times 5 = 50$ μC, $q_2 = 50$ μC
Charge on each capacitor will become 5 times
(ii) P.d. across C_1 is still 5V and across C_2,
$q = (5C)\, V$

$$V' = \frac{V}{5} = \frac{5}{5} = \mathbf{1V}$$

Question 12.
Figure shows two identical capacitors C^1 and C^2 each of 1.5 μF capacitance, connected to a battery of 2 V. Initially switch 'S' is closed. After sometime 'S' is left open and dielectric slabs of dielectric constant K = 2 are inserted to fill completely the space between the plates of the two capacitors. How will the
(i) charge and
(ii) potential difference between the plates of the capacitors be affected after the slabs are inserted?



Answer:
(i) When switch S is open and dielectric is introduced, charge on each capacitor, will be
$q_1 = C_1V$,
$q_2 = C_2V$,
$q_1 = 2CV = 2 \times 1.5 \times 2 = 6\ \mu C$, $q_2 = 6\ \mu C$
Charge on each capacitor will become twice.
(ii) P.d. across C_1 is still 2V and across C_2,
q = (2C) V'

$$\therefore \quad V' = \frac{V}{2} = \frac{2}{2} = \mathbf{1V}$$

Question 13.
Net capacitance of three identical capacitors in series is 1 pF. What will be their net capacitance if connected in parallel?
Find the ratio of energy stored in the two configurations if they are both connected to the same source.
Answer:
Let C be the capacitance of a capacitor
Given : $C_1 = C_2 = C_3 = C$ When connected in series:

When connected in series:

$$C_S = \frac{C}{3} = 1\ \mu F \qquad \therefore C = 3\ \mu F$$

When connected in parallel:

$$C_p = C + C + C = 3 + 3 + 3 = 9\ \mu F$$

Energy stored in capacitor

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

$$\therefore \quad \frac{E_s}{E_p} = \frac{\frac{1}{2}C_sV^2}{\frac{1}{2}C_pV^2} = \frac{C_s}{C_p} = \frac{1}{9} = \mathbf{1:9}$$

Question 14.
Net capacitance of three identical capacitors in series is 3 pF. What will be their net capacitance if connected in parallel?
Find the ratio of energy stored in the two configurations if they are both connected to the same source.
Answer:
Let C_1, C_2 and C_3 be the capacitances of three capacitors. But these three capacitors are of same capacitance,

so C is the capacitance of each capacitor.

$C_1 = C_2 = C_3 = C$

When C_1, C_2 and C_3 are connected in series :

$$\frac{1}{C_S} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

$$\Rightarrow \quad \frac{1}{C_S} = \frac{1}{C} + \frac{1}{C} + \frac{1}{C} = \frac{3}{C}$$

$$\therefore \quad C_S = \frac{C}{3} = 3\ \mu F \qquad \text{...}[\because C_S = 3\ \mu F$$

$$\therefore \quad C = 9\ \mu F$$

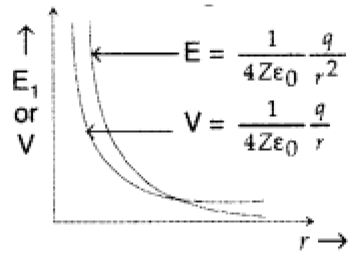
When C_1, C_2 and C_3 are connected in parallel

$$C_p = 3C = 3 \times 9\ \mu F = 27\ \mu F$$

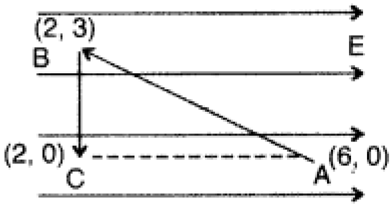
Energy stored in capacitor is, $E = \frac{1}{2}CV^2$

$$\therefore \quad \frac{E_s}{E_p} = \frac{C_s}{C_p} = \frac{3}{27} = \frac{1}{9} \qquad \therefore \textbf{ Ratio = 1 : 9}$$

Question 15.
Draw a plot showing the variation of
(i) electric field (E) and
(ii) electric potential
(iii) with distance r due to a point charge Q.
Answer:



Question 16.
A test charge 'q' is moved without acceleration from A to C along the path from A to B and then from B to C in electric field E as shown in the figure.



(i) Calculate the potential difference between A and C.
(ii) At which point (of the two) is the electric potential more and why?
Answer:

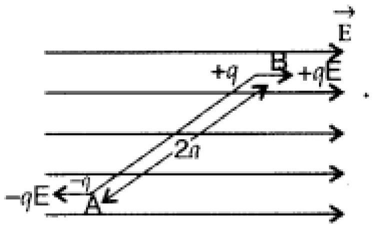
(i) P.D does not depend upon the path along which the test charge q moves

$$\therefore \quad E = \frac{-dV}{dr} = -\left(\frac{V_C - V_A}{d}\right) = \frac{V_A - V_C}{d}$$

$$\because \quad d_{AC} = 4 \qquad \text{So } V_A - V_C = E \times 4 = 4E$$

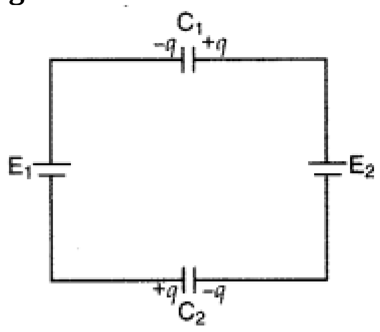
(ii) At point C, electric potential will be more as potential decreases in the direction of electric field.

Question 17.
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 alligned parallel to the field.
Find the work done in rotating it through the angle of 180°.
Answer:
(i) Force acting on point A due to charge -q is -qE
Force acting on point B due to charge +q. is + qE
Net force acting on
= -qE + qE = 0 (zero)



Hence, the net force acting on electric dipole held in a uniform electric field is zero.
(ii) W = -pE(cos 0_2 — cos θ_2)
W = -pE(cos 180° – cos 0°)
=> W = -pE(-1 – (1)) = +2pE

Question 18.
Determine the potential difference across the plates of the capacitor 'C_1' of the network shown in the figure.



[Assume $E_2 > E_1$]
Answer:
Net E = $E_2 – E_1$
Both capacitors are in series

$$\therefore \quad \frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} \qquad \Rightarrow C = \frac{C_1 \times C_2}{C_1 + C_2}$$

∴ V_1, (Potential difference across the plates of the capacitor C_1) = qC1

4 Mark Questions

Question 1.
Derive an expression for the energy stored in a parallel plate capacitor.
On charging a parallel plate capacitor to a potential V, the spacing between the plates is halved, and a dieletric medium of $\varepsilon_r = 10$ is introduced between the plates, without disconnecting the d.c. source. Explain, using suitable expressions, how the
(i) capacitance,
(ii) electric field and
(iii) energy density of the capacitor change.
Answer:
(a) Consider a parallel plate capacitor with plate area ‘A’ and separation between the plates equal to ‘d’. Suppose at any instant of time charge on the capacitor plate is ‘q’ and potential difference due to this charge is V. To supply a charge ‘dq’ further to the capacitor amount of work required is

$$dW = Vdq \quad \text{or } dW = \frac{q}{C}\, dq \quad [\because q = Cv]$$

In order to supply a charge 'Q'

Work required, $W = \frac{1}{C}\int_0^Q q\, dq$

$$\Rightarrow W = \frac{1Q^2}{2C}$$

Thus energy stored by capacitor is, $U = \frac{1Q^2}{2C}$

(b) (i) $C_f = \frac{K\varepsilon_0 A}{d'} = \frac{K\varepsilon_0 A}{d/2}$ $\quad (\because d' = d/2)$

$C_f = \frac{20\varepsilon_0 A}{d} = 20\ C_i$ $\quad (\because C_i = \frac{\varepsilon_0 A}{d})$

$\therefore$ *Capacitance becomes 20 times*

(ii) $E_f = \frac{V}{d'} = \frac{V}{d/2}$ $\quad (\because d' = d/2)$

$E_f = 2\frac{V}{d} = 2E_i$ $\quad (\because E_i = \frac{V}{d})$

$\therefore$ *Electric field is doubled*

(iii) Energy density,

$$U_f^{\circ} = \frac{1}{2}\frac{\sigma^2}{\varepsilon_0} = \frac{1}{2}\varepsilon_0\left(\frac{\sigma}{\varepsilon_0}\right)^2 = \frac{1}{2}\ \varepsilon_0\ (E_i)^2$$

$(\because E_i = \frac{\sigma}{\varepsilon_0})$

$U_f = \frac{1}{2}\varepsilon_r\ \varepsilon_0\ E_f^2$ or $U_f = \frac{10}{2}\ \varepsilon_0\ (2E_i)^2$

$\therefore U_f = 40\ (\frac{1}{2}\ \varepsilon_0\ E_i^2) = \mathbf{40\ Ui}$

So energy density is 40 times

Question 2.

(a) Write two properties of equipotential surfaces. Depict equipotential surfaces due to an isolated point charge. Why do the equipotential surfaces get closer as the distance between the equipotential surface and the source charge decreases?

(b) An electric dipole of dipole moment $\vec{p}$, is placed in a uniform electric field $\vec{E}$,. Deduce the expression for the torque 'x acting on it.

Answer:

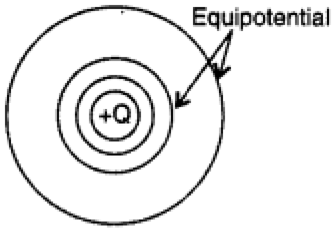
(a) Properties of equipotential surfaces:

(i) No work is done in moving a test charge over an equipotential surface.

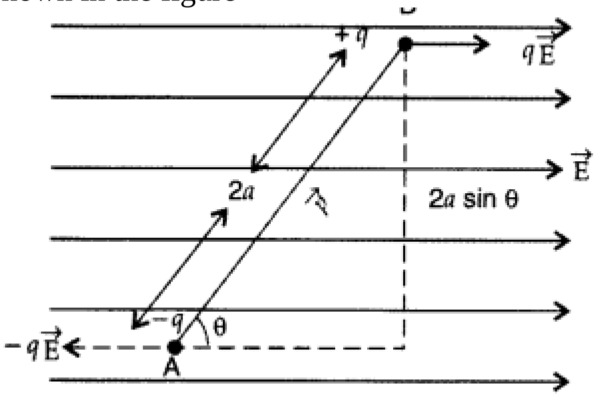
(ii) No two equipotential surfaces can inter-sect each other.
(iii) Equipotential surface due to an isolated point charge is spherical.
(iv) The electric field at every point is normal to the equipotential surface passing through that point. (any two)

As $E = \frac{-dV}{dr}$ or $dr = \frac{-dV}{E}$

For the same charge in the value, V, i.e., when dV = constant,
we have dr ∝1E
Hence, equipotential surface gets closer as the distance between the equipotential surface and the source charge decreases.



Equipotential surface due to an isolated charge
(b) Consider a dipole with charges +q and -q placed in a uniform electric field E→ such that AB = 2a as shown in the figure



Since the dipole experiences no net force in a uniform electric field but experiences a torque (τ) is given by

$\vec{\tau} = \vec{p} \times \vec{E}$ $\therefore\ \tau = pE \sin\theta$

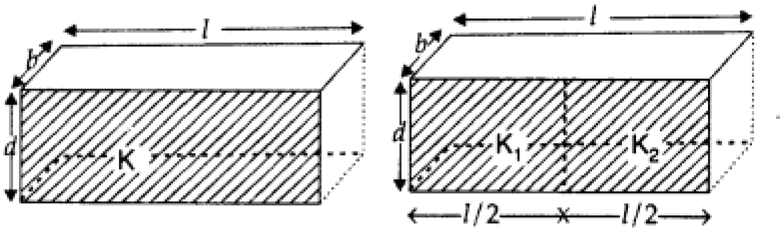
It tends to rotate the dipole in clockwise direction. To rotate the dipole anti-clock wise has to be done on the dipole.

$$W = \int_{\theta_1}^{\theta_2} \tau d\theta \qquad \text{or } W = \int_{\theta_1}^{\theta_2} pE \sin\theta\, d\theta$$

$$\text{or} \quad W = pE\left[-\cos\theta\right]_{\theta_1}^{\theta_2}$$

$$\therefore \quad \mathbf{W = -pE\,[\cos\theta_2 - \cos\theta_1]}$$

Question 3.
(a) Obtain the expression for the potential due to an electric dipole of dipole moment p at a point V on the axial line.
(b) Two identical capacitors of plate dimensions l × b and plate separation d have di-electric slabs filled in between the space of the plates as shown in the figure.



Obtain the relation between the dielectric constants K, K_1 and K_2.
Answer:
(a) Potential at a point due to an electric dipole : Let us consider an electric dipole consisting of two equal and opposite charges -q at A and +q at B, separated by a distance 21 with centre at O. We have to calculate potential at a point P, whose polar co-ordinates are (r, 0); i.e. OP = r and ∠BOP = θ, as shown in the figure. Here AP = r_1, and BP = r_2, we can easily calculate potential as P due to point charges at A and B using V = 14πε0qr.

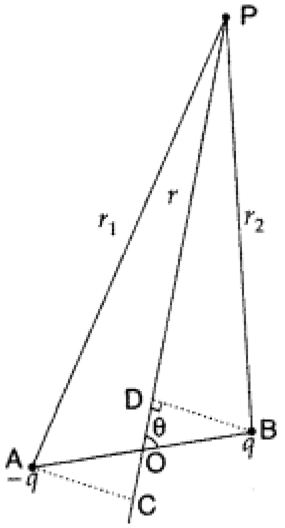
$$V_1 = \frac{1}{4\pi\varepsilon_0} \times \frac{(-q)}{r_1} \quad \text{and} \quad V_2 = \frac{1}{4\pi\varepsilon_0} \times \frac{q}{r_2}$$

Total potential at P due to both the charges of the dipole is given by
$v = v_1 + v_2$

$$\text{That is, } V = \frac{q}{4\pi\varepsilon_0}\left[\frac{1}{r_2} - \frac{1}{r_1}\right] \qquad \ldots(i)$$

To put this result in a more convenient form, we draw normals from A and B on the line joining O and P. From ΔBOD, we note that OD = l cos θ and from ΔOAC we note that OC = l cos θ. For a small dipole (AB << OP), from the figure, we can take PB = PD and PA = PC.
Hence $r_1 = r + l \cos\theta$,
Using these results in equation (1), we get

$$V = \frac{q}{4\pi\varepsilon_0}\left[\frac{1}{(r - l\cos\theta)} - \frac{1}{(r + l\cos\theta)}\right]$$
$$= \frac{q}{4\pi\varepsilon_0}\left[\frac{(2l\cos\theta)}{(r^2 - l^2\cos^2\theta)}\right] = \frac{q \times 2l\cos\theta}{4\pi\varepsilon_0 r^2}$$



where we have neglected the term containing second power of l since l << r
In terms of dipole (p = q × 21), we can express this result as

$$V = \frac{p\cos\theta}{4\pi\varepsilon_0 r^2} \qquad \ldots(ii)$$

This result shows that unlike the potential due to a point charge, the potential due to a dipole is inversely proportional to the square r of the distance.
Let us now consider its special cases.
Special Cases
Case I : When point P lies on the axial line of the dipole on the side of positive charge,
θ = 0 and cos θ = 1
Then equation (ii) reduces to

$$V_{AXIS} = \frac{p}{4\pi\varepsilon_0 r^2} \qquad \ldots(iii)$$

Case II : When point P lies on the axial line of the dipole but on the side of negative charge,
θ = 180° and cos θ = 1

$$\text{Then} \quad V_{AXIS} = -\frac{p}{4\pi\varepsilon_0 r^2} \qquad \ldots(iv)$$

Case III :When point P lies on the equatorial line of the dipole (perpendicular bisector of AB), θ = 90° and cos θ = 0
Then $V_{equitorial}$ = 0 … (i)
Thus, electric potential due to a dipole is zero at every point on the equatorial line of the dipole.

$$(b)\ \text{In first case, } C_1 = \frac{\varepsilon_0 K \times (l \times b)}{d} \qquad \ldots(i)$$

In second case, these two apartments are in parallel, their net capacity would be the sum of two individual capacitances
$C_2 = C'_2 + C''_2$

$$= \frac{\varepsilon_0 K_1\left(\frac{l}{2}\times b\right)}{d} + \frac{\varepsilon_0 K_2\left(\frac{l}{2}\times b\right)}{d}$$

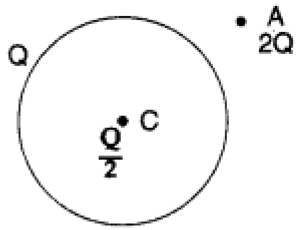
$$\Rightarrow C_2 = 2\varepsilon_0 \frac{(l\times b)}{d}(K_1 + K_2) \qquad \ldots(ii)$$

Since these are identical capacitors, comparing (i) and (ii),
We have $C_1 = C_2$

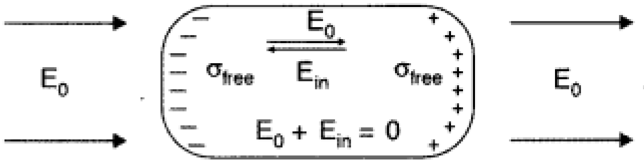
$$\frac{\varepsilon_0 K(l\times b)}{d} = \varepsilon_0 \frac{(l\times b)}{d}\left(\frac{K_1+K_2}{2}\right)$$

$$\therefore \; K = \frac{K_1+K_2}{2}$$

Question 4.
(a) Explain, using suitable diagrams, the difference in the behaviour of a
(i) conductor and
(ii) dielectric in the presence of external electric field. Define the terms polarization of a dielectric and write its relation with susceptibility.
(b) A thin metallic spherical shell of radius R carries a charge Q on its surface. A point charge Q2 is placed at its centre C and another charge +2Q is placed outside the shell at a distance x from the centre as shown in the figure.

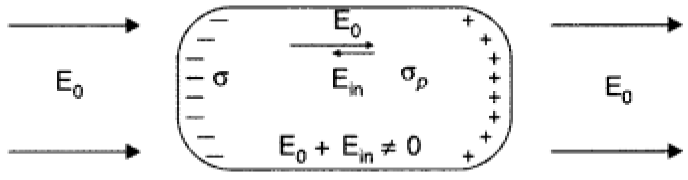


Find
(i) the force on the charge at the centre of shell and at the point A,
(ii) the electric flux through the shell.
Answer:
(a) (i) Behaviour of conductor in an external electric field :



Conductor

(ii) Behaviour of a dielectric in an external electrical field :



Dielectric

Explanation: In the presence of electric field, the free charge carriers in a conductor move the charge distribution and the conductor readjusts itself so that the net Electric field within the conductor becomes zero.
In a dielectric, the external electric field induces a net dipole moment, by stretching / reorienting the molecules. The electric field, due to this induced dipole moment, opposes, but does not exactly cancel the external electric field.

Polarisation: Induced Dipole moment, per unit volume, is called the polarisation. For Linear isotropic dielectrics having a susceptibility x_c, we have polarisation (p) as:
$p = X_cE$
(b) (i) Net Force on the charge y, placed at the centre of the shell, is zero.
Force on charge '2Q' kept at point A,

$$F = E \times 2Q = \frac{1\left(\frac{3Q}{2}\right)2Q}{4\pi\varepsilon_0 x^2} = \frac{(K)3Q^2}{x^2}$$

$$\ldots\left[K = \frac{1}{4\pi\varepsilon_0}\right.$$

(*ii*) Electric flux through the shell,

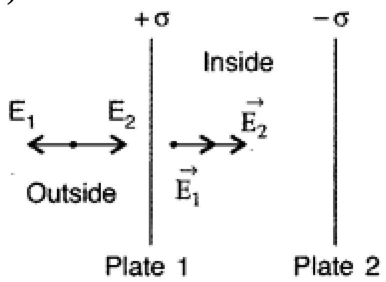
$$\phi = \frac{1}{\varepsilon_0} \times \text{magnitude of the charge enclosed by the shell}$$

$$\phi = \frac{1}{\varepsilon_0} \times \frac{Q}{2}$$

$$\therefore \quad \phi = \frac{Q}{2\varepsilon_0}.$$

Question 5.
(i) If two similar large plates, each of area A having surface charge densities +a and -a are separated by a distance d in air, find the expressions for
(a) field at points between the two plates and on outer side of the plates. Specify the direction of the field in each case.
(b) the potential difference between the plates.
(c) the capacitance of the capacitor so formed.
(ii) Two metallic spheres of radii R and 2R are charged so that both of these have same surface charge density a. If they are connected to each other with a conducting wire, in which direction will the charge flow and why?

Answer:
(i) Given :



(*a*) Inside $\vec{E} = \vec{E}_1 + \vec{E}_2 = \dfrac{\sigma + \sigma}{2\varepsilon_0} = \dfrac{\sigma}{\varepsilon_0}$

Outside $\vec{E} = \vec{E}_2 - \vec{E}_1 = \dfrac{\sigma - \sigma}{2\varepsilon_0} = 0$

(*b*) Potential difference between plates,

$$\mathbf{V} = Ed = \frac{1Qd}{\varepsilon_0 A}$$

(*c*) Capacitance, $C = \dfrac{Q}{V} = \dfrac{\varepsilon_0 A}{d}$

(*ii*) As potential on and inside a charged sphere is given

$$V = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r} = \frac{1}{4\pi\varepsilon_0}\cdot\frac{4\pi r^2\sigma}{r}$$

...[r = radius of sphere)

Now, potential of metallic sphere of radius R is given by,

$$V_R = \frac{Q}{4\pi\varepsilon_0 R} = \frac{\delta(4\pi R^2)}{4\pi\varepsilon_0 R} = \frac{\delta R}{\varepsilon_0} \qquad ...(i)$$

Similarly, potential of metallic sphere of radius 2R is given by,

$$V_{2R} = \frac{Q}{4\pi\varepsilon_0(2R)} = \frac{\delta(4\pi(2R)^2)}{4\pi\varepsilon_0(2R)} = \frac{\delta 2R}{\varepsilon_0} \qquad ...(ii)$$

From (i) and (ii), we know that $V_{2R} > V_R$
Hence, the bigger sphere will be at a higher potential, so charge will flow from bigger sphere to smaller sphere.

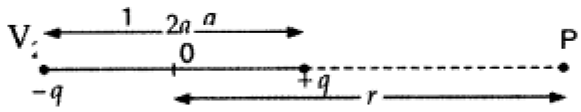
Hence potential at this point

$$V = W = \frac{Q}{4\pi\varepsilon_0 r}$$

(*b*) Potential at point P due to charge $(-q)$

$$V_1 = \frac{-1}{4\pi\varepsilon_0}\frac{q}{(r+a)}$$

Potential due to charge $+q$



Hence total potential at point P

$$V = V_1 + V_2 = \frac{q}{4\pi\varepsilon_0}\left[\frac{-1}{(r+a)} + \frac{1}{(r-a)}\right]$$

$$= \frac{q \times 2a}{4\pi\varepsilon_0 (r^2 - a^2)^2}$$

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

where $\vec{p} = q \times 2a$ = dipole moment

For $r >> a$

$$\Rightarrow \quad V = \frac{1}{4\pi\varepsilon_0}.\frac{p}{r^2} \qquad \Rightarrow V \propto \frac{1}{r^2}.$$

Hence potential at this point

$$V = W = \frac{Q}{4\pi\varepsilon_0 r}$$

(*b*) Potential at point P due to charge $(-q)$

$$V_1 = \frac{-1}{4\pi\varepsilon_0}\frac{q}{(r+a)}$$

Potential due to charge $+q$

Hence total potential at point P

$$V = V_1 + V_2 = \frac{q}{4\pi\varepsilon_0}\left[\frac{-1}{(r+a)} + \frac{1}{(r-a)}\right]$$

$$= \frac{q \times 2a}{4\pi\varepsilon_0 (r^2 - a^2)^2}$$

$$V = \frac{1}{4\pi\varepsilon_0}\cdot\frac{p}{(r^2 - a^2)}$$

where $\vec{p} = q \times 2a =$ dipole moment

For $r >> a$

$$\Rightarrow \quad V = \frac{1}{4\pi\varepsilon_0}\cdot\frac{p}{r^2} \qquad \Rightarrow V \propto \frac{1}{r^2}.$$

7 Marks Question

Q1) Two charges –q and +q, are located at points (0, 0, –a) and (0, 0, a), respectively.
(a) What is the electrostatic potential at the points (0, 0, z) and (x, y, 0)?
(b) Obtain the dependence of potential on the distance r of a point from the origin when r/a >> 1.
(c) How much work is done in moving a small test charge from the point (5,0,0) to (–7,0,0) along the x-axis? Does the answer change if the path of the test charge between the same points is not along the x-axis?

Solution:

(a) Two charges –q and +q, are located at points (0, 0, –a) and (0, 0, a), respectively. They will form a dipole. The point (0, 0, z) is on the axis of the dipole and (x,y,0) is normal to the dipole. The electrostatic potential at (x,y,0) is zero. The electrostatic potential at (0,0,z) is given by

$$V = \frac{1}{4\pi\epsilon_0}\left(\frac{q}{z-a}\right) + \frac{1}{4\pi\epsilon_0}\left(-\frac{q}{z+a}\right)$$

$$V = \frac{q(z+a-z+a)}{4\pi\epsilon_0(z^2-a^2)}$$

$$V = \frac{q(2a)}{4\pi\epsilon_0(z^2-a^2)}$$

$$= \frac{p}{4\pi\epsilon_0(z^2-a^2)}$$

ε_0 = Permittivity of free space

p = dipole moment of the system= q x 2a

(b) The distance “r” is much larger than half of the distance between the two charges. Therefore, the potential at the point r is inversely proportional to the square of the distance, i.e. $V \propto (1/r^2)$.

(c) x,y plane is a equipotential surface and x-axis is a equipotential line. Therefore, the change in potential (dV) along the x-axis will be zero. The work done in moving a small test charge from the point (5,0,0) to (–7,0,0) along the x-axis is given by

Potential at (5,0,0)

$$V_1 = \frac{1}{4\pi\epsilon_0}\left(\frac{q}{\sqrt{(5-0)^2-a^2}}\right) + \frac{1}{4\pi\epsilon_0}\left(-\frac{q}{\sqrt{(5-0)^2-(-a)^2}}\right) = 0$$

Potential at (-7,0,0)

$$V_2 = \frac{1}{4\pi\epsilon_0}\left(\frac{q}{\sqrt{((-7)-0)^2 - a^2}}\right) + \frac{1}{4\pi\epsilon_0}\left(-\frac{q}{\sqrt{((-7)-0)^2 - (-a)^2}}\right) = 0$$

$V_2 - V_1 = 0$

Work done = Charge (q) x Change in Potential ($V_2 - V_1$)

Since the change in potential is zero, the work done is also zero.

The change in potential is independent of the path taken between the two points. Therefore, the work done in moving a point charge will remain zero.

Q 2.) An electrical technician requires a capacitance of 2 μF in a circuit across a potential difference of 1 kV. A large number of 1 μF capacitor are available to him, each of which can withstand a potential difference of not more than 400 V. Suggest a possible arrangement that requires the minimum number of capacitors.

Solution:

Required Capacitance, C= 2μF

Potential difference, V = 1 kV = 1000 V

The capacitance of each capacitor, C_1 = 1μF

Potential difference that the capacitors can withstand, V_1 = 400 V

Suppose a number of capacitors are connected in series and then connected parallel to each other. Then the number of capacitors in each row is given by

1000/400 = 2.5

Therefore, the number of capacitors connected in series is three.

So the capacitance of each row is

Let there be n parallel rows. Each of these rows will have 3 capacitors. Therefore, the equivalent capacitance of the circuit is given as

The required capacitance of the circuit is 2μF

Therefore, n/3 = 2

n = 6

Therefore, there are 6 rows of three capacitors in the circuit. A minimum of 6 x 3 = 18 capacitors are required.

Q 3) What is the area of the plates of a 2 F parallel plate capacitor, given that the separation between the plates is 0.5 cm? [You will realise from your answer why ordinary capacitors are in the range of µF or less. However, electrolytic capacitors do have a much larger capacitance (0.1 F) because of the very minute separation between the conductors.]

Solution:

The capacitance of the parallel plate capacitor, $C = \varepsilon_0 A/d$

The capacitance of the capacitor, C=2 F

Separation between the plates, d= 0.5 cm = 0.5×10^{-2} m

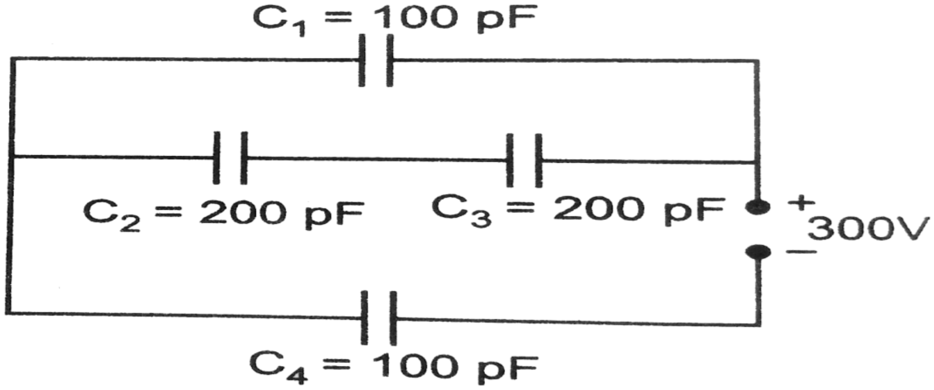
ε_0 = permittivity of the free space = $8.85 \times 10^{-12}\ C^2N^{-1}m^{-2}$

Area of the plates, $A = Cd/\varepsilon_0$

$A = [2 \times 0.5 \times 10^{-2}]/8.85 \times 10^{-12}$

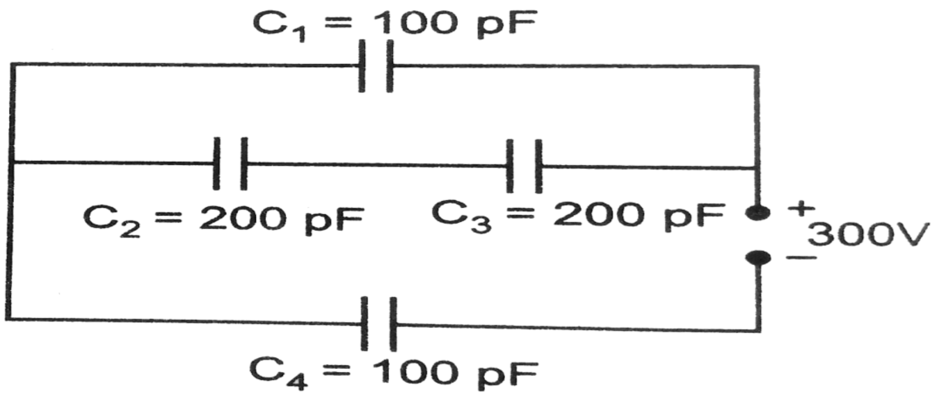
$= 1130 \times 10^6\ m^2$

Q4.) Obtain the equivalent capacitance of the network in Figure. For a 300 V supply, determine the charge and voltage across each capacitor.



Solution:

The above figure can be redrawn as given below



The capacitors C_2 and C_3 are connected in series. The equivalent capacitance C'

$$\frac{1}{C'} = \frac{1}{C_2} + \frac{1}{C_3} = \frac{1}{200} + \frac{1}{200} = \frac{2}{200}$$

C' = 100 pF

The capacitors C' and C_1 are parallel. The equivalent capacitance is C" = C' + C_1

C" = 100 + 100 = 200 pF

C" and C_4 are connected in series. Let the equivalent capacitance be C

$$\frac{1}{C} = \frac{1}{C''} + \frac{1}{C_4} = \frac{1}{200} + \frac{1}{100} = \frac{3}{200}$$

C = 200/3 pF

Hence, the equivalent capacitance of the circuit is 200/3 pF

Total charge, Q = CV =

$$\frac{200}{3} \times 10^{-12} \times 300 = 2 \times 10^{-8} C$$

Q = Q_4 = 2 x 10^{-8} C

Potential difference across C_4, V_4 = Q/C_4

$= (2 \times 10^{-8})/(100 \times 10^{-12}) = 200$ V

Potential difference across C", V" = 300 V – 200 V = 100 V

Potential difference across C_1, V_1 = V" = 100 V

Charge across C_1, $Q_1 = C_1V_1 = (100 \times 10^{-12}) \times 100 = 10^{-8}$ C

The charge across C_2 and C_3, $Q_2 = Q - Q_1 = 2 \times 10^{-8} - 10^{-8}$

$= 10^{-8}$ C

Potential across C_2, $V_2 = Q_2/C_2 = 10^{-8}/ (200 \times 10^{-12}) = 50$ V

Potential across C_3, $V_3 = Q_2/C_3 = 10^{-8}/(200 \times 10^{-12}) = 50$ V

Therefore,

$Q_1 = 10^{-8}$ C , $V_1 = 100$ V

$Q_2 = 10^{-8}$ C, $V_2 = 50$ V

$Q_2 = Q_3 = 10^{-8}$ C, $V_3 = 50$ V

$Q_4 = 2 \times 10^{-8}$ C , $V_4 = 200$ V

Fill in the blanks

1. The process in which a region is made free from any electric field is known as ________________.(**Electrostatic shielding**)

2.The formula for electrostatic potential is_______________________.**(Electrostatic potential = Work done/charge)**

3.1 Volt =___________________style-type: lower-alpha **(1 Joule / 1 Coulomb)**

4.The work done in moving a unit positive test charge over a closed path in anelectric field is___. **(Zero)**

5.The electrostatic potential on the perpendicular bisector due to an electric dipole is ________________ **.(Zero)**

6.A surface that has the same electrostatic potential at every point on it is known as
_______________ . (**Equipotential surface)**

7.The work done against electrostatic force gets stored in which form of energy---------------

(Potential energy)

8.Dielectrics are____________________**(Non-conducting substances)**

Multiple choice questions

1. Which of the following statement is true?
(a) Electrostatic force is a conservative force.
(b) Potential at a point is the work done per unit charge in bringing a charge fromany point to infinity.
(c) Electrostatic force is non-conservative
(d) Potential is the productof charge and work.

Answer: a

2. 1 volt is equivalent to
(a) $\frac{\text{newton}}{\text{second}}$ (b) $\frac{\text{newton}}{\text{coulomb}}$
(c) $\frac{\text{joule}}{\text{coulomb}}$ (d) $\frac{\text{joule}}{\text{second}}$

Answer: c

3. The work done in bringing a unit positive charge from infinite distance to a pointat distance x from a positive charge Q is W. Then the potential at that point is
(a) $\frac{WQ}{x}$ (b) W
(c) $\frac{W}{x}$ (d) WQ

Answer: b

4. Consider a uniform electric field in the z-direction. The potential is a constant
(a) for any x for a given z
(b) for any y for a given z
(c) on the x-y plane for a given z
(d) all of these

Answer: d

5. Equipotential surfaces
(a) are closer in regions of large electric fields compared to regions of lower electricfields.
(b) will be more crowded near sharp edges of a conductor.
(c) will always be equally spaced.
(d) both (a) and (b) are correct.

Answer: d

6. In a region of constant potential
(a) the electric field is uniform.
(b) the electric field is zero.
(c) there can be no charge inside the region.
(d) both (b) and (c) are correct.

Answer: d

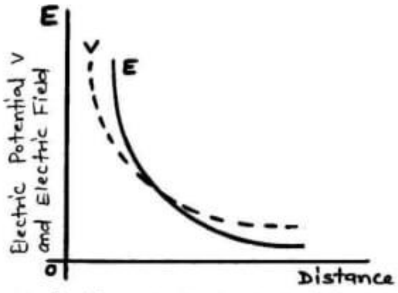
7. An electric dipole of moment $\vec{p}$ is placed in a uniform electric field $\vec{E}$. Then
(i) the torque on the dipole is $\vec{p} \times \vec{E}$
(ii) the potential energy of the system is $\vec{p} . \vec{E}$
(iii) the resultant force on the dipole is zero. Choose the correct option.
(a) (i), (ii) and (iii) are correct
(b) (i) and (iii) are correct and (ii) is wrong
(c) only (i) is correct
(d) (i) and (ii) are correct and (iii) is wrong

Answer: b

Diagrams

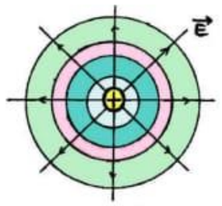
$$V = \frac{q}{4\pi\epsilon_0 r} \qquad V \propto \frac{1}{r}$$

$$E = \frac{q}{4\pi\epsilon_0 r^2} \qquad E \propto \frac{1}{r^2}$$

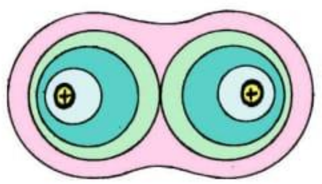


Variation of Electrostatic Potential and Electric field with distance

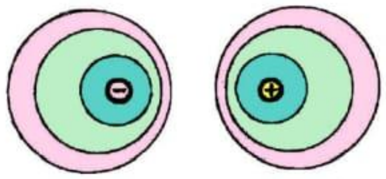
Some equipotential surfaces are shown in figures.



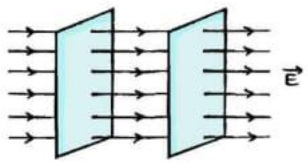
(a) For a point charge



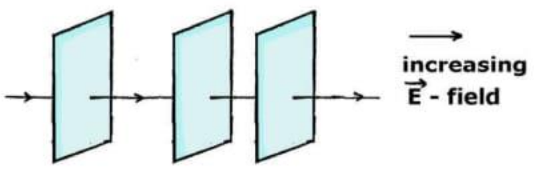
(b) For two identical Positive charges



(c) For an electric dipole

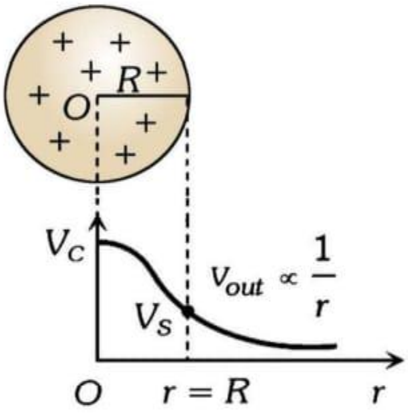


(d) For uniform electric field



(e) For nonuniform electric field.

Electric potential due to an insulating sphere



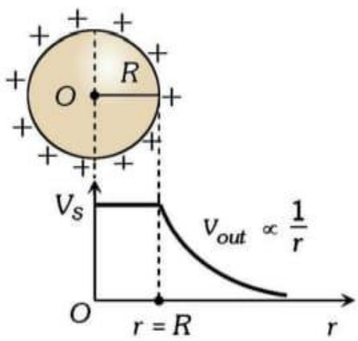
$$\boxed{V_{out} = \frac{q}{4\pi\epsilon_0 r}}$$

$$\boxed{V_s = \frac{q}{4\pi\epsilon_0 R}}$$

$$\boxed{V_{in} = \frac{q}{4\pi\epsilon_0}\left[\frac{3R^2 - r^2}{2R^3}\right]}$$

$$\boxed{V_c = \frac{q}{4\pi\epsilon_0}\left(\frac{3}{2R}\right)}$$

Electric potential due to hollow or conducting sphere

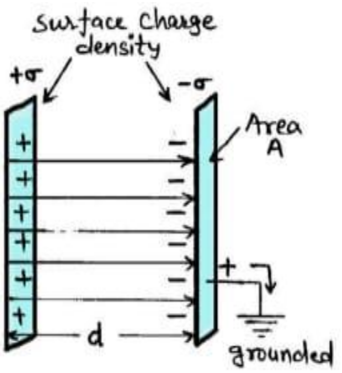


$$\boxed{V_{out} = \frac{q}{4\pi\epsilon_0 r}}$$

$$\boxed{V_s = \frac{q}{4\pi\epsilon_0 R}}$$

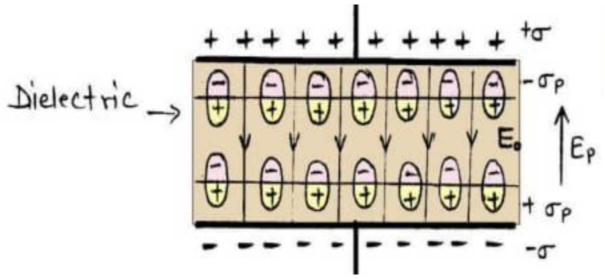
$$\boxed{V_{in} = \frac{q}{4\pi\epsilon_0 R}}$$

Parallel plate Capacitor



$$\boxed{C = \frac{\epsilon_0 A}{d}}$$

Effect of Dielectric an Capacitance

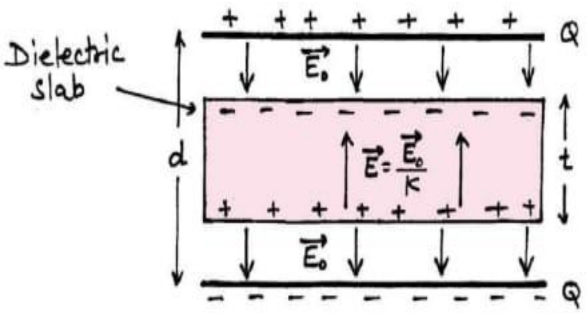


$$\boxed{C = \frac{K\epsilon_0 A}{d}}$$

$$K = \frac{\epsilon}{\epsilon_0}$$

$$\boxed{C = K C_0}$$

Capacitance of a parallel plate capacitor with a dielectric slab



$$\boxed{C = \frac{\epsilon_0 A}{d - t + \frac{t}{K}}}$$

SUMMARY

- **Electrostatic Potential at a Point:**
  It is the work done by per unit charge by an external agency, in bringing a charge from infinity to that point.
- **Electrostatic Potential due to a Charge at a Point:**
  $$V(r) = \frac{2}{4\pi\varepsilon_0}\frac{Q}{r}$$
- The electrostatic potential at a point with position vector r due to a point dipole of dipole moment p place at the origin is
  $$V(r) = \frac{1}{4\pi\varepsilon_0}\frac{\vec{p}.\vec{r}}{r^2}$$
  The result is true also for a dipole (with charges –q and q separated by 2a) for r >> a.
- For a charge configuration q_1, q_2, …… q_n with position vectors r_1, r_2, ….r_n, the potential at a point P is given by the superposition principle,
  $$V = \frac{1}{4\pi\varepsilon_0}\left(\frac{q_1}{r_{1p}} + \frac{q_2}{r_{2p}} + \;.....\; + \frac{q_n}{r_{np}}\right)$$
  where r_{1p} is the distance between q_1, and P, as and so on.
- **Electrostatics Potential Energy Stored in a System of Charges:**
  It is the work done (by an external agency) in assembling the charges at their locations.
- **Electrostatic Potential Energy of Two Charges q_1, q_2, at r_1, r_2:**
  $$U = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r_{12}}$$
  where r_{12} is distance between q_1 and q_2
- **Potential Energy of a Charge q in an External Potential:**
  V(r)= qV(r)
- **Potential Energy of a Dipole of Dipole Moment p in a Uniform Electric Field:**
  E = –p.E.
- **Equipotential Surface:**
  An equipotential surface is a surface over which potential has a constant value.
  a) For a point charge, concentric spheres centered at a location of the charge are equipotential surfaces.
  b) The electric field E at a point is perpendicular to the equipotential surface through the point.
  c) E is in the direction of the steepest decrease of potential.
- **Capacitance C of a System of Two Conductors Separated by an Insulator:**
  It is defined as,
  $$C = \frac{Q}{V}$$

where Q and – Q are the charges on the two conductors V is the potential difference between them.

- Capacitance is determined purely geometrically, by the shapes, sizes, and relative positions of the two conductors.
- **Capacitance C of a parallel plate capacitor (with vacuum between the plates):**

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

where A is the area of each plate and d the separation between them.

- **For capacitors in the series combination:**

The total capacitance C is

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \ldots.$$

- **For capacitors in the parallel combination:**

The total capacitance C is

$$C = C_1 + C_2 + C_3 + \ldots\ldots$$

where C_1, C_2, C_3... are individual capacitances

- **The energy U stored in a capacitor of capacitance C, with charge Q and voltage V:**

$$U = \frac{1}{2}QV = \frac{1}{2}CV^2 = \frac{1}{2}\frac{Q^2}{C}$$

- **The electric energy density (energy per unit volume) in a region with electric field:**

$$(1/2)\varepsilon_0 E^2$$

- **The potential difference between the conductor (radius r_0) inside & outside spherical shell (radius R):**

$$\phi(r_0) - \phi(R) = \frac{q}{4\pi\varepsilon_0}\left(\frac{1}{r_0} - \frac{1}{R}\right)$$

which is always positive.

- **When the medium between the plates of a capacitor filled with an insulating substance:**

Changes observed are as follows:

i. Polarization of the medium gives rise to a field in the opposite direction.
ii. The net electric field inside the insulating medium is reduced.
iii. Potential difference between the plates is thus reduced.
iv. Capacitance C increases from its value when there is no medium (vacuum).

where K is the dielectric constant of the insulating substance.

- **Electrostatic Shielding:**

A conductor has a cavity with no charge inside the cavity, then no matter what happens outside the conductor. Even if there are intense electric fields outside the conductor, the cavity inside has, shielding whatever is inside the cavity from whatever is outside the cavity. This is called electrostatic shielding.