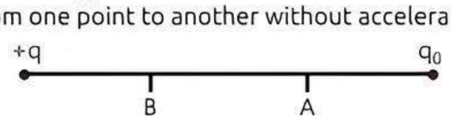
2 Electrostatic Potential and Capacitance

Fastrack Revision

- **Electric Potential:** The electric potential or electrostatic potential at a point in an electric field is the amount of work done in moving a unit positive charge from infinity to that point against the electrostatic forces.
  - It is a scalar quantity.
  - Electric potential $= \dfrac{W}{q}$
  - Its unit is $\dfrac{J}{C}$ = volt (V).
- **Electric Potential Difference:** The electric potential difference between two points (A and B) is defined as the work done (W_{AB}) by external agent in moving a unit charge (q_0) from one point to another without acceleration.



Hence, electric potential difference, $V_B - V_A = \dfrac{W_{AB}}{q_0}$

  - **Electric Potential due to a Point Charge**

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

  - **Electric Potential due to a System of Point Charges:** Potential at a point due to number of charges is equal to the algebraic sum of all the potentials produced at that point due to all charges separately.

$$V = V_1 + V_2 + V_3 + \dots.$$

$$V = \frac{1}{4\pi\varepsilon_0}\left[\frac{q_1}{r_1}+\frac{q_2}{r_2}+\frac{q_3}{r_3}+\cdots\right]$$

  - **Potential on the Axis of a Dipole**
    The electric potential of a dipole,

$$V = \frac{1}{4\pi\varepsilon_0}\frac{\vec{p}\cdot\hat{r}}{r^2}; (r >> l)$$

$$V = \frac{1}{4\pi\varepsilon_0}\frac{p}{r^2-l^2} \qquad [\because \vec{p}\cdot\hat{r} = p\cos\theta]$$

If $r^2 >> l^2$, then $V = \pm\dfrac{1}{4\pi\varepsilon_0}\dfrac{p}{r^2}$

Positive sign for $\theta = 0°$ and negative sign for $\theta = \pi$

  - **Potential at Equatorial Point**

$$V = 0$$

  - **Potential due to Dipole at any General Point**

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

or $\quad V = \dfrac{1}{4\pi\varepsilon_0}\dfrac{\vec{p}\cdot\hat{r}}{r^2}$

or $\quad V = \dfrac{1}{4\pi\varepsilon_0}\dfrac{\vec{p}\cdot\vec{r}}{r^3} \qquad [\because \hat{r} = \dfrac{\vec{r}}{r}]$

- **Equipotential Surfaces:** A surface at which potential of each point is same, is called equipotential surface. *e.g.*, Surface of a charged conductor.

Characteristics of Equipotential Surface

  - Potential difference between any two points on equipotential surface is zero.
  - The direction of electric field near the equipotential surface is always perpendicular to it.
  - Two equipotential surface do not cross each other. If they do, it means two potentials at the same point which is absurd.
  - Electric field is stronger where equipotential surface are close to each other and where they are farther apart, electric field is weaker.
  - **Electric Potential Energy:** Potential energy of a system of charge is defined as the work done in bringing the charge from infinity to its present position without acceleration.
  - **Potential Energy of System of Two Point Charges**

$$U = \frac{1}{4\pi\varepsilon_0 K}\left[\frac{q_1q_2}{r}\right]$$

For air, $K = 1$

$$\therefore \quad U = \frac{1}{4\pi\varepsilon_0}\frac{q_1q_2}{r}$$

  - **Potential Energy of a Dipole in Uniform Electric Field**

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

- **Electrostatics of Conductors:** A conductor is a substance that can be used to carry or conduct electric charges from one place to the another as it contains a large number of free electrons.
  Some of the important results regarding electrostatics of conductor are given below:
  - Electric field inside the charged conductor is zero.
  - Just outside the surface of charged conductor, electric field is perpendicular to the surface.
  - The interior of conductor can have no excess charge in static situation.
  - It behaves as the total charge is concentrated at the centre of the sphere.

- Potential at every point inside the charged conductor is same and is equal to the potential at surface of conductor.

$$E = -\frac{dV}{dr} = 0 \quad \text{or} \quad dV = 0$$

- **Insulator:** Insulator are the substances which do not allow physical movement of electric charges through them when an external electric field is applied.
  For example: diamond, glass, wood, etc.
- **Electric Field at the Surface of Charged Conductor**

$$E = \frac{\sigma}{\varepsilon_0}$$

- **Electrostatic Shielding:** Electrostatic shielding / screening is the phenomenon of protecting a certain region of space from external electric field.

  Application of Electrostatic Shielding

  (i) To protect sensitive electronic devices from external electric field by placing them in metallic boxes.
  (ii) During thunderstorm or lightning, it is safe to sit in the car.
  (iii) Coaxial cable are shielded by metallic wire gauge.
- **Capacitors and Capacitance:** A capacitor is a system of two conductors separated by an insulator. The conductors have charges Q_1 and Q_2 and potentials V_1 and V_2.
  - The total charge of capacitor is zero.
  - The electric field in the region between the conductor is proportional to the charge Q.

    i.e., $V \propto Q$ so, $C = Q/V$

    where, C is called the capacitance of the capacitor.
  - C depends only on geometrical configuration (shape, size and separation).
  - Its SI unit is farad and $1\text{F} = \text{CV}^{-1} = \frac{\text{J}}{\text{V}^2} = \frac{\text{C}^2}{\text{J}}$ etc.
  - Capacitance of an isolated spherical conductor which has radius r, is $C = 4\pi\varepsilon_0 r$.
- **Dielectric Constant:** The dielectric constant of a substance can be defined as the ratio of the permittivity of the substance to the permittivity of the free space.

$$K = \frac{\varepsilon}{\varepsilon_0}$$

  It is a unitless quantity.
- **Dielectric Strength:** The maximum electric field that a dielectric medium can withstand without break-down is called its dielectric strength.
- **Parallel Plate Capacitor:** It comprises of two metal plates of area A separated by distance d. The capacitance of parallel plate capacitor without dielectric medium between plates is given by

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

  where, A = area of plates
  d = distance between plates.
  - When a dielectric medium of dielectric constant K is filled fully between the plates of the capacitor, then

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

- **Capacitance of a Parallel Plate Capacitor with a Conducting Slab Inserted between its Plate**

$$C = \frac{Q}{V} = \frac{\varepsilon_0 A}{\left(d - t + \frac{t}{K}\right)}$$

  where, K = dielectric constant,
  t = thickness of dielectric medium
- **Combination of Capacitors**
  - Capacitors in series: $\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2}$
  - Capacitors in parallel: $C = C_1 + C_2$
- **Energy Stored in a Capacitor**

$$W = \frac{Q^2}{2C} = \frac{1}{2}CV^2 = \frac{1}{2}QV \quad [\because Q = CV]$$

Practice Exercise

Multiple Choice Questions

Q 1. Which of the following statement is not true?
a. Electrostatic force is a conservative force.
b. Potential energy of charge q at a point is the work done per unit charge in bringing a charge from any point to infinity.
c. Spring force and gravitational force are conservative force.
d. Both a. and c.

Q 2. Which of the following is true about electrostatic potential for a point charge?
a. It is inversely proportional to distance.
b. It is the product of charge and work done.
c. Electric field and potential can never be equal in magnitude.
d. Both a. and c.

Q 3. Electric potential due to a point charge $-q$ at distance x from it is given by:
a. Kq/x^2
b. Kq/x
c. $-Kq/x^2$
d. $-Kq/x$

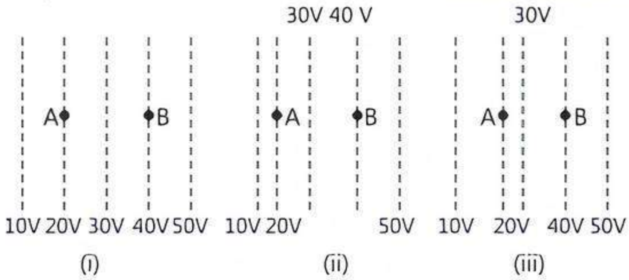
Q 4. The potential at a point, due to a positive charge of 100 μC at a distance of 9 m, is:
a. 10^4 V
b. 10^6 V
c. 10^5 V
d. 10^7 V

Q 5. Three charges 1 μC, 2 μC, 3 μC are kept at vertices of an equilateral triangle of side 1 m. If they are brought nearer, so they now form an equilateral triangle of side 0.5 m, then the work done is:
a. 11 J
b. 1.1 J
c. 0.01 J
d. 0.1 J

Q 6. Which of the following is not the property of an equipotential surface? *(CBSE SQP 2023-24)*

a. They do not cross each other.
b. The work done in carrying a charge from one point to another on an equipotential surface is zero.
c. For a uniform electric field, they are concentric spheres.
d. They can be imaginary spheres.

Q 7. Figures show some equipotential lines distributed in space. A charged object is moved from point A to point B. *(NCERT EXEMPLAR)*



a. The work done in figure (i) is the greatest
b. The work done in figure (ii) is the least
c. The work done is the same in figures (i), (ii) and (iii)
d. The work done in figure (iii) is greater than figure (ii) but equal to that in figure (i)

Q 8. The electric potential on the axis of an electric dipole at a distance r from its centre is V. Then the potential at a point at the same distance on its equatorial line will be: *(CBSE SQP 2022-23)*

a. $2V$ b. $-V$ c. $V/2$ d. zero

Q 9. Equipotentials at a great distance from a collection of charges whose total sum is not zero, are approximately: *(NCERT EXEMPLAR, CBSE 2021 Term-1)*

a. spheres
b. planes
c. paraboloids
d. ellipsoids

Q 10. The electrostatic potential on the surface of a charged conducting sphere is 100 V. Two statements are made in this regard: *(NCERT EXEMPLAR)*

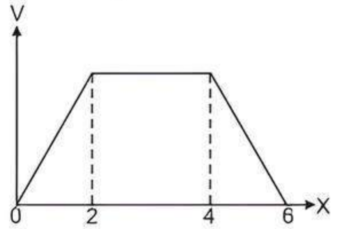
S_1 : At any point inside the sphere, electric intensity is zero.

S_2 : At any point inside the sphere, the electrostatic potential is 100 V.

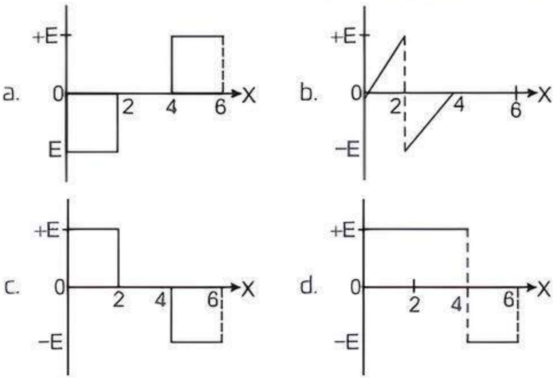
Which of the following is a correct statement?

a. S_1 is true but S_2 is false
b. Both S_1 and S_2 are false
c. S_1 is true, S_2 is also true and S_1 is the cause of S_2
d. S_1 is true, S_2 is also true but the statements are independent

Q 11. The electric potential V as a function of distance X is shown in the figure.



The graph of the magnitude of electric field intensity E as a function of X is: *(CBSE SQP 2022-23)*



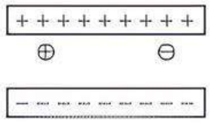
Q 12. Potential difference between any two points on equipotential surface is:

a. zero
b. infinity
c. unity
d. None of these.

Q 13. Which of the following is not the property of equipotential surface?

a. They do not cross each other.
b. The rate of change of potential with distance on them is zero.
c. For a uniform electric field, they are concentric spheres.
d. They can be imaginary spheres.

Q 14. A free electron and a free proton are placed between two oppositely charged parallel plates. Both are closer to the positive plate than the negative plate. See the below figure.



Which of the following statements is true?

I. The force on the proton is greater than the force on the electron.

II. The potential energy of the proton is greater than that of the electron.

III. The potential energy of the proton and the electron is the same.

a. Only I
b. Only II
c. III and I
d. II and I

Q 15. Two charges of magnitude 5 nC and −2 nC, one placed at points (2 cm, 0, 0) and (x cm, 0, 0) in a region of space, where there is no other external field. If the electrostatic potential energy of the system is − 0.5μJ. The value of x is:

a. 20 cm
b. 80 cm
c. 4 cm
d. 16 cm

Q 16. Two point charges +10 μC and −10 μC are separated by a distance of 2 cm in water of dielectric constant 80. The potential energy of the system is:

a. −45J
b. −0.56 J
c. +45 J
d. +0.56 J

Q 17. A conducting sphere of radius R is given a charge Q. The electric potential and the electric field at the centre of the sphere respectively are:

a. zero and $\frac{Q}{4\pi\varepsilon_0 R^2}$ b. $\frac{Q}{4\pi\varepsilon_0 R}$ and zero

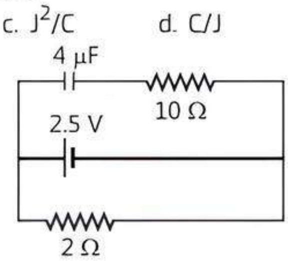
c. $\frac{Q}{4\pi\varepsilon_0 R}$ and $\frac{Q}{4\pi\varepsilon_0 R^2}$ d. Both are zero

Q 18. When a ringing mobile is placed in a stainless steel box, it stops ringing because of:
a. increase in electrical capacitance inside box
b. electrostatic potential induced by the battery of mobile
c. electrostatic shielding provided by box
d. absorption of EM waves by stainless steel box

Q 19. Capacitance depends upon which of the following factors?
a. Size and shape of conductor
b. Permittivity
c. Presence of other conductors nearby
d. All of the above

Q 20. The SI unit of capacitance is:
a. J/C b. Farad c. J^2/C d. C/J

Q 21. A capacitor of 4μF is connected as shown in the circuit. The internal resistance of the battery is 0.5Ω. The amount of charge on the capacitor plates will be: *(NCERT EXEMPLAR)*

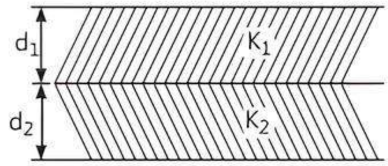


a. 0 b. 4 μC c. 16 μC d. 8μC

Q 22. How we can increase the capacitance of a parallel plate capacitor?
a. By increasing the charge
b. By decreasing the plate area
c. By increasing the plate separation
d. By decreasing the plate separation

Q 23. A parallel plate capacitor is made of two dielectric blocks in series. One of the blocks has thickness d_1 and dielectric constant K_1 and the other has thickness d_2 and dielectric constant K_2 as shown in figure. This arrangement can be thought as a dielectric slab of thickness d ($= d_1 + d_2$) and effective dielectric constant K. Then K is:

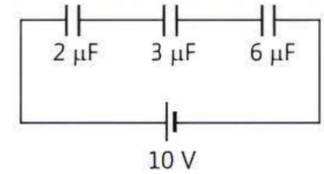
(NCERT EXEMPLAR)



a. $\frac{K_1d_1 + K_2d_2}{d_1 + d_2}$ b. $\frac{K_1d_1 + K_2d_2}{K_1 + K_2}$

c. $\frac{K_1K_2(d_1 + d_2)}{K_2d_1 + K_1d_2}$ d. $\frac{2K_1K_2}{K_1 + K_2}$

Q 24. The charge on 3 μF capacitor shown in the figure is:

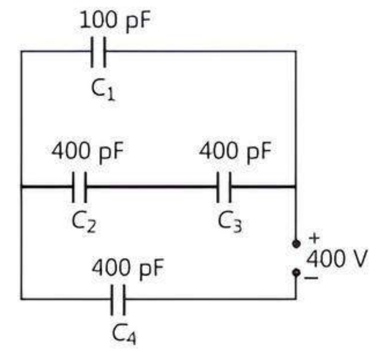


a. 2 μC b. 10 μC c. 6 μC d. 8 μC

Q 25. A 20 μF and a 10 μF capacitor are connected in series and a potential difference is applied across the combination. Then 20 μF capacitor has:
a. twice the charge of the 10μF capacitor
b. half the charge of the 10μF capacitor
c. half the potential difference of 10μF capacitor
d. twice the potential difference of 10μF capacitor

Q 26. Two capacitors of 2 μF and 4 μF are connected in parallel. A third capacitor of 6 μF is connected in series. The combination is connected across a 12 V battery. The voltage across 2μF capacitor is:
a. 2 V b. 8 V c. 6 V d. 1 V

Q 27. The equivalent capacitance for the network shown in the figure is:



a. $\frac{1200}{7}$ pF b. $\frac{1000}{4}$ pF

c. $\frac{1800}{7}$ pF d. $\frac{1300}{3}$ pF

Q 28. Three capacitors 2 μF, 3 μF and 6 μF are joined in series with each other. The equivalent capacitance is:
a. 1/2 μF b. 1 μF
c. 2 μF d. 11 μF

Q 29. A capacitor plates are charged by a battery with 'V' volts. After charging battery is disconnected and a dielectric slab with dielectric constant 'K' is inserted between its plates. The potential across the plates of a capacitor will become:
a. zero b. $V/2$
c. V/K d. KV

Q 30. Two parallel plate capacitors X and Y have the same area of plates and same separation between plates. X has air and Y with dielectric of constant 2 between its plates. They are connected in series to a battery of 12 V. The ratio of electrostatic energy stored in X and Y is:

a. 4 : 1 b. 1 : 4 c. 2 : 1 d. 1 : 2

Assertion & Reason Type Questions

Directions (Q.Nos. 31-39): *In the following questions, a statement of Assertion (A) is followed by a statement of Reason (R). Mark the correct choice as:*

a. Both Assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of Assertion (A).
b. Both Assertion (A) and Reason (R) are true but Reason (R) is not the correct explanation of Assertion (A).
c. Assertion (A) is true but Reason (R) is false.
d. Both Assertion (A) and Reason (R) are false.

Q 31. Assertion (A): Work done in moving a charge between any two points in an electric field is independent of the path followed by the charge, between these points.
Reason (R): Electrostatic force is a non-conservative force.

Q 32. Assertion (A): For a point charge, concentric spheres centered at a location of the charge are equipotential surfaces.
Reason (R): An equipotential surface is a surface over which potential has zero value.

Q 33. Assertion (A): An electron has a higher potential energy when it is at a location associated with a negative value of potential and has a lower potential energy when at a location associated with a positive potential.
Reason (R): Electrons move from a region of higher potential to a region of lower potential.
[CBSE SQP 2023-24]

Q 34. Assertion (A): If the distance between parallel plates of a capacitor is halved and dielectric constant is made three times, then the capacitance becomes six times.
Reason (R): Capacitance of the capacitor does not depend upon the nature of the material of the plates.

Q 35. Assertion (A): The dielectric constant for metals is infinity.
Reason (R): When a charged capacitor is filled completely with a metallic slab, its capacity becomes very large.

Q 36. Assertion (A): When air between the plates of a parallel plate condenser is replaced by an insulating medium of dielectric constant, its capacity increases.
Reason (R): Electric field intensity between the plates with dielectric in between it is reduced.

Q 37. Assertion (A): In a parallel combination of capacitors, the total capacitance of the combination is the sum of capacitance of the individual capacitors.
Reason (R): In such a combination, voltage across each capacitor is same.

Q 38. Assertion (A): If three capacitors of capacitance $C_1 < C_2 < C_3$ are connected in parallel, then their equivalent capacitance $(C_p) >$ equivalent capacitance in series (C_s).

Reason (R): $\frac{1}{C_p} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$

Q 39. Assertion (A): The capacity of a given conductor remains same even if charge is varied on it.
Reason (R): Capacitance depends upon nearly medium as well as size and shape of conductor.

Fill in the Blanks Type Questions

Q 40. Electric field E at a point is perpendicular to the .... surface through the point.

Q 41. The potential energy of a charge q in an electric field placed at potential $V(r)$ is ....

Q 42. It is safer to be inside the car rather than standing outside under a trace during lightening is based on .... concept.

Q 43. Two capacitor plates are charged by a battery. After charging, battery is disconnected and a dielectric slab is inserted between the plates, the charge on the plates of capacitor is ....

Q 44. The amount of work done in bringing a charge q from infinity to a point without acceleration is equal to .... acquired by the charge.

Q 45. Electric field is always .... near to an equipotential surface.

Q 46. The SI unit of capacitance is ....

Answers

1. (b) Potential energy of charge q at a point is the work done per unit charge in bringing a charge from any point to infinity.

2. (a) It is inversely proportional to distance.

Knowledge BOOSTER

Electrostatic potential due to a point charge $= \frac{1}{4\pi\varepsilon_0}\frac{q}{r}$

3. (d) $-Kq/x$

Electric potential at distance x due to charge $-q$ is given by,

$$V = \frac{-q}{4\pi\varepsilon_0 x} = \frac{-Kq}{x} \qquad \left[\because K = \frac{1}{4\pi\varepsilon_0}\right]$$

4. (c) 10^5 V

Here, $q = 100\ \mu C = 100 \times 10^{-6}$ C, $r = 9$ m

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

$$V = \frac{9\times10^9 \times 100\times10^{-6}}{9} = 10^5 \text{ V}$$

COMMON ERR(!)R

Most of students forget to convert cm into m.

5. (c) 0.01 J

Given that, $q_1 = 1\times10^{-6}$ C

$q_2 = 2\times10^{-6}$ C

$q_3 = 3\times10^{-6}$ C

and $r_1 = 1$ m, $r_2 = 0.5$ m

Initial PE of the three charges,

$$U_i = k\frac{q_1q_2 + q_2q_3 + q_1q_3}{r_1}$$

$$= 9\times10^9\left[\frac{1\times2\times10^{-12} + 2\times3\times10^{-12} + 1\times3\times10^{-12}}{1}\right]$$

$$= 99\times10^{-3}\text{J}$$

Final PE of the system

$$U_f = 9\times10^9\left[\frac{1\times2\times10^{-12} + 2\times3\times10^{-12} + 1\times3\times10^{-12}}{0.5}\right]$$

$$= \frac{99\times10^{-3}}{0.5} = 198\times10^{-3}\text{J}$$

Hence, $W = U_f - U_i = (198-99)\times10^{-3}$J

$= 99\times10^{-3}$J $= 0.099 = 0.01$ J

6. (c) For a uniform electric field, they are concentric spheres.

7. (c) The work done is the same in figures (i), (ii) and (iii)

In all the three figures, $V_A = 20$ and $V_B = 40$V

Work done in carrying a charge q from A to B is

$$W = q(V_B - V_A)$$

Hence, work done is same in all figures.

8. (d) zero

The electric potential at a distance 'r' from the dipole is $V = \frac{p\cos\theta}{4\pi\varepsilon_0 r^2}$

where, p = dipole moment.

r = distance of the point from the centre of the dipole

θ = angle between p and r

For point on the equatorial line, $\theta = 2\pi$

So, $V = 0$

9. (a) spheres

For a collection of charges, whose total sum is not zero, equipotentials at large distances must be spheres only.

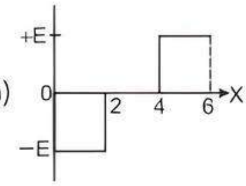
10. (c) S_1 is true, S_2 is also true and S_1 is the cause of S_2.

Potential at any point inside a charged conducting sphere = Potential on the surface

$$V = \frac{kq}{R} = 100 \text{ V}$$

Now, $E = -\frac{dV}{dr} = 0$ [$\because V$ is constant]

11. (a)



12. (a) zero

13. (c) For a uniform electric field, they are concentric spheres.

In uniform electric field, equipotential surfaces are never concentric spheres but are planes perpendicular to electric field lines.

14. (b) Only II

Let force on the proton = F_p

and force on the electron = F_e

We know that, $F = qE$

$\therefore$ $F_p = F_e$ [$\because q_p = q_e$]

The potential energy of the charges is equal in magnitude but positive for proton and negative for electron. For scalars, positive numbers are greater than negative numbers, *i.e.*,

$$(\text{PE})_p > (\text{PE})_e$$

15. (a) 20 cm

Potential energy of system, $U = \frac{1}{4\pi\varepsilon_0}\frac{q_1q_2}{r}$

$$\Rightarrow -0.5\times10^{-6} = \frac{9\times10^9\times5\times10^{-9}\times(-2)\times10^{-9}}{(x-2)\times10^{-2}}$$

$\Rightarrow$ $x = 20$ cm

16. (b) −0.56 J

Potential energy, $U = \frac{1}{4\pi\varepsilon_0}\frac{q_1q_2}{r}$

$$= 9\times10^9\times\frac{10\times10^{-6}\times(-10)\times10^{-6}}{2\times10^{-2}}$$

$$= -\frac{9}{2}\times10^9\times10^{-12}\times10^4$$

$$= -45 \text{ J}$$

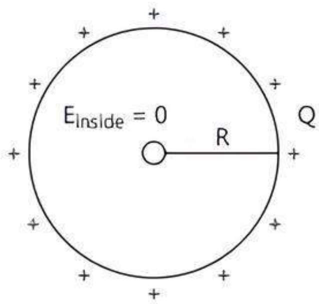
Due to dielectric potential energy $= \frac{U}{K} = -\frac{45}{80}$

$= -0.56$ J

17. (b) $\frac{Q}{4\pi\varepsilon_0 R}$ and zero

Electric field, $E_{\text{inside}} = 0$

and $V_{\text{inside}} = V_{\text{surface}} = \frac{1}{4\pi\varepsilon_0}\frac{Q}{R}$



18. (c) electrostatic shielding provided by box

19. (d) All of the above

20. (b) Farad

21. (d) 8 μC

Current in the lower arm of the circuit.

$$I = \frac{2.5\text{V}}{2\Omega + 0.5\Omega} = 1 \text{ A}$$

Potential difference across the internal resistance of cell $= (0.5\ \Omega)(1\text{A}) = 0.5$ V

and potential difference across the 4μF capacitor

$= 2.5\text{V} - 0.5\text{V} = 2$ V

Charge on the capacitor plates, $Q = CV$

$= (4\mu\text{F})\ (2\text{V}) = 8\ \mu\text{C}$

22. (d) By decreasing the plate separation.

23. (c) $\dfrac{K_1K_2(d_1 + d_2)}{K_2d_1 + K_1d_2}$

For block-1, the capacitance,

$$C_1 = \frac{K_1\varepsilon_0 A}{d_1}$$

Similarly, for block-2, the capacitance,

$$C_2 = \frac{K_2\varepsilon_0 A}{d_2}$$

$\because$ Both dielectric blocks are connected in series, so equivalent capacitance $\dfrac{1}{C} = \dfrac{1}{C_1} + \dfrac{1}{C_2}$

or $$C = \frac{C_1 \times C_2}{C_1 + C_2}$$

$$= \frac{\dfrac{K_1\varepsilon_0 A}{d_1} \times \dfrac{K_2\varepsilon_0 A}{d_2}}{\dfrac{K_1\varepsilon_0 A}{d_1} + \dfrac{K_2\varepsilon_0 A}{d_2}} = \frac{K_1K_2\varepsilon_0 A}{K_1d_2 + K_2d_1} \quad \text{...(1)}$$

$\because$ We know that,

$$C = \frac{K\varepsilon_0 A}{d_1 + d_2} \quad \text{...(2)}$$

On comparing eqs. (1) and (2), we get

$$K = \frac{K_1K_2(d_1 + d_2)}{K_1d_2 + K_2d_1}$$

24. (b) 10 μC

Since, all the capacitors are connected in series, therefore, equivalent capacitance is

$$\frac{1}{C_{eq}} = \frac{1}{2} + \frac{1}{3} + \frac{1}{6} = 1$$

$\because$ $C_{eq} = 1\ \mu\text{F}$

Charge on each capacitor is same. $[\because V = 10\text{V}]$

$Q = C_{eq}V = 1 \times 10 = 10\ \mu\text{C}$

25. (c) half the potential difference of 10μF capacitor

According to the question,

$$C_{eq} = \frac{20 \times 10}{20 + 10} = \frac{200}{30}\mu\text{F}$$

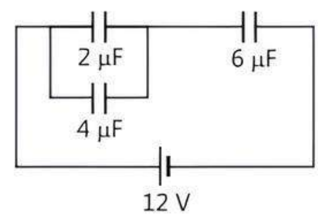
Charge on each capacitor, $Q = C_{eq}V = \left(\dfrac{200}{30}V\right)$

$$V_1 = \frac{\dfrac{200}{30}V}{20} = \frac{V}{3} \Rightarrow V_2 = \frac{\dfrac{200}{30}V}{10} = \frac{2V}{3}$$

Hence, 20μF capacitor has half the potential difference of 10μF capacitor.

26. (c) 6 V

$C_p = 2 + 4 = 6\ \mu\text{F}$



$$\frac{1}{C} = \frac{1}{6} + \frac{1}{6} = \frac{2}{6} = \frac{1}{3} \text{ or } C = 3\ \mu\text{F}$$

Total charge,

$Q = CV = 3 \times 12 = 36\ \mu\text{C}$

Voltage across 6μF capacitor

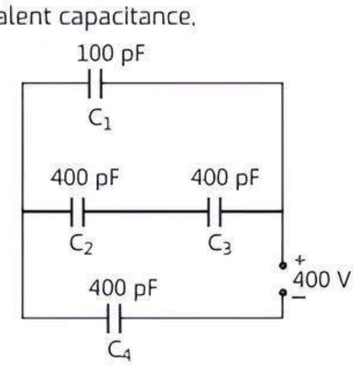
$$= \frac{36\ \mu\text{C}}{6\ \mu\text{F}} = 6 \text{ V}$$

$\therefore$ Voltage across each 2μF and 4μF capacitors $= 12\text{ V} - 6\text{ V}$

$\Rightarrow V = 6\text{V}$

27. (a) $\dfrac{1200}{7}$ pF

Capacitors C_2 and C_3 are connected in series, so equivalent capacitance,



$$\frac{1}{C'} = \frac{1}{400} + \frac{1}{400} = \frac{2}{400} \quad \text{or} \quad C' = 200 \text{ pF}$$

Capacitors C_1 and C' are in parallel then their, equivalent capacitance,

$$C'' = C' + C_1 = 200 + 100 = 300 \text{ pF}$$

Capacitors C'' and C_4 are connected in series.

Equivalent capacitance

$$\frac{1}{C_{eq}} = \frac{1}{C''} + \frac{1}{C_4} = \frac{1}{300} + \frac{1}{400}$$

$$\frac{1}{C_{eq}} = \frac{7}{1200}$$

$$\therefore \quad C_{eq} = \frac{1200}{7} \text{pF}$$

28. (b) $1\ \mu$F

Equivalent capacitance in series,

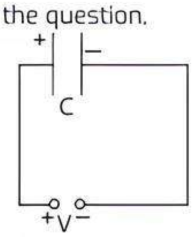
$$\frac{1}{C_s} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

$$\frac{1}{C_s} = \frac{1}{2} + \frac{1}{3} + \frac{1}{6} = \frac{3+2+1}{6} = \frac{6}{6}$$

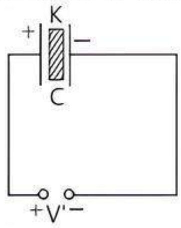
$$\frac{1}{C_s} = 1 \Rightarrow C_s = 1\ \mu\text{F}$$

29. (c) V/K

According to the question,



When battery is disconnected and a dielectric slab with dielectric constant 'K' is inserted between plates.



Initially, charge $Q = CV$

where, C = capacitance of the capacitor without dielectric slab

and V = potential difference

Capacitance of capacitor with dielectric slab,

$C' = KC$

Now charge $Q' = C'V'$

$\therefore Q' = KCV'$

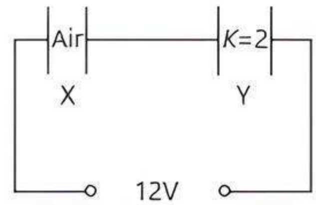
But charge remain constant

$\therefore Q' = Q$

$$\therefore Q = KCV' \text{ or } V' = \frac{Q}{KC} = \frac{V}{K} \qquad \left(\because V = \frac{Q}{C}\right)$$

30. (c) 2 : 1

According to the question,



For capacitor X and Y

A = Same

d = Same

Q = Same in series

Capacitance, $C_X = \dfrac{\varepsilon_0 A}{d}$ and $C_Y = \dfrac{2\varepsilon_0 A}{d}$

Energy, $U_x = \dfrac{Q^2}{2C_X}$ and $U_Y = \dfrac{Q^2}{2C_Y}$

$$\therefore \quad \frac{U_X}{U_Y} = \frac{C_Y}{C_X} = \frac{2C_X}{C_X} = \frac{2}{1} \Rightarrow U_X : U_Y = 2:1$$

31. (c) Electrostatic force is conservative force.

32. (c) An equipotential surface is a surface over which potential is constant.

33. (c) Reason is false because electrons move from a region of lower potential to higher potential.

34. (c) The capacitance C with dielectric between the plates is given by

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

As, $d' = \dfrac{d}{2}$, $K' = 3K$, then new capacitance becomes

$$C' = \frac{\varepsilon_0 3KA}{\frac{d}{2}} \Rightarrow C' = \frac{6\varepsilon_0 KA}{d} = 6C$$

The capacitance C depends upon nature of the material (shape, size and separation) of the conductors.

35. (c) The capacitance of a capacitor filled partially with a dielectric of thickness t is given by

$$C = \frac{\varepsilon_0 A}{d - t(1 - 1/K)}$$

For metals, $K = \infty$

$$\therefore \quad C = \frac{\varepsilon_0 A}{d - t}$$

Now, if the capacitor is filled completely with a metallic slab, then $t = d$.

$\therefore C = \infty$ i.e., when a charged capacitor filled fully with a metallic slab, then capacitor is short circuited i.e., it will no more work as a capacitor.

36. (a) The capacity of a parallel plate condenser is given by,

$$C = \frac{Q}{V} \quad \text{...(1)}$$

Electric field intensity becomes $\frac{1}{K}$ times (as, $K = E_0/E$), therefore potential V also becomes $1/K$ times.
Hence, from eq. (1), capacity becomes K times.
Thus, electric field decreases and capacitance increases when condenser is filled with insulated medium of some dielectric constant.

37. (a) Both Assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of Assertion (A).

38. (c) Equivalent capacitance of parallel combination is $C_p = C_1 + C_2 + C_3$ and in series, it will be $\frac{1}{C_s} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$

39. (a) Capacitance is basically a geometrical quantity.

40. equipotential **41.** $qV(r)$

42. electrostatic shielding **43.** remains same

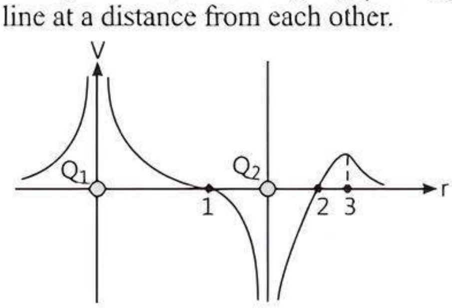
44. electrostatic potential energy

45. perpendicular **46.** farad

Case Study Based Questions

Case Study 1

The potential at any observation point P of a static electric field is defined as the work done by the external agent (or negative of work done by electrostatic field) in slowly bringing a unit positive point charge from infinity to the observation point. Figure shows the potential variation along the line of charges. Two point charges Q_1 and Q_2 lie along a line at a distance from each other.



Read the given passage carefully and give the answer of the following questions:

Q 1. At which of the points 1, 2 and 3 is the electric field zero?

a. 1 b. 2
c. 3 d. Both a. and b.

Q 2. The signs of charges Q_1 and Q_2 respectively are:

a. positive and negative b. negative and positive
c. positive and positive d. negative and negative

Q 3. Which of the two charges Q_1 and Q_2 is greater in magnitude?

a. Q_2 b. Q_1
c. Same d. Can't be determined

Q 4. Which of the following statement is not true?

a. Electrostatic force is a conservative force.
b. Potential energy of charge q at a point is the work done per unit charge in bringing a charge from any point to infinity.
c. When two like charges lie infinite distance apart, their potential energy is zero.
d. Both a. and c.

Q 5. Positive and negative charges of equal magnitude are kept at $\left(0, 0, \frac{a}{2}\right)$ and $\left(0, 0, \frac{-a}{2}\right)$ respectively.

The work done by the electric field when another positive point charge is moved from $(-a, 0, 0)$ to $(0, a, 0)$, is:

a. positive
b. negative
c. zero
d. depends on the path connecting the initial and final positions.

Answers

1. (c) 3

As $\frac{-dV}{dr} = E_r$, the negative of the slope of V *versus* r curve represents the components of electric field along r. Slope of curve is zero only at point 3. Therefore, the electric field vector is zero at point 3.

2. (a) positive and negative

Near positive charge, net potential is positive and near a negative charge, net potential is negative. Thus, charge Q_1 is positive and Q_2 is negative.

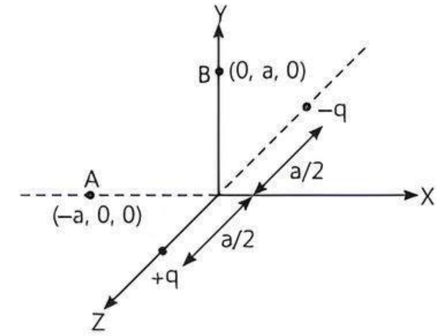
3. (b) Q_1

From the figure, it can be seen that net potential due to two charges is positive everywhere in the region left to charge Q_1. Therefore, the magnitude of potential due to charge Q_1 is greater than due to Q_2.

4. (b) Potential energy of charge q at a point is the work done per unit charge in bringing a charge from any point to infinity.

5. (c) zero

It can be seen that potential at the points both A and B are zero. When the charge is moved from A to B, work done by the electric field on the charge will be zero.



Case Study 2

This energy possessed by a system of charges by virtue of their positions. When two like charges lie infinite distance apart, their potential energy is zero because no work has to be done in moving one charge at infinite distance from the other. In carrying a charge q from point A to point B, work done $W = q(V_A - V_B)$. This work may appear as change in KE/PE of the charge. The potential energy of two charges q_1 and q_2 at a distance r in air is $\frac{q_1 q_2}{4\pi\varepsilon_0 r}$. It is measured in joule. It may be positive, negative or zero depending on the signs of q_1 and q_2.

Read the given passage carefully and give the answer of the following questions:

Q 1. Calculate work done in separating two electrons from a distance of 1 m to 2 m in air, where e is electric charge and K is electrostatic force constant.

a. Ke^2 b. $e^2/2$ c. $-Ke^2/2$ d. zero

Q 2. Two points A and B are located in diametrically opposite directions of a point charge +2 μC at distances 2 m and 1 m respectively from it. The potential difference between A and B is:

a. 3×10^3 V   b. 6×10^4 V
c. -9×10^3 V   d. -3×10^3 V

Q 3. Two points charges $A = +3$ nC and $B = +1$ nC are placed 5cm apart in air. The work done to move charge B towards A by 1 cm is:

a. 2.0×10^{-7} J   b. 1.35×10^{-7} J
c. 2.7×10^{-7} J   d. 12.1×10^{-7} J

Q 4. A charge Q is placed at the origin. The electric potential due to this charge at a given point in space is V. The work done by an external force in bringing another charge q from infinity up to the point is:

a. $\frac{V}{q}$ b. Vq c. $V + q$ d. V

Answers

1. (c) $-Ke^2/2$

$W = (\text{PE})_{\text{final}} - (\text{PE})_{\text{initial}}$

$$= \frac{Ke^2}{2} - \frac{Ke^2}{1} = \frac{-Ke^2}{2}$$

2. (c) -9×10^3 V

Here, $q = 2\mu C = 2 \times 10^{-6}$ C, $r_A = 2$ m, $r_B = 1$ m

$$\therefore V_A - V_B = \frac{q}{4\pi\varepsilon_0}\left[\frac{1}{r_A} - \frac{1}{r_B}\right]$$

$$= 2 \times 10^{-6} \times 9 \times 10^9 \left[\frac{1}{2} - \frac{1}{1}\right] \text{V}$$

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

3. (b) 1.35×10^{-7} J

Given that

$$A = +3 \text{ nC} = 3 \times 10^{-9} \text{ C}$$
$$B = +1 \text{ nC} = 1 \times 10^{-9} \text{ C}$$

Distance $r_1 = 5$ cm $= 5 \times 10^{-2}$ m

and $r_2 = r_1 - 1$
$= 5 - 1 = 4$ cm $= 4 \times 10^{-2}$ m

∴ Required work done = Change in potential energy of the system

$$W = U_f - U_i = K\frac{q_1 q_2}{r_f} - K\frac{q_1 q_2}{r_i}$$

$$= Kq_1q_2\left[\frac{1}{r_f} - \frac{1}{r_i}\right]$$

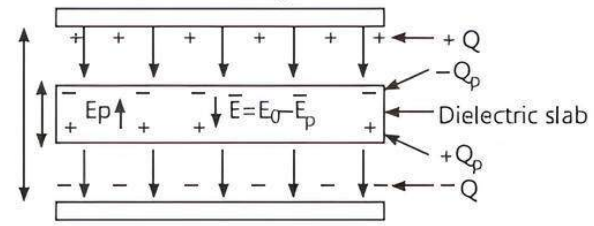
$$\therefore W = (9 \times 10^9)(3 \times 10^{-9} \times 1 \times 10^{-9}) \times \left[\frac{1}{4 \times 10^{-2}} - \frac{1}{5 \times 10^{-2}}\right]$$

$$= 27 \times 10^{-9} \times \frac{1}{20 \times 10^{-2}} = 1.35 \times 10^{-7} \text{ J}$$

4. (b) Vq

Case Study 3

A dielectric slab is a substance which does not allow the flow of charges through it but permits them to exert electrostatic forces on one another. When a dielectric slab is placed between the plates, the field E_0 polarises the dielectric. This induce charge $-Q_p$ on the upper surface are $+Q_P$ on the lower surface of the dielectric. These induced charges set up a field E_p inside the dielectric in the opposite direction of $\vec{E}_0$ as shown.



Read the given passage carefully and give the answer of the following questions:

Q 1. In a parallel plate capacitor, the capacitance increases from 4 μF to 80 μF, on introducing a dielectric medium between the plates. What is the dielectric constant of the medium?

a. 10   b. 20   c. 50   d. 100

Q 2. A parallel plate capacitor with air between the plates has a capacitance of 8 pF. The separation between the plates is now reduced half and the space between them is filled with a medium of dielectric constant 5. Calculate the value of capacitance of the capacitor in second case.

a. 8 pF   b. 10 pF   c. 80 pF   d. 100 pF

Q 3. A dielectric introduced between the plates of a parallel plate condenser:

a. decreases the electric field between the plates
b. increases the capacity of the condenser
c. increases the charge stored in the condenser
d. increases the capacity of the condenser

Q 4. A parallel plate capacitor of capacitance 1 pF has separation between the plates d. When the distance of separation becomes $2d$ and wax of dielectric constant x is inserted in it, the capacitance becomes 2 pF. What is the value of x?

a. 2 b. 4 c. 6 d. 8

Q 5. A parallel plate capacitor having area A and separated by distance d is filled by copper plate of thickness b. The new capacity is:

a. $\dfrac{\varepsilon_0 A}{d+\frac{b}{2}}$ b. $\dfrac{\varepsilon_0 A}{2d}$ c. $\dfrac{\varepsilon_0 A}{d-b}$ d. $\dfrac{2\varepsilon_0 A}{d+\frac{b}{2}}$

Answers

1. (b) 20

Dielectric constant

$$K = \frac{\text{Capacitance with dielectric}}{\text{Capacitance without dielectric}}$$

$$= \frac{80\mu F}{4\mu F} = 20$$

2. (c) 80 pF

Capacitance of the capacitor with air between plates

$$C' = \frac{\varepsilon_0 A}{d} = 8pF$$

With the capacitor filled with dielectric ($K = 5$) between its plates and the distance between the plates is reduced by half, capacitance become

$$C = \frac{\varepsilon_0 KA}{d/2} = \frac{\varepsilon_0 \times 5 \times A}{d/2} = 10\, C' = 10 \times 8 = 80 \text{ pF}$$

3. (d) increases the capacity of the condenser

If a dielectric medium of dielectric constant K is filled completely between the plates, then capacitance increases by K times.

4. (b) 4

$$C = \frac{\varepsilon_0 A}{d} = 1 pF \quad \text{...(1)}$$

$$C' = \frac{X\varepsilon_0 A}{(2d)} = 2 \text{ pF} \quad \text{...(2)}$$

Dividing eq. (2) by eq. (1),

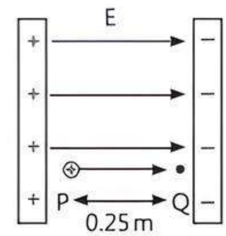
$$\frac{x}{2} = \frac{2}{1} \Rightarrow x = 4$$

5. (c) $\dfrac{\varepsilon_0 A}{d-b}$

As capacitance, $C_0 = \dfrac{\varepsilon_0 A}{d}$

$\therefore$ After inserting copper plate, $C = \dfrac{\varepsilon_0 A}{d-b}$

Case Study 4



Potential difference (ΔV) between two points A and B separated by a distance x in a uniform electric field E is given by $\Delta V = -Ex$, where x is measured parallel to the field lines. If a charge q_0 moves from P to Q, the change in potential energy (ΔU) is given as $\Delta U = q_0 \Delta V$. A proton is released from rest in uniform electric field of magnitude 4.0×10^8 Vm^{-1} directly along the positive X-axis. The proton undergoes a displacement of 0.25 m in the direction of E.

Mass of a proton = 1.66×10^{-27} kg and charge of proton = 1.6×10^{-19}C

Read the given passage carefully and give the answer of the following questions:

Q 1. What will be the change in electric potential of the proton between the points A and B?

Q 2. What will the change in electric potential energy of the proton for displacement from A to B?

Q 3. Calculate the mutual electrostatic potential energy between two protons which are at a distance of 9×10^{-15} m, in $_{92}U^{235}$ nucleus.

Q 4. If a system consists of two charges 4 μC and -3 μC with no external field placed at (–5cm, 0, 0) and (5 cm, 0, 0) respectively, find the amount of work required to separate the two charges infinitely away from each other.

Q 5. As the proton moves from P to Q, then what will happen?

Answers

1. $\Delta V = -E\,\Delta X = -(4 \times 10^8) \times 0.25 = -10^8$ V

2. As, $\Delta U = q\,\Delta V = 1.6 \times 10^{-19} \times (-1.0 \times 10^8)$
$= -1.6 \times 10^{-11}$ J

3. Potential energy, $U = \dfrac{1}{4\pi\varepsilon_0}\dfrac{q_1 q_2}{r}$

$$= \frac{9 \times 10^9 \times 1.6 \times 10^{-19} \times 1.6 \times 10^{-19}}{9 \times 10^{-15}}$$

$$= 2.56 \times 10^{-14} J$$

4. $$U = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r}$$

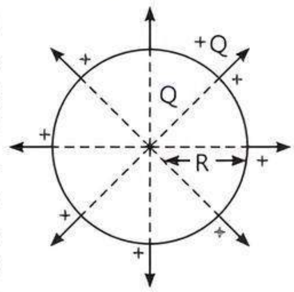
$$= \frac{9 \times 10^9 \times 4 \times 10^{-6} \times (-3) \times 10^{-6}}{0.1} = -1.1 \text{ J}$$

5. As proton moves in the direction of the electric field or from P to Q, then its potential energy decreases.

Case Study 5

The electrical capacitance of a conductor is the measure of its ability to hold electric charge.

An isolated spherical conductor of radius R and charge Q is uniformly distributed over its entire surface. It can be assumed to be concentrated at the centre of the sphere. The potential at any point on the surface of the spherical conductor will be



$$V = \frac{1}{4\pi\varepsilon_0}\frac{Q}{R}$$

Capacitance of the spherical conductor situated in vacuum is

$$C = \frac{Q}{V} = \frac{Q}{\frac{1}{4\pi\varepsilon_0}\cdot\frac{Q}{R}} \quad \text{or } C = 4\pi\varepsilon_0 R$$

Clearly, the capacitance of a spherical conductor is proportional to its radius.

The radius of the spherical conductor is 1F capacitance is $R = \frac{1}{4\pi\varepsilon_0}.C$ and this radius is about 1500 times the radius of earth ($\sim 6 \times 10^3$ km).

Read the given passage carefully and give the answer of the following questions:

Q 1. If an isolated sphere has a capacitance 50 pF, then what is the radius sphere?

Q 2. How much charge should be placed on a capacitance of 25 pF to raise its potential to 10^5 V?

Q 3. Metallic sphere of radius R is charged to potential V. Then charge q is proportional to which parameter?

Q 4. If 64 identical spheres of charge q and capacitance C each are combined to form a large sphere, what will be the charge and capacitance of the large sphere?

Answers

1. Here, $C = 50$ pF $= 50 \times 10^{-12}$ F.

$$R = \frac{1}{4\pi\varepsilon_0}.C = 9 \times 10^9 \text{mF}^{-1} \times 50 \times 10^{-12} \text{ F}$$

$$= 45 \times 10^{-2} \text{m} = 45 \text{ cm}$$

2. As, $q = CV = 25 \times 10^{-12} \times 10^5 = 2.5\mu$C

3. As charge, $q = CV = (4\pi\varepsilon_0 R)V$

$\therefore$ q depends on both V and R. i.e., q is proportional to both R and V.

4. 64 drops have formed a single drop of radius R.

Volume of large sphere = 64 × Volume of small sphere

$$\therefore \quad \frac{4}{3}\pi R^3 = 64 \times \frac{4}{3}\pi r^3$$

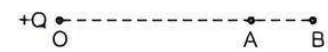
$$\Rightarrow \quad R = 4r \quad \text{and} \quad Q_{total} = 64q$$

$$C = 4\pi\varepsilon_0 R \quad \Rightarrow \quad C' = (4\pi\varepsilon_0)\cdot 4r$$

$$\Rightarrow \quad C' = 4C$$

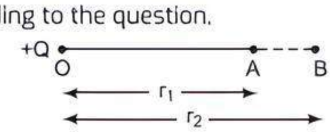
Very Short Answer Type Questions

Q 1. 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?



(CBSE 2016)

Ans. According to the question,



$r_2 > r_1$ (Given)

Potential at point A due to charge + Q, $(V_A) = K\,Q/r_1$

Potential at point B due to charge + Q, $(V_B) = K\,Q/r_2$

As $V_A \propto (1/r_1)$ and $V_B \propto (1/r_2)$ and $r_2 > r_1$ so, $V_A > V_B$.

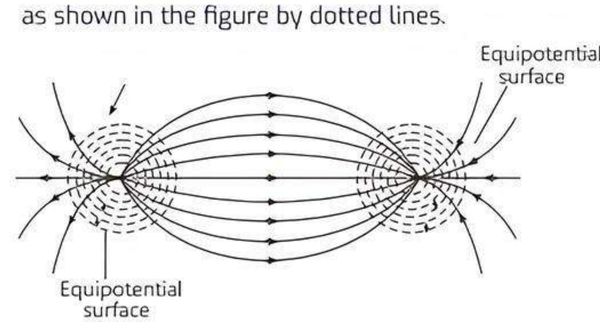
Thus, $(V_A - V_B)$ is positive.

Q 2. Does the charge given to a metallic sphere depend on whether it is hollow or solid? Give reason for your answer. *(CBSE 2017)*

Ans. In case of metallic sphere, charge given to it, is mostly resides on its surface. Therefore, there is no difference whether the sphere is hollow or solid. As in both the cases, the charge that will reside will be same.

Q 3. Draw the equipotential surfaces due to an electric dipole. *(CBSE 2019)*

Ans. The equipotential surfaces for an electric dipole are as shown in the figure by dotted lines.



Q 4. Do electrons tend to go to region of low or high potential?

Ans. Low potential.

Q 5. Can electric potential at any point in space be zero while intensity of electric field at that point is not zero?

Ans. Yes.

Q 6. What is the electric potential of earth?

Ans. Zero.

Q 7. How is displacement current produced between the plates of a parallel plate capacitor during charging? *(CBSE 2020)*

Ans. Displacement current is produced by time varying electric flux and electric field across the dielectric medium between capacitor plates that leads to polarisation and displacement of charges.

Q 8. What is the capacitance of the earth?

Ans. Infinity.

Q 9. Where does the energy of capacitor reside?

Ans. Electric field.

Short Answer Type-I Questions

Q 1. Three charges $-q$, Q and $-q$ are placed at equal distances on a straight line. If the potential energy of the system of these charges is zero, then what is the ratio $Q : q$? *(CBSE SQP 2022-23)*

Sol. The potential energy between the charged particles is given as, $U = K\dfrac{Q_1 Q_2}{d}$

where, $K = \dfrac{1}{4\pi\varepsilon_0}$

Net U = potential energy due to $(-q)$ and (Q)
+ potential energy due to (Q) and $(-q)$
+ potential energy due to $(-q)$ and $(-q)$

$\because \quad U_{net} = 0$

or $\quad U_{net} = \dfrac{K(-q)Q}{x} + \dfrac{KQ(-q)}{x} + \dfrac{K(-q)(-q)}{2x} = 0$

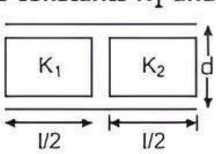
or $\quad \dfrac{-2KqQ}{x} + \dfrac{Kq^2}{2x} = 0$

or $\quad \dfrac{Kq^2}{2x} = \dfrac{2KqQ}{x}$

$\therefore \quad q = 4Q$ or $\dfrac{Q}{q} = \dfrac{1}{4}$

So, the ratio $Q : q = 1 : 4$.

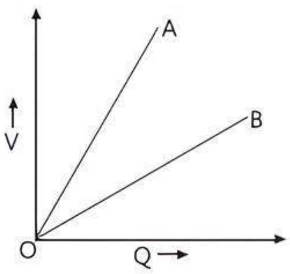
Q 2. Two dielectric slabs of dielectric constants K_1 and K_2 are filled in between the two plates, each of area A, of the parallel plate capacitor as shown. Find net capacitance of the capacitor.



Sol. $$C = C_1 + C_2 = \frac{K_1\varepsilon_0 A/2}{d} + \frac{K_2\varepsilon_0 A/2}{d}$$

$$\Rightarrow \quad C = \frac{\varepsilon_0 A}{2d}(K_1 + K_2) = \frac{\varepsilon_0 A}{d}\left(\frac{K_1 + K_2}{2}\right) = \left(\frac{K_1 + K_2}{2}\right)C_0$$

Q 3. The graph shows the variation of voltage V across the plates of two capacitors A and B versus increase of charge Q stored on them. Which of the capacitor has higher capacitance? Give reason for your answer.



Ans. B has higher capacitance.

Reason: $C = \dfrac{Q}{V}$

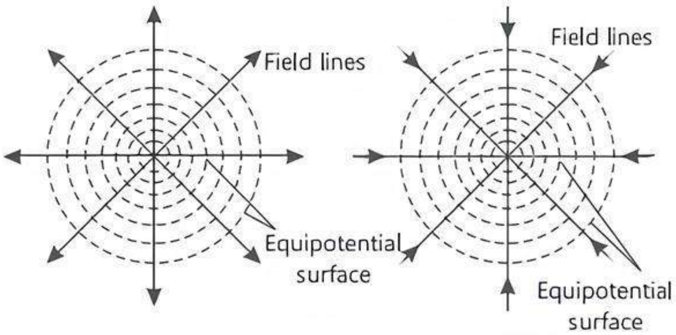
If V = constant, then $C \propto Q$

As $\quad Q_B > Q_A$

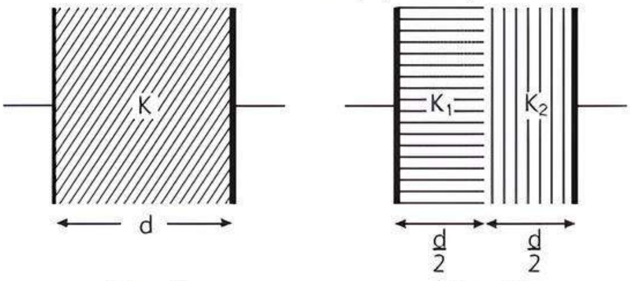
$\Rightarrow \quad C_B > C_A$

Q 4. Draw an equipotential surface and corresponding electric field lines for a single point charge (i) $+Q(Q>0)$ and (ii) $-Q(Q<0)$. *(CBSE 2016)*

Ans. (i) $Q > 0$. (ii) $Q < 0$



Q 5. The space between the plates of a parallel plate capacitor is completely filled in two ways. In the first case, it is filled with a slab of dielectric constant K. In the second case, it is filled with two slabs of equal thickness and dielectric constants K_1 and K_2 respectively as shown in the figure. The capacitance of the capacitor is same in the two cases. Obtain the relationship between K, K_1 and K_2.



(Case 1) (Case 2)

Ans. The capacitance of condenser is proportional to the area and inversely proportional to the distance between its plates. If a medium of dielectric constant K is filled in the space between the plates, its capacitance becomes K times the capacitance when there is air between the plates.

After inserting the dielectric medium, let their capacitances become C_1' and C_2'.

For C_1', $$C_1' = KC = \frac{K\varepsilon_0 A}{d}$$

For C_2', $$C_2' = \left(\frac{2K_1K_2}{K_1+K_2}\right)\frac{\varepsilon_0 A}{d}$$

C_2 acts as if two capacitors each of area $A/2$ and separation d are connected in series combination.

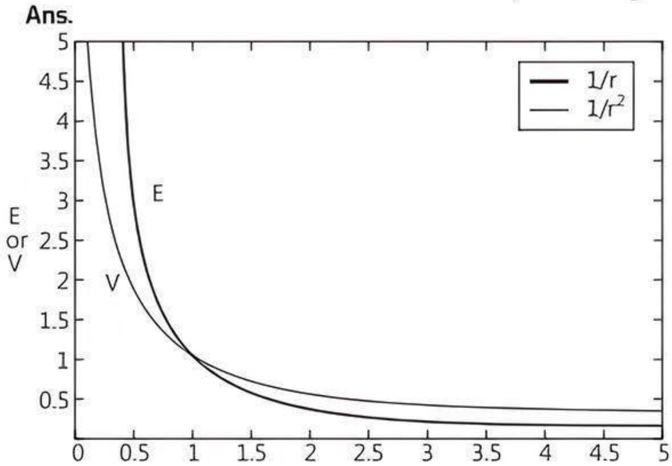
According to the question, $C_1' = C_2'$

$$\Rightarrow \quad \frac{K\varepsilon_0 A}{d} = \left(\frac{2K_1K_2}{K_1+K_2}\right)\frac{\varepsilon_0 A}{d}$$

$$\Rightarrow \quad K = \frac{2K_1K_2}{K_1+K_2}$$

Q 6. Graphically show the variation of electric potential and electric field with distance for a point charge.

Ans.



Q 7. The two charged conductors are touched mutually and then separated. What will be the charge on them?

Ans. The charge on them will be divided in the ratio of the capacitances. We know that $Q = CV$. When the charge conductors touch, they acquire the same potential. Hence, Q is proportional to capacitance.

Q 8. A parallel plate capacitor is charged by a battery to a potential difference V. It is disconnected from battery and then connected to another uncharged capacitor of the same capacitance. Calculate the ratio of the energy stored in the combination to the initial energy on the single capacitor. *(CBSE 2019)*

Sol. Let, the charge on the first capacitor be Q, potential difference be V and capacitance be C, then

Initial potential energy, $U_i = \frac{1}{2}CV^2$ ...(1)

Common potential difference of the combination,

$$V' = \frac{C_1V_1 + C_2V_2}{C_1+C_2}$$

As $V_2 = 0$ and $C_1 = C_2 = C$, then

$$V' = \frac{CV}{2C} = \frac{V}{2}$$

Net capacitance of the combination, $C' = C_1 + C_2 = 2C$

Final potential energy, $U_f = \frac{1}{2}C'V'^2$

$$= \frac{1}{2}(2C)\left(\frac{V}{2}\right)^2 = \frac{CV^2}{4} \quad ...(2)$$

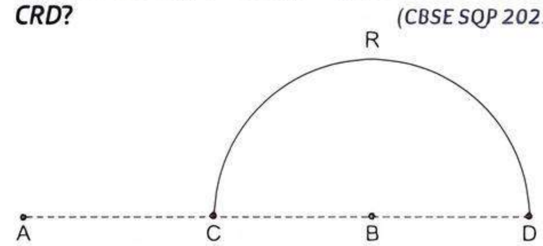
Dividing eq. (2) by eq. (1), we get

$$\frac{U_f}{U_i} = \frac{CV^2}{4} \times \frac{2}{CV^2} = \frac{1}{2}$$

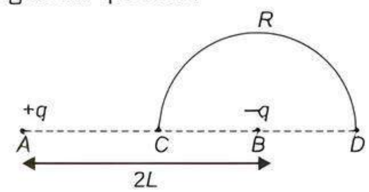
Hence, $U_f : U_i = 1:2$

Short Answer Type-II Questions

Q 1. Charges $(+q)$ and $(-q)$ are placed at the points A and B respectively which are a distance $2L$ apart. C is the mid-point between A and B. What is the work done in moving a charge $+Q$ along the semicircle CRD? *(CBSE SQP 2023-24)*



Sol. According to the question,



From figure, $AC = L$, $BC = L$, $BD = BC = L$

$AD = AB + BD = 2L + L = 3L$

Potential at C is given by

$$V_C = \frac{1}{4\pi\varepsilon_0}\left[\frac{q}{AC} + \frac{(-q)}{BC}\right] = \frac{1}{4\pi\varepsilon_0}\left[\frac{q}{L} - \frac{q}{L}\right] = 0$$

Potential at D is given by

$$V_D = \frac{1}{4\pi\varepsilon_0}\left[\frac{q}{AD} + \frac{(-q)}{BD}\right] = \frac{1}{4\pi\varepsilon_0}\left[\frac{q}{3L} - \frac{q}{L}\right]$$

$$= \frac{1}{4\pi\varepsilon_0}\frac{q}{L}\left[\frac{1}{3} - 1\right] = \frac{-q}{6\pi\varepsilon_0}$$

Work done in moving charge $+Q$ along the semicircle CRD is given by

$$W = (V_D - V_C)(+Q) = \left[\frac{-q}{6\pi\varepsilon_0} - 0\right](Q) = \frac{-qQ}{6\pi\varepsilon_0 L}$$

Q 2. (i) Define an equipotential surface? *(CBSE 2016, 15)*

(ii) Write any two properties of an equipotential surface.

Ans. (i) **Equipotential Surface:** A surface drawn in an electric field at which every point has the same potential is known as equipotential surface.

(ii) **Properties of Equipotential Surface:**

(a) No work is done in moving a test charge from one point to another over an equipotential surface.

(b) Electric field is always normal to the equipotential surface at every point.

(c) Two equipotential surfaces can never intersect each other.

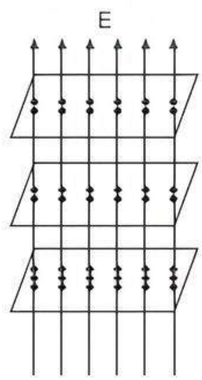
(d) Equipotential surfaces are closer in regions of strong field and farther in regions of weak field. (Any two)

Q 3. (i) Draw equipotential surfaces corresponding to the electric field that uniformly increases in magnitude along with the *Z*-directions.

(ii) Two charges $-q$ and $+q$ are located at points (0, 0 $-a$) and (0, 0, a). What is the electrostatic potential at the points (0, 0, $\pm z$) and (x, y, 0)?

(CBSE 2019)

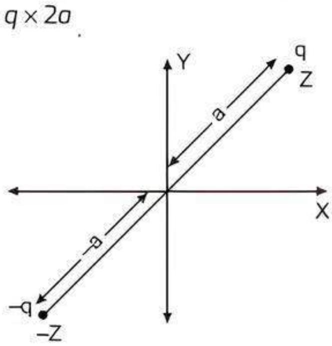
Ans. (i) Equipotential surface in a constant electric field is shown in the figure given below:



(ii) Two charges $-q$ and $+q$ are located at the points (0, 0, $-a$) and (0, 0, a).

It forms an electric dipole with moment

$\vec{p} = q \times 2a$.



Electrostatic potential at the point (0, 0, $\pm z$) is

$$V = \frac{1}{4\pi\varepsilon_0}\frac{q \times 2a}{(z^2 - a^2)}$$

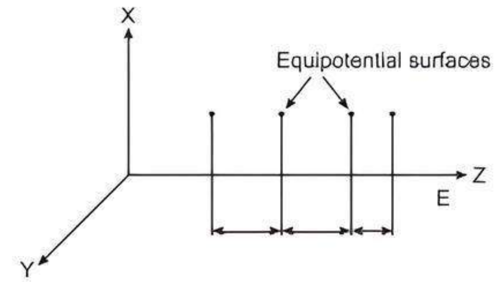
Electrostatic potential at the point (x, y, 0) is

$$V = 0$$

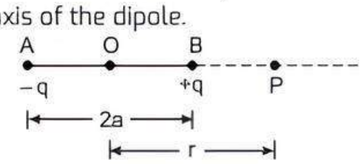
Q 4. (i) Draw the equipotential surfaces corresponding to a uniform electric field in the *Z*-direction.

(ii) Derive an expression for the electric potential at any point along the axial line of an electric dipole. *(CBSE 2019)*

Ans. (i) The equipotential surfaces are plane parallel to *X-Y* plane. As the field is increasing in magnitude, the spacing between surfaces decreases.



(ii) Let us consider an electric dipole consisting of charges $+q$ and $-q$ separated by a distance $2a$. Let O be the centre of dipole and P be a point on the axis of the dipole.



Electric potential at point P due to the dipole will be,

$$V = V_1 + V_2 = \frac{1}{4\pi\varepsilon_0}\frac{(-q)}{AP} + \frac{1}{4\pi\varepsilon_0}\frac{(+q)}{BP}$$

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

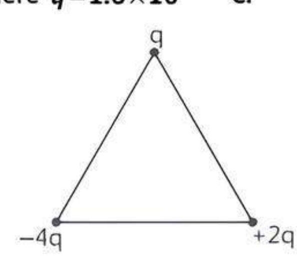
$$= \frac{q}{4\pi\varepsilon_0}\left[\frac{1}{(r-a)} - \frac{1}{(r+a)}\right] = \frac{q}{4\pi\varepsilon_0}\left(\frac{2a}{r^2 - a^2}\right)$$

$$= \frac{1}{4\pi\varepsilon_0}\cdot\frac{p}{r^2 - a^2} \qquad [\because p = q \times 2a]$$

For short dipole $a^2 << r^2$

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

Q 5. Calculate the work done to dissociate the system of three charges placed on the vertices of an equilateral triangle of side 10 cm as shown in figure. Here $q = 1.6 \times 10^{-10}$ C. *(CBSE 2016)*



Sol. Required work done = − potential energy of the system

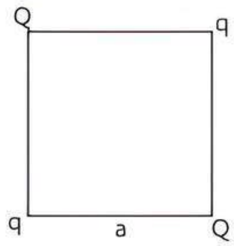
$$W = -\frac{1}{4\pi\varepsilon_0}\left[\frac{q_1 q_2}{r_{12}} + \frac{q_2 q_3}{r_{23}} + \frac{q_3 q_1}{r_{31}}\right]$$

$$\Rightarrow \quad W = -\frac{1}{4\pi\varepsilon_0}\left[\frac{q(-4q)}{a} + \frac{(-4q)(2q)}{a} + \frac{q(2q)}{a}\right]$$

$$\Rightarrow \quad W = -\frac{1}{4\pi\varepsilon_0}\left[-\frac{4q^2}{a} - \frac{8q^2}{a} + \frac{2q^2}{a}\right] = +\frac{1}{4\pi\varepsilon_0}\frac{10q^2}{a}$$

$$\Rightarrow \quad W = 9 \times 10^9 \times \frac{10 \times (1.6 \times 10^{-10})^2}{10 \times 10^{-2}} = 2.304 \times 10^{-8}\ \text{J}$$

Q 6. **Four point charges Q, q, Q and q are placed at the corners of a square of side a as shown in figure.**

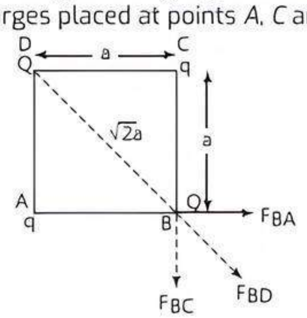


Find the:

(i) resultant electric force on a charge Q and

(ii) potential energy of this system. *(CBSE 2018)*

Sol. (i) Force acting on charge Q placed at point B, is due to charges placed at points A, C and D.

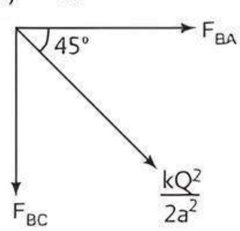


Here, magnitude of force on charge at point B due to charge at point A is $F_{BA} = \frac{kQq}{a^2}$

Similarly, magnitude of force on charge at point B due to charge at point C is $F_{BC} = \frac{kQq}{a^2}$

Also, the magnitude of force on charge at point B due to charge at point D is

$$F_{BD} = \frac{kQ^2}{(\sqrt{2}a)^2} = \frac{kQ^2}{2a^2}$$



Let F is resultant of F_{BA} and F_{BC}.

$$\therefore \quad F = \sqrt{2}\cdot\frac{kQq}{a^2} \qquad \left[\because F_{BA} = F_{BC} = \frac{kQq}{a^2}\right]$$

$\therefore$ The resultant electric force on charge Q is

$$F_{net} = F + \frac{kQ^2}{2a^2} = \sqrt{2}\frac{kQq}{a^2} + \frac{kQ^2}{2a^2}$$

$$= \frac{KQ}{a^2}\left(\sqrt{2}q + \frac{Q}{2}\right) \text{N}$$

(ii) The potential energy of the system is given by

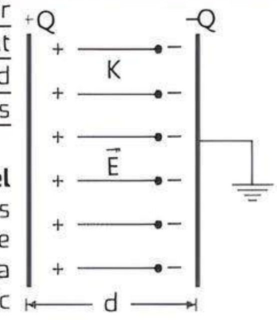
$$U = U_{AB} + U_{BC} + U_{CD} + U_{DA} + U_{AC} + U_{BD}$$

$$= \frac{kQq}{a} + \frac{kQq}{a} + \frac{kQq}{a} + \frac{kQq}{a} + \frac{kq^2}{\sqrt{2}a} + \frac{kQ^2}{\sqrt{2}a}$$

$$= \left[4\left(\frac{kQq}{a}\right) + \frac{kq^2}{\sqrt{2}a} + \frac{kQ^2}{\sqrt{2}a}\right]$$

Q 7. **What is a capacitor? Deduce an expression for the capacitance of a parallel plate capacitor with air as the medium between the plates.** *(CBSE 2017)*

Ans. Capacitor is an arrangement required to increase the capacity of a conductor so that a large amount of charge can be stored in it without changing its dimensions.



Capacitance of parallel plate capacitor: Let us consider a parallel plate capacitor filled with a medium of dielectric constant K as shown in the figure.

Electric field between the plates is

$$E = \frac{\sigma}{\varepsilon_0 K} = \frac{Q}{\varepsilon_0 KA}$$

$\Rightarrow$ Potential difference between the plates is

$$V = E\cdot d = \frac{Qd}{\varepsilon_0 KA}$$

$$\Rightarrow \quad C = \frac{Q}{V} = \frac{Q}{\frac{Qd}{\varepsilon_0 KA}} = K\frac{\varepsilon_0 A}{d}$$

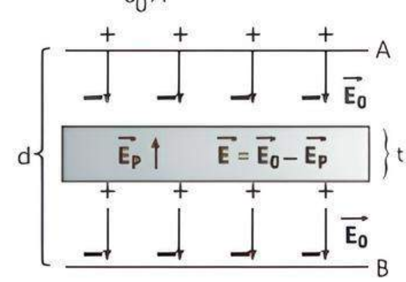
If air is as the medium between the plates, then $K = 1$.

$$\Rightarrow \quad C_0 = \frac{\varepsilon_0 A}{d}$$

Q 8. **A dielectric slab of thickness 't' is introduced without touching between the plates of a parallel plate capacitor separated by a distance 'd' ($t < d$). Derive an expression for the capacitance of the capacitor.**

Ans. Electric field between the plates in air is

$$E_0 = \frac{Q}{\varepsilon_0 A}$$



Electric field in dielectric slab.

$$E = E_0 - E_p = E_0 - \frac{\sigma_p}{\varepsilon_0} = \frac{E_0}{K} = \frac{Q}{\varepsilon_0 KA}$$

$\Rightarrow$ Potential difference between the plates is

$$V = E_0(d-t) + \frac{E_0}{K}t = E_0\left[(d-t) + \frac{t}{K}\right] = \frac{Q}{\varepsilon_0 A}\left[(d-t) + \frac{t}{K}\right]$$

$$\Rightarrow \quad C = \frac{Q}{V} = \frac{Q}{\frac{Q}{\varepsilon_0 A}\left[(d-t)+\frac{t}{K}\right]} \Rightarrow C = \frac{\varepsilon_0 A}{(d-t) + \frac{t}{K}}$$

Q 9. **A 200 μF parallel plate capacitor having plate separation of 5 mm is charged by a 100 V DC source. It remains connected to the source. Using an insulated handle, the distance between the plates is doubled and a dielectric slab of thickness 5 mm and dielectric constant 10 is introduced between the plates. Explain with reason, how the (i) capacitance, (ii) electric field between the plates and (iii) energy density of the capacitor will change?** *(CBSE 2019)*

Ans. Given, $C = 200\ \mu F$, $d = 5$ mm, $t = 5$ mm, $V = 100$ V

(i) $C = \frac{\varepsilon_0 A}{d} \Rightarrow A = \frac{Cd}{\varepsilon_0}$

$$A = \frac{200\times10^{-6}\times5\times10^{-3}}{8.85\times10^{-12}} = 112.99\times10^{3}\ m^2$$

When $d' = 2d$, then new capacitance

$$C' = \frac{\varepsilon_0 A}{2d - t + \frac{t}{K}}$$

$$= \frac{8.85\times10^{-12}\times112.99\times10^{3}}{\left(10-5+\frac{5}{10}\right)\times10^{-3}}$$

$$= 181.8\times10^{-6} = 181.8\ \mu F$$

(ii) Charge on capacitor, $q = C_0 V_0$

$$= 200\times10^{-6}\times100$$
$$= 2\times10^{-2}\ C$$

$\Rightarrow$ $C_0 V_0 = C' V'$

or $V' = \frac{C_0 V_0}{C'} = \frac{2\times10^{-2}}{181.8\times10^{-6}} = 110$ V

$$E_0 = \frac{V_0}{d} = \frac{100}{5\times10^{-3}} = 20\times10^{3}\ V/m$$

Change in electric field,

$$E' = \frac{V'}{2d} = \frac{110}{10\times10^{-3}} = 11\times10^{3}\ V/m$$

(iii) $\bar{U} = \frac{1}{2}\varepsilon_0 E_0^2 = \frac{1}{2}\times8.85\times10^{-12}\times(20\times10^{3})^2$

$$= 1770\times10^{-6}\ J/m^3$$

$\Rightarrow$ Now new energy density $(\bar{U})' = \frac{1}{2}\times\varepsilon_0(E')^2$

$$= \frac{1}{2}\times8.85\times10^{-12}\times(11\times10^{3})^2$$

$$= 535.42\times10^{-6}\ J/m^3$$

Long Answer Type Questions

Q 1. **(i) Draw equipotential surfaces for (a) an electric dipole and (b) two identical positive charges placed near each other.**

(ii) In a parallel plate capacitor with air between the plates, each plate has an area of $6\times10^{-3} m^2$ and the separation between the plates is 3 mm.

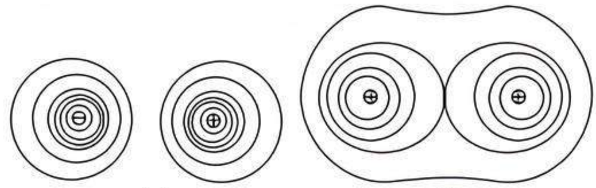
(a) Calculate the capacitance of the capacitor.

(b) If the capacitor is connected to 100 V supply, what would be the charge on each plate?

(c) How would charge on the plate be affected if a 3 mm thick mica sheet of $k = 6$ is inserted between the plates while the voltage supply remains connected?

(CBSE SQP 2022, 23)

Ans. (i) Equipotential surfaces for an electric dipole and two identical positive charges are given as:



(a) (b)

Equipotential surface for (a) an electric dipole, (b) two identical positive charge

(ii) Given, area of plate, $A = 6\times10^{-3}\ m^2$

Separation between the plates, $d = 3$ mm $= 3\times10^{-3}$ m

(a) Capacitance, $C = \varepsilon_0 A/d$

$$= (8.85\times10^{-12}\times6\times10^{-3}/3\times10^{-3})$$
$$= 17.7\times10^{-12}\ F.$$

(b) Given, voltage supply, $V = 100$ V

$\therefore$ Charge, $Q = CV = 17.7\times10^{-12}\times100$
$$= 17.7\times10^{-10}\ C$$

(c) $\because$ A sheet of thick mica with k = 6 is inserted.

$\therefore$ New charge $Q' = kQ = 6\times17.7\times10^{-10}$
$$= 1.062\times10^{-8}\ C$$

Q 2. **(i) Find the expression for the potential energy of a system of two point charges q_1 and q_2 located at $\vec{r_1}$ and $\vec{r_2}$, respectively in an external electric field $\vec{E}$.**

(ii) Draw equipotential surfaces due to an isolated point charge $(-q)$ and depict the electric field lines.

(iii) Three point charges $+1\mu C, -1\mu C$ and $+2\mu C$ are initially infinite distance apart. Calculate the work done in assembling these charges at the vertices of an equilateral triangle of side 10 cm. *(CBSE 2020)*

Ans. (i) Work done in bringing q from infinity against the field E.

$$W_1 = q_1 V|\vec{r_1}|$$

Work done on q_2 against field E,

$$W_2 = q_2 V|\vec{r_2}|$$

Work done on q_2 against the field due to q_1.

$$W_3 = \frac{q_1 q_2}{4\pi\varepsilon_0 (r_{12})}$$

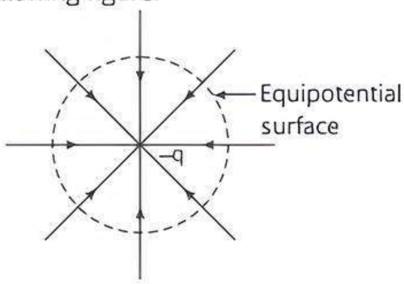
Potential energy of the system

= Total work done in assembling the system

$$= W_1 + W_2 + W_3$$

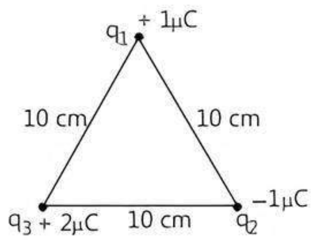
$$= q_1 V|\vec{r_1}| + q_2 V|\vec{r_2}| + \frac{q_1 q_2}{4\pi\varepsilon_0 (r_{12})}$$

(ii) The equipotential surface due to an isolated point charge $(-q)$ and electric field lines are shown in the following figure:



(iii) Work done = Change in potential energy

$$=\frac{Kq_1q_2}{r_{12}}+\frac{Kq_1q_3}{r_{13}}+\frac{Kq_2q_3}{r_{23}} \quad ...(1)$$



Given, $r_{12}=r_{13}=r_{23}=10\text{cm}=0.1\text{m}$

$q_1=+1\,\mu\text{C}=1\times10^{-6}\text{C}$

$q_2=-1\times10^{-6}\text{C}$

and $q_3=2\times10^{-6}\text{C}$

$\therefore$ $K=9\times10^{9}\ \text{Nm}^2\text{C}^{-2}$

Putting these values in eq. (1), we get

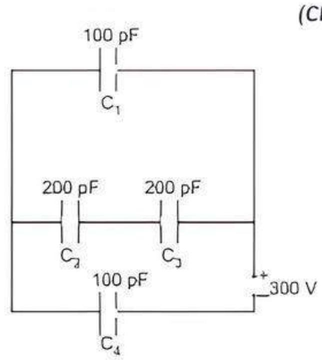
$$\text{Work done}=\frac{9\times10^{9}\times10^{-6}}{0.1}[1\times(-1)+(-1)\times2+1\times2]$$

$$=9\times10^{4}(-1-2+2)=-9\times10^{4}\ \text{J}$$

Q 3. (i) Derive an expression for the capacitance of a parallel plate capacitor with air present between the two plates.

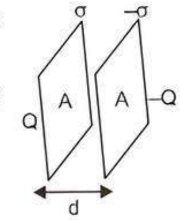
(ii) Obtain the equivalent capacitance of the network shown in figure. For a 300V supply, determine the charge on each capacitor.

(CBSE SQP 2023-24)



Ans. (i) Let the two plates be kept parallel to each other separated by a distance d and cross-sectional area of each plate is A. Electric field by a single thin plate $E=\sigma/2\varepsilon_0$

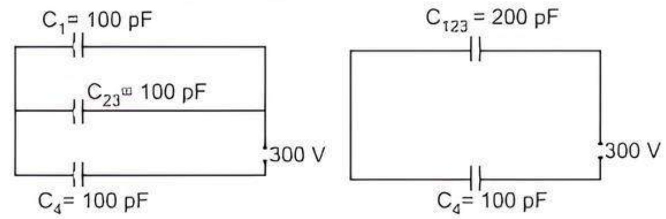
Total electric field between the plates $E=\sigma/\varepsilon_0=Q/A\varepsilon_0$



Potential difference between the plates $V=Ed=[Q/A\varepsilon_0]\,d$.

Capacitance $C=Q/V=A\varepsilon_0/d$

(ii) By simplifying given network,



The equivalent capacitance $=\frac{200}{3}\text{pF}$

Charge on $C_4=\frac{200}{3}\times10^{-12}\times300=2\times10^{-8}C.$

Potential difference across

$$C_4=\frac{200\times10^{-12}\times300}{3\times100\times10^{-12}}=200\text{ V}$$

Potential difference across $C_1=300-200=100$ V

Charge on $C_1=100\times10^{-12}\times100=1\times10^{-8}$ C

Potential difference across C_2 and C_3 in series combination = 100 V

Potential difference across C_2 and C_3 each = 50 V

Charge on C_1 and C_3 each $=200\times10^{-12}\times50$

$=1\times10^{-8}$C

Q 4. A capacitor of capacitance C_1 is charged to a potential V_1 while another capacitor of capacitance C_2 is charged to a potential difference V_2. The capacitors are now disconnected from their respective charging batteries and connected in parallel to each other.

(i) Find the total energy stored in the two capacitors before they are connected.

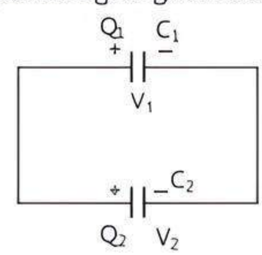
(ii) Find the total energy stored in the parallel combination of the two capacitors.

(iii) Explain the reason for the difference of energy in parallel combination in comparison to the total energy before they are connected.

(CBSE 2019)

Ans. Let two capacitors of capacitances C_1 and C_2 of potentials V_1 and V_2 are connected in parallel.

According to the figure given below:



After connecting the charges redistribute in such a way that the potential differences across C_1 and C_2 become equal.

Hence, before connection, charges are

$$Q_1 = C_1V_1, Q_2 = C_2V_2$$

Common potential after connection,

$$V = \frac{Q_1+Q_2}{C_1+C_2}$$

Hence, $$V = \frac{C_1V_1+C_2V_2}{C_1+C_2} \quad ...(1)$$

After sharing, let the charges be Q'_1 and Q'_2.

$$\Rightarrow \quad \frac{Q'_1}{Q'_2} = \frac{C_1V}{C_2V} = \frac{C_1}{C_2} \quad ...(2)$$

(i) Hence, the total energy stored in the two capacitors before they are connected together will be

$$U = U_1+U_2 = \frac{1}{2}C_1V_1^2 + \frac{1}{2}C_2V_2^2 \quad ....(3)$$

(ii) When the two capacitors are connected in parallel together, total charge on the capacitor,

$$Q = Q_1 + Q_2 = C_1V_1 + C_2V_2$$

Total capacitance, $C = C_1 + C_2$

Hence, total energy after they are connected parallel.

$$U' = \frac{1}{2}\frac{Q^2}{C} = \frac{1}{2}\frac{(C_1V_1+C_2V_2)^2}{C_1+C_2} \quad ...(4)$$

(iii) Subtracting eq. (4) from eq. (3), we get

$$U-U' = \left(\frac{1}{2}C_1V_1^2+\frac{1}{2}C_2V_2^2\right) - \frac{1}{2}\frac{(C_1V_1+C_2V_2)^2}{C_1+C_2}$$

$$\Delta U = \frac{C_1C_2(V_1-V_2)^2}{2(C_1+C_2)}$$ is a positive quantity.

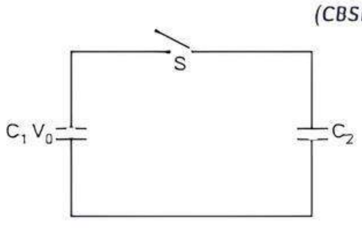
where, ΔU is the loss of energy in sharing charges.

Since ΔU is positive, there is always a loss of energy arises. Hence, when two charged capacitors are connected together, energy loss comes in the form of heat radiations due to electric current while charging.

Q 5. (i) A dielectric slab of thickness 't' is kept between the plates of a parallel plate capacitor with plate separation 'd' ($t < d$). Derive the expression for the capacitance of the capacitor.

(ii) A capacitor of capacity C_1 is charged to the potential of V_0. On disconnecting with the battery, it is connected with an uncharged capacitor of capacity C_2 as shown in the adjoining figure. Find the ratio of energies before and after the connection of switch S.

(CBSE SQP 2023-24)



Ans. (i) Let A is the area of the two plates of the parallel plate capacitor and d is the separation between them. A dielectric slab of thickness $t < d$ and area A is kept between the two plates. The total electric field inside the dielectric slab will be,

$$E = \frac{E_0}{K} = E_0 - E'$$

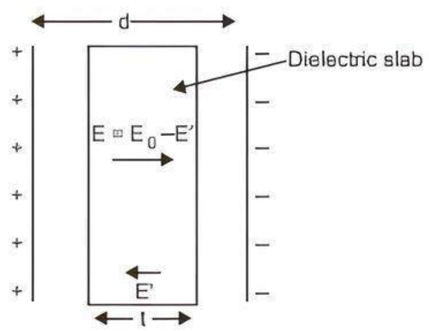
where, E' is the opposite field developed inside the slab due to polarisation of slab. Total potential difference between the plates,

$$V = E_0(d-t) + Et$$

$$= \frac{\sigma}{\varepsilon_0}(d-t) + \frac{\sigma}{K\varepsilon_0}t$$

$$= \frac{\sigma}{\varepsilon_0}\left[(d-t)+\frac{t}{K}\right]$$

$$V = \frac{q}{A\varepsilon_0}\left[(d-t)+\frac{t}{K}\right]$$



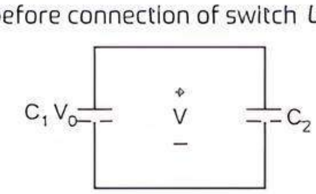
where, q is the charge on each plate.

Since, $C = \frac{q}{V}$

or $$C = \frac{q}{\frac{q}{A\varepsilon_0}\left[(d-t)+\frac{t}{K}\right]}$$

or $$C = \frac{A\varepsilon_0}{\left[(d-t)+\frac{t}{K}\right]}$$

(ii) Energy before connection of switch $U_1 = \frac{1}{2}C_1V_0^2$



After connecting switch,

$$C_1V_0 = (C_1 + C_2)V$$

$$V = \frac{C_1V_0}{C_1+C_2}$$

$$U_2 = \frac{1}{2}(C_1+C_2)\frac{C_1^2V_0^2}{(C_1+C_2)^2} = \frac{1}{2}\frac{C_1^2V_0^2}{(C_1+C_2)}$$

$\therefore$ Ratio of energies $$\frac{U_1}{U_2} = \frac{1/2\,C_1V_0^2}{1/2\,\frac{C_1^2V_0^2}{(C_1+C_2)}}$$

$$\frac{U_1}{U_2} = \frac{C_1+C_2}{C_1}$$

Chapter Test

Multiple Choice Questions

Q 1. What is not true for equipotential surface for uniform electric field?

a. Equipotential surface is flat
b. Two equipotential surfaces can cross each other
c. Electric lines are perpendicular to equipotential surface
d. Work done is zero

Q 2. A point *P* lies at a distance *x* from the mid-point of an electric dipole on its axis. The electric potential at point *P* is proportional to: *(CBSE 2023)*

a. $\frac{1}{x^2}$ b. $\frac{1}{x^3}$ c. $\frac{1}{x}$ d. $\frac{1}{x^{1/2}}$

Assertion and Reason Type Questions

Directions (Q.Nos. 3-4): *In the following questions, a statement of Assertion (A) is followed by a statement of Reason (R). Mark the correct choice as:*

a. Both Assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of Assertion (A).
b. Both Assertion (A) and Reason (R) are true but Reason (R) is not the correct explanation of Assertion (A).
c. Assertion (A) is true but Reason (R) is false.
d. Both Assertion (A) and Reason (R) are false.

Q 3. Assertion (A): Electric potential of the earth is zero.
Reason (R): The electric field due to the Earth is zero.

Q 4. Assertion (A): If distance between the parallel plates of a capacitor is halved, then its capacitance is doubled.
Reason (R): The capacitance depends on the introduced dielectric.

Fill in the blanks

Q 5. Dimension of capacitance is ....

Q 6. In a charged capacitor, the energy resides in the .... between the plates.

Case Study Based Question

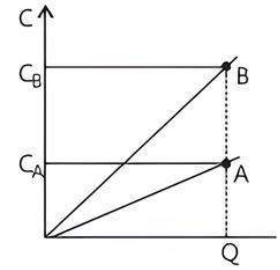
Q 7. A device that stores electrical energy in an electric field is known as to be capacitor. It is a passive electronic component with two terminals. It basically consists of two conductors separated by a non-conductive region. This non-conductive region can either be a vacuum or an electrical insulator material known as a dielectric. From Coulomb's law, a charge on one conductor will exert a force on the charge carriers within the other conductor, attracting opposite polarity charge and repelling like polarity charges, thus an opposite polarity charge will be induced on the surface of the other conductor. The conductors thus hold equal and opposite charges on their facing surfaces, and the dielectric develops an electric field.

An ideal capacitor is characterised by a constant capacitance C. Farad in the SI system of unit which is defined as the ratio of the positive or negative charge Q on each conductor to the voltage V between them. Parallel plate capacitor is the most commonly used capacitor.

Read the given passage carefully and give the answer of the following questions:

(i) When a dielectric is placed in an electric field, what will happen?

(ii) The graph shows the variation of capacitances the plates of two capacitors *A* and *B* *versus* increase of charge *Q* stored in them. Which of the capacitors has higher potential?



(iii) A parallel plate capacitor with plates of area 1m² each, are at a separation of 0.1 m. If the electric field between the plates is 100 N/C, what will be the value of the magnitude of charge on each plate?

$$\left(\text{Take, } \varepsilon_0 = 8.85 \times 10^{-12} \frac{C^2}{N\text{-}m^2}\right)$$

(iv) When we consider a parallel plate air capacitor, its capacitance does not depends on which parameter?

Very Short Answer Type Questions

Q 8. Two plates have net charges 70 pC and −70 pC connected to a potential of 20 V, calculate the capacitance of the system.

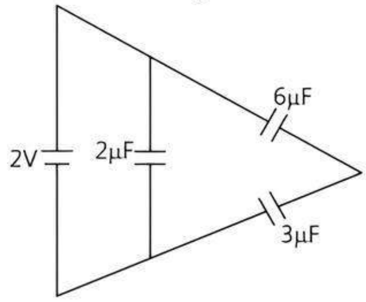
Q 9. A parallel plate capacitor is charged. If the plates are pulled apart, then what will happen?

Q 10. Calculate the energy stored in a capacitor whose value is 10μF, charged by a battery of 100 V.

Short Answer Type-I Questions

Q 11. A cube of side x has charge q at each of its vertices. What will be the potential due to this charge array at the centre of the cube?

Q 12. Find the total energy stored in the condenser system shown in the figure.



Short Answer Type-II Questions

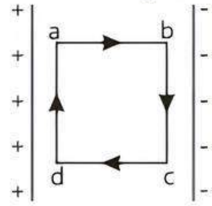
Q 13. A parallel plate capacitor (A) of capacitance C is charged by a battery to voltage V. The battery is disconnected and an uncharged capacitor (B) of capacitance $2C$ is connected across A. Find the ratio of:

(i) final charges on A and B.

(ii) total electrostatic energy stored in A and B finally and that stored in A initially. *(CBSE 2023)*

Q 14. (i) The intensity of an electric field inside a capacitor is E. What is the work done to move a charge q in a closed rectangular loop?

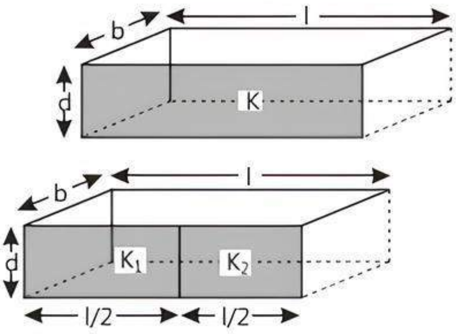
(ii) In a parallel plate capacitor of capacitance C, a metal sheet is inserted between the plates, parallel to them. If the thickness of the sheet is half of the separation between the plates, what will be the value of capacitance?



Long Answer Type Questions

Q 15. (i) Obtain the expression for the potential due to an electric dipole of dipole moment P at a point r on the axial line.

(ii) Two identical capacitors of plate dimensions $l \times b$ and plate separation d have dielectric slabs filled in between the space of the plates as shown in the figure.



Obtain the relation between dielectric constants K, K_1 and K_2.

Q 16. State the significance of negative value of electrostatic potential energy of a system of charges.

Three charges are placed at the corners of an equilateral triangle ABC of side 2.0 m as shown in figure. Calculate the electric potential energy of the system of three charges. *(CBSE 2023)*