

Electrostatic Potential and Capacitance

CASE STUDY / PASSAGE BASED QUESTIONS

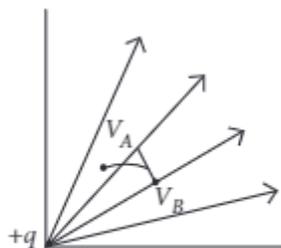
Questions 1-10 are Case Study based questions and are compulsory. Attempt any 4 sub parts from each question. Each question carries 1 mark.

1

Electrostatics Potential and Potential Energy

Electrostatic potential energy of a system of point charges is defined as the total amount of work done in bringing the different charges to their respective positions from infinitely charge mutual separations. The work is stored in the system of two point charges in the form of electrostatic potential energy U of the system. Electric potential difference between any points A and B in an electric field is the amount of work done in moving a unit positive test charge from A to B along any path against the electrostatic force

$$V_B - V_A = \frac{W_{AB}}{q_0} = \int \vec{E} \cdot d\vec{l}.$$



- (i) A test charge is moved from lower potential point to a higher potential point. The potential energy of test charge will
- (a) remain the same (b) increase
(c) decrease (d) become zero
- (ii) 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).
- (iii) Work done in moving a charge from one point to another inside a uniformly charged conducting sphere is
- (a) always zero (b) non-zero (c) may be zero (d) none of these

Syllabus

Electric potential, potential difference, electric potential due to a point charge, a dipole and system of charges; equipotential surfaces, electrical potential energy of a system of two point charges and of electric dipole in an electrostatic field.

Conductors and insulators, free charges and bound charges inside a conductor.

Dielectrics and electric polarisation, capacitors and capacitance, combination of capacitors in series and in parallel, capacitance of a parallel plate capacitor with and without dielectric medium

between the plates, energy stored in a capacitor.

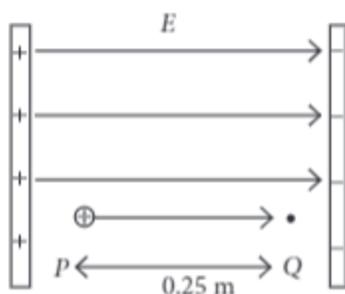
- (iv) The work done in bringing a unit positive charge from infinite distance to a point at distance x from a positive charge Q is W . Then the potential ϕ at that point is
- (a) $\frac{WQ}{x}$ (b) W (c) $\frac{W}{x}$ (d) WQ
- (v) If $1\mu\text{C}$ charge is shifted from A to B and it is found that work done by an external force is $40\mu\text{J}$. In doing so against electrostatics force, the potential difference $V_A - V_B$ is
- (a) 40V (b) -40V (c) 20V (d) -60V

2

Potential Energy of the Proton

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 $4.0 \times 10^8\text{V m}^{-1}$ directed along the positive X -axis. The proton undergoes a displacement of 0.25m in the direction of E .

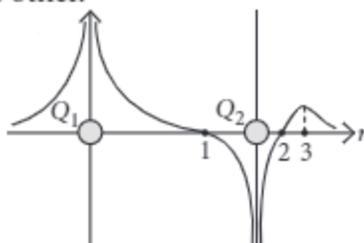
Mass of a proton = $1.66 \times 10^{-27}\text{kg}$ and charge of proton = $1.6 \times 10^{-19}\text{C}$



- (i) The change in electric potential of the proton between the points A and B is
- (a) $-1 \times 10^8\text{V}$ (b) $1 \times 10^8\text{V}$
(c) $6.4 \times 10^{-19}\text{V}$ (d) $-6.4 \times 10^{-19}\text{V}$
- (ii) The change in electric potential energy of the proton for displacement from A to B is
- (a) $1.6 \times 10^{11}\text{J}$ (b) $0.5 \times 10^{23}\text{J}$
(c) $-1.6 \times 10^{-11}\text{J}$ (d) $3.2 \times 10^{22}\text{J}$
- (iii) The mutual electrostatic potential energy between two protons which are at a distance of $9 \times 10^{-15}\text{m}$, in ${}_{92}\text{U}^{235}$ nucleus is
- (a) $1.56 \times 10^{-14}\text{J}$ (b) $5.5 \times 10^{-14}\text{J}$
(c) $2.56 \times 10^{-14}\text{J}$ (d) $4.56 \times 10^{-14}\text{J}$
- (iv) If a system consists of two charges 4mC and -3mC with no external field placed at $(-5\text{cm}, 0, 0)$ and $(5\text{cm}, 0, 0)$ respectively. The amount of work required to separate the two charges infinitely away from each other is
- (a) -1.1J (b) 2J
(c) 2.5J (d) 3J
- (v) As the proton moves from P to Q , then
- (a) the potential energy of proton decreases (b) the potential energy of proton increases
(c) the proton loses kinetic energy (d) total energy of the proton increases.

Potential of Two Point Charges

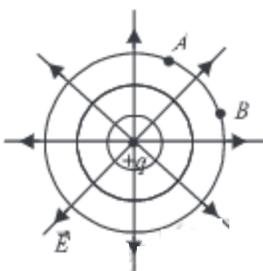
The potential at any observation point P of a static electric field is defined as the work done by the external agent (or negative of work done by electrostatic field) in slowly bringing a unit positive point charge from infinity to the observation point. Figure shows the potential variation along the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



- (i) At which of the points 1, 2 and 3 is the electric field is zero?
 (a) 1 (b) 2 (c) 3 (d) Both (a) and (b)
- (ii) 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
- (iii) 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 determined
- (iv) 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).
- (v) Positive and negative point 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.

Equipotential Surfaces

For the various charge systems, we represent equipotential surfaces by curves and line of force by full line curves. Between any two adjacent equipotential surfaces, we assume a constant potential difference the equipotential surfaces of a single point charge are concentric spherical shells with their centres at the point charge. As the lines of force point radially outwards, so they are perpendicular to the equipotential surfaces at all points.



- (i) Identify the wrong statement.
- (a) Equipotential surface due to a single point charge is spherical.
 (b) Equipotential surface can be constructed for dipoles too.
 (c) The electric field is normal to the equipotential surface through the point.
 (d) The work done to move a test charge on the equipotential surface is positive.
- (ii) Nature of equipotential surface for a point charge is
- (a) Ellipsoid with charge at foci
 (b) Sphere with charge at the centre of the sphere
 (c) Sphere with charge on the surface of the sphere
 (d) Plane with charge on the surface.
- (iii) A spherical equipotential surface is not possible
- (a) inside a uniformly charged sphere
 (b) for a dipole
 (c) inside a spherical condenser
 (d) for a point charge
- (iv) The work done in carrying a charge q once round a circle of radius a with a charge Q at its centre is
- (a) $\frac{qQ}{4\pi\epsilon_0 a}$ (b) $\frac{qQ}{4\pi\epsilon_0 a^2}$ (c) $\frac{q}{4\pi\epsilon_0 a}$ (d) zero
- (v) The work done to move a unit charge along an equipotential surface from P to Q
- (a) must be defined as $-\int_P^Q \vec{E} \cdot d\vec{l}$ (b) is zero
 (c) can have a non-zero value (d) both (a) and (b) are correct.

5

Electric Potential Energy

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 $\frac{q_1 q_2}{4\pi\epsilon_0 r}$. It is measured in joule. It may be positive, negative or zero depending on the signs of q_1 and q_2 .

- (i) 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
- (ii) Four equal charges q each are placed at four corners of a square of side a each. Work done in carrying a charge $-q$ from its centre to infinity is
- (a) zero (b) $\frac{\sqrt{2}q^2}{\pi\epsilon_0 a}$ (c) $\frac{\sqrt{2}q}{\pi\epsilon_0 a}$ (d) $\frac{q^2}{\pi\epsilon_0 a}$

(v) If 64 identical spheres of charge q and capacitance C each are combined to form a large sphere. The charge and capacitance of the large sphere is

- (a) $64q, C$ (b) $16q, 4C$ (c) $64q, 4C$ (d) $16q, 64C$

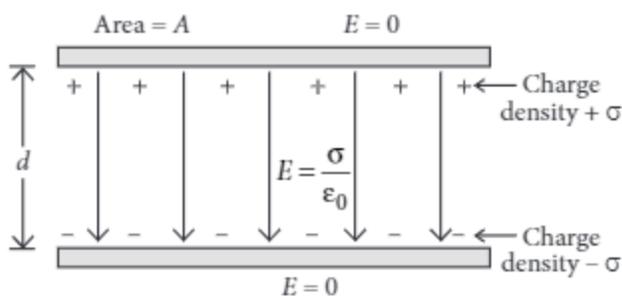
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Parallel Plate Capacitor

The simplest and the most widely used capacitor is the parallel plate capacitor. It consists of two large plane parallel conducting plates, separated by a small distance.

In the outer regions above the upper plate and below the lower plate, the electric fields due to the two charged plates cancel out. The net field is zero.

In the inner region between the two capacitor plates, the electric fields due to the two charged plates add up. The net field is $\frac{\sigma}{\epsilon_0}$.



For a uniform electric field, potential difference between the plates = Electric field \times distance between the plates. Capacitance of the parallel plate capacitor is, the charge required to supplied to either of the conductors of the capacitor so as to increase the potential difference between then by unit amount.

(i) A parallel plate capacitor is charged and then isolated. The effect of increasing the plate separation on charge, potential and capacitance respectively are

(ii) In a parallel plate capacitor, the capacity increases if

- (a) area of the plate is decreases (b) distance between the plates increases
(c) area of the plate is increases (d) dielectric constant decreases.

(iii) A parallel plate capacitor has two square plates with equal and opposite charges. The surface charge densities on the plates are $+\sigma$ and $-\sigma$ respectively. In the region between the plates the magnitude of the electric field is

- (a) $\frac{\sigma}{2\epsilon_0}$ (b) $\frac{\sigma}{\epsilon_0}$ (c) 0 (d) none of these.

(iv) If a parallel plate air capacitor consists of two circular plates of diameter 8 cm. At what distance should the plates be held so as to have the same capacitance as that of sphere of diameter 20 cm?

- (a) 9 mm (b) 4 mm (c) 8 mm (d) 2 mm

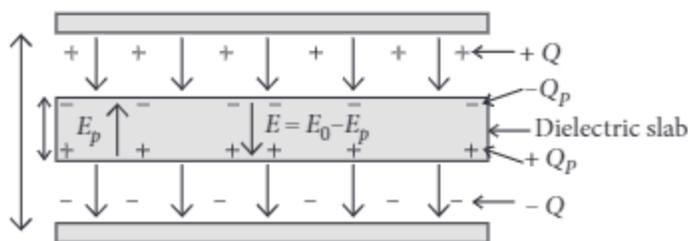
(v) If a charge of $+2.0 \times 10^{-8}$ C is placed on the positive plate and a charge of -1.0×10^{-8} C on the negative plate of a parallel plate capacitor of capacitance 1.2×10^{-3} μ F, then the potential difference developed between the plates is

- (a) 6.25 V (b) 3.0 V (c) 12.5 V (d) 25 V

Dielectric Slab

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.

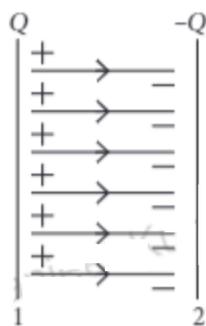
When a dielectric slab is placed between the plates, the field E_0 polarises the dielectric. This induces charge $-Q_p$ on the upper surface and $+Q_p$ on the lower surface of the dielectric. These induced charges set up a field E_p inside the dielectric in the opposite direction of \vec{E}_0 as shown.



- (i) In a parallel plate capacitor, the capacitance increases from $4\mu\text{F}$ to $80\mu\text{F}$, on introducing a dielectric medium between the plates. What is the dielectric constant of the medium?
- (a) 10 (b) 20 (c) 50 (d) 100
- (ii) 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
- (iii) 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
- (iv) A parallel plate capacitor of capacitance 1 pF has separation between the plates is 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
- (v) 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) $\frac{\epsilon_0 A}{d + \frac{b}{2}}$ (b) $\frac{\epsilon_0 A}{2d}$ (c) $\frac{\epsilon_0 A}{d - b}$ (d) $\frac{2\epsilon_0 A}{d + \frac{b}{2}}$

Energy Stored in Capacitor

A capacitor is a device to store energy. The process of charging up a capacitor involves the transferring of electric charges from its one place to another. This work done in charging the capacitor is stored as its electrical potential energy.



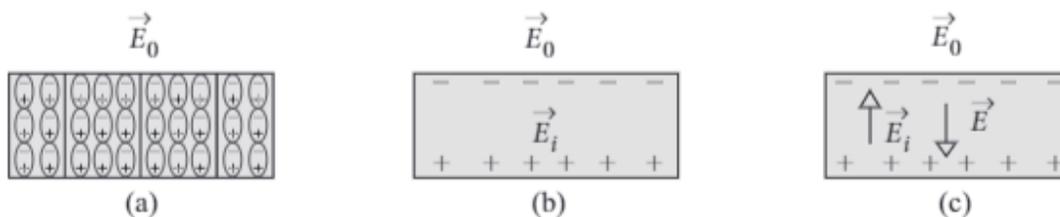
If q is the charge and V is the potential difference across a capacitor at any instant during its charging, then small work done in storing an additional small charge dq against the repulsion of charge q already stored on it is $dW = V \cdot dq = (q/C) dq$

- (i) A system of 2 capacitors of capacitance $2 \mu\text{F}$ and $4 \mu\text{F}$ is connected in series across a potential difference of 6 V. The energy stored in the system is
 (a) $3 \mu\text{J}$ (b) $24 \mu\text{J}$ (c) $30 \mu\text{J}$ (d) $108 \mu\text{J}$
- (ii) A capacitor of capacitance of $10 \mu\text{F}$ is charged to 10 V. The energy stored in it is
 (a) $100 \mu\text{J}$ (b) $500 \mu\text{J}$ (c) $1000 \mu\text{J}$ (d) $1 \mu\text{J}$
- (iii) A parallel plate air capacitor has capacity C farad, potential V volt and energy E joule. When the gap between the plates is completely filled with dielectric
 (a) both V and E increase (b) both V and E decrease
 (c) V decreases, E increases (d) V increases, E decreases
- (iv) A capacitor with capacitance $5 \mu\text{F}$ is charged to $5 \mu\text{C}$. If the plates are pulled apart to reduce the capacitance to $2 \mu\text{F}$, how much work is done?
 (a) $6.25 \times 10^{-6} \text{ J}$ (b) $3.75 \times 10^{-6} \text{ J}$ (c) $2.16 \times 10^{-6} \text{ J}$ (d) $2.55 \times 10^{-6} \text{ J}$
- (v) A metallic sphere of radius 18 cm has been given a charge of $5 \times 10^{-6} \text{ C}$. The energy of the charged conductor is
 (a) 0.2 J (b) 0.6 J (c) 1.2 J (d) 2.4 J

10

Polarisation of Dielectric

When an insulator is placed in an external field, the dipoles become aligned. Induced surface charges on the insulator establish a polarization field \vec{E}_i in its interior. The net field \vec{E} in the insulator is the vector sum of \vec{E}_0 and \vec{E}_i as shown in the figure.



On the application of external electric field, the effect of aligning the electric dipoles in the insulator is called polarisation and the field \vec{E}_i is known as the polarisation field.

The dipole moment per unit volume of the dielectric is known as polarisation (\vec{P}).

For linear isotropic dielectrics, $\vec{P} = \chi \vec{E}$, where χ = electrical susceptibility of the dielectric medium.

- (i) Which among the following is an example of polar molecule?
 (a) O_2 (b) H_2 (c) N_2 (d) HCl

- (ii) When air is replaced by a dielectric medium of constant K , the maximum force of attraction between two charges separated by a distance
- (a) increases K times (b) remains unchanged (c) decreases K times (d) increases $2K$ times.
- (iii) Which of the following is a dielectric?
- (a) Copper (b) Glass (c) Antimony (Sb) (d) None of these
- (iv) For a polar molecule, which of the following statements is true ?
- (a) The centre of gravity of electrons and protons coincide.
 (b) The centre of gravity of electrons and protons do not coincide.
 (c) The charge distribution is always symmetrical.
 (d) The dipole moment is always zero.
- (v) When a comb rubbed with dry hair attracts pieces of paper. This is because the
- (a) comb polarizes the piece of paper
 (b) comb induces a net dipole moment opposite to the direction of field
 (c) electric field due to the comb is uniform
 (d) comb induces a net dipole moment perpendicular to the direction of field

ASSERTION & REASON

For question numbers 11-30, two statements are given-one labelled Assertion (A) and the other labelled Reason (R). Select the correct answer to these questions from the codes (a), (b), (c) and (d) as given below.

- (a) Both A and R are true and R is the correct explanation of A
 (b) Both A and R are true but R is NOT the correct explanation of A
 (c) A is true but R is false
 (d) A is false and R is also false
11. **Assertion (A)** : Positive charge always moves from a higher potential point to a lower potential point.
Reason (R) : Electric potential is a vector quantity.
12. **Assertion (A)** : The whole charge of a conductor cannot be transferred to another isolated conductor.
Reason (R) : The total transfer of charge from one to another is not possible.
13. **Assertion (A)** : Electric potential of the earth is zero.
Reason (R) : The electric field due to the earth is zero.
14. **Assertion (A)** : Capacity of a parallel plate capacitor increases when distance between the plates is decreased.
Reason (R) : Capacitance of capacitor is inversely proportional to distance between them.
15. **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.
16. **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.
17. **Assertion (A)** : Two adjacent conductors, carrying the same positive charge have no potential difference between them.
Reason (R) : The potential of a conductor does not depend upon the charge given to it.

18. **Assertion (A)** : When a dielectric medium is filled between the plates of a condenser, its capacitance increases.
Reason (R) : The dielectric medium reduces the potential difference between the plates of the condenser.
19. **Assertion (A)** : A capacitor is connected to a battery. If we move its plate further apart, work will be done against the electrostatic attraction between the plates and the energy of the capacitor gets decreased.
Reason (R) : The energy stored in capacitor is dissipated in the form of heat energy.
20. **Assertion (A)** : Circuits containing capacitors should be handled cautiously even when there is no current.
Reason (R) : The capacitors are very delicate and so quickly breakdown.
21. **Assertion (A)** : A capacitor can be broken by placing large amount of charge on it.
Reason (R) : After breakage potential, capacitor is destroyed.
22. **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.
23. **Assertion (A)** : Charge on all the condensers connected in series is the same.
Reason (R) : Capacitance of capacitor is directly proportional to charge on it.
24. **Assertion (A)** : Increasing the charge on the plates of a capacitor means increasing the capacitance.
Reason (R) : Capacitance is directly proportional to charge.
25. **Assertion (A)** : The surface of a conductor is an equipotential surface.
Reason (R) : Conductor allows the flow of charge.
26. **Assertion (A)** : Conductors having equal positive charge and volume, must also have same potential.
Reason (R) : Potential depends only on charge and volume of conductor.
27. **Assertion (A)** : No work is done in taking a positive charge from one point to other inside a positively charged metallic sphere while outside the sphere work is done in taking the charge toward the sphere.
Reason (R) : Inside the sphere electric potential is same at each potential, but outside it is different for different points.
28. **Assertion (A)** : An applied electric field will polarize the polar dielectric material.
Reason (R) : In polar dielectrics, each molecule has a permanent dipole moment but these are randomly oriented in the absence of an externally applied electric field.
29. **Assertion (A)** : An electric field is preferred in comparison to magnetic field for detecting the electron beam in a television picture tube.
Reason (R) : Electric field requires low voltage.
30. **Assertion (A)** : Lines of force are perpendicular to conductor surface.
Reason (R) : Generally electric field is perpendicular to equipotential surface.

HINTS & EXPLANATIONS

1. (i) (c)

(ii) (b)

(iii) (a): Since, $E = 0$ inside the conductor and has no tangential component on the surface, no work is done in moving a small test charge within the conductor and on its surface.

(iv) (b): The work done in bringing unit positive charge from infinity to a point which is at a distance x from the positive charge Q is defined as the potential at the given point due to the charge Q . Therefore $\phi = W$.

(v) (b): $W_{\text{ext}} = q_0 \Delta V$

$$(W_{AB})_{\text{ext}} = q(V_B - V_A)$$

$$40\mu\text{J} = 1\mu\text{C} (V_B - V_A)$$

$$V_A - V_B = -40\text{ V}$$

2. (i) (a) : As $\Delta V = -E\Delta x = -(4.0 \times 10^8 \text{ V/m})(0.25 \text{ m}) = -10^8 \text{ V}$

(ii) (c) : As $\Delta U = q_0\Delta V = (1.6 \times 10^{-19}) \times (-1.0 \times 10^8 \text{ V}) = -1.6 \times 10^{-11} \text{ J}$

(iii) (c) : Here, $q_1 = q_2 = 1.6 \times 10^{-19} \text{ C}$, $r = 9 \times 10^{-15} \text{ m}$

$$U = \frac{9 \times 10^9 \times 1.6 \times 10^{-19} \times 1.6 \times 10^{-19}}{9 \times 10^{-15}} = 2.56 \times 10^{-14} \text{ J}$$

(iv) (a) : Here, $q_1 = 4 \mu\text{C}$, $q_2 = -3 \mu\text{C}$

$$r = 10 \text{ cm} = 0.1 \text{ m}$$

Electrostatic potential energy,

$$U = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r} = 9 \times 10^9 \times \frac{4 \times 10^{-6} \times (-3) \times 10^{-6}}{0.1} = -1.1 \text{ J}$$

(v) (a) : As proton moves in the direction of the electric field, then its potential energy decreases.

3. (i) (c) : As $\frac{-dV}{dr} = E_r$, the negative of the slope of

V versus r curve represents the component of electric field along r . Slope of curve is zero only at point 3.

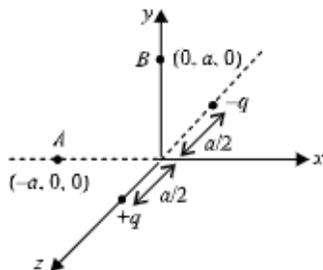
Therefore, the electric field vector is zero at point 3.

(ii) (a) : 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.

(iii) (b) : 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 .

(iv) (b)

(v) (c) : 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.



4. (i) (d)

(ii) (b)

(iii) (b)

(iv) (d) : The electrical potential at any point on circle of radius a due to charge

$$Q \text{ at its centre is } V = \frac{1}{4\pi\epsilon_0} \frac{Q}{a}$$



It is an equipotential surface.

Hence, work done in carrying a charge q round the circle is zero.

(v) (d) : Work done to move a unit charge along an equipotential surface from P to Q ,

$$W = - \int_P^Q \vec{E} \cdot d\vec{l}$$

On equipotential surface $\vec{E} \perp d\vec{l}$

$$W = - \int_P^Q E(dl) \cos 90^\circ = 0$$

5. (i) (c) : $W = (\text{P.E.})_{\text{final}} - (\text{P.E.})_{\text{initial}}$

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

(ii) (b) : Potential at the centre of the square due to four equal charges q at four corners

$$V = \frac{4q}{4\pi\epsilon_0(a\sqrt{2})/2} = \frac{\sqrt{2}q}{\pi\epsilon_0 a}$$

$$W_{0 \rightarrow \infty} = -W_{\infty \rightarrow 0} = -(-q)V = \frac{\sqrt{2}q^2}{\pi\epsilon_0 a}$$

(iii) (c) : Here, $q = 2 \mu\text{C} = 2 \times 10^{-6} \text{ C}$, $r_A = 2 \text{ m}$, $r_B = 1 \text{ m}$

$$\therefore V_A - V_B = \frac{q}{4\pi\epsilon_0} \left[\frac{1}{r_A} - \frac{1}{r_B} \right]$$

$$= 2 \times 10^{-6} \times 9 \times 10^9 \left[\frac{1}{2} - \frac{1}{1} \right] \text{ V} = -9 \times 10^3 \text{ V}$$

(iv) (b) : Required work done = Change in potential energy of the system

$$W = U_f - U_i = k \frac{q_1 q_2}{r_f} - k \frac{q_1 q_2}{r_i} = k q_1 q_2 \left[\frac{1}{r_f} - \frac{1}{r_i} \right]$$

$$\therefore W = (9 \times 10^9) (3 \times 10^{-9} \times 1 \times 10^{-9})$$

$$\times \left[\frac{1}{4 \times 10^{-2}} - \frac{1}{5 \times 10^{-2}} \right]$$

$$= 27 \times 10^{-7} \times (0.05) = 1.35 \times 10^{-7} \text{ J}$$

(v) (b)

6. (i) (b) : Here $C = 50 \text{ pF} = 50 \times 10^{-12} \text{ F}$, $V = 10^4 \text{ V}$

$$R = \frac{1}{4\pi\epsilon_0} \cdot C = 9 \times 10^9 \text{ mF}^{-1} \times 50 \times 10^{-12} \text{ F}$$

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

(ii) (d): As $q = CV = 25 \times 10^{-12} \times 10^5 = 2.5 \mu\text{C}$

(iii) (c)

(iv) (c): As charge, $q = CV = (4\pi\epsilon_0 R)V$

$\therefore q$ depends on both V and R .

(v) (c): 64 drops have formed a single drop of radius R .

Volume of large sphere = 64 \times Volume of small sphere

$$\therefore \frac{4}{3}\pi R^3 = 64 \frac{4}{3}\pi r^3 \Rightarrow R = 4r \text{ and } Q_{\text{total}} = 64q$$

$$C' = 4\pi\epsilon_0 R \Rightarrow C' = (4\pi\epsilon_0) \cdot 4r \Rightarrow C' = 4C$$

7. (i) (b): As the capacitor is isolated after charging, charge Q on it remains constant. Plate separation

d increases, capacitance decreases as $C = \frac{\epsilon_0 A}{d}$ and hence, potential increases as $V = \frac{Q}{C}$.

(ii) (c): In a parallel plate capacitor, the capacity of capacitor

$$C = \frac{K\epsilon_0 A}{d} \text{ i.e., } C \propto A$$

The capacity of capacitor increases if area of the plate increases.

(iii) (b): The magnitude of the electric field between

$$\text{the plates is } E = \frac{\sigma}{2\epsilon_0} - \left(-\frac{\sigma}{2\epsilon_0}\right) = \frac{\sigma}{\epsilon_0}$$

$$(iv) (b): \text{As, } \frac{\epsilon_0 A}{d} = 4\pi\epsilon_0 R \text{ or } \frac{\epsilon_0 \pi D^2}{4d} = 4\pi\epsilon_0 R$$

$$\text{or } d = \frac{D^2}{16R} = \frac{(0.08)^2}{16 \times 0.10} = 4 \times 10^{-3} \text{ m} = 4 \text{ mm}$$

$$(v) (c): \text{Here, } V = \frac{q_1 - q_2}{2C} \\ = \frac{2.0 \times 10^{-8} + 1.0 \times 10^{-8}}{2 \times 1.2 \times 10^{-9}} = 12.5 \text{ V}$$

$$8. (i) (b): k = \frac{\text{Capacitance with dielectric}}{\text{Capacitance without dielectric}}$$

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

(ii) (c): Capacitance of the capacitor with air between plates

$$C' = \frac{\epsilon_0 A}{d} = 8 \text{ pF}$$

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

$$C = \frac{\epsilon_0 k A}{d/2} = \frac{\epsilon_0 \times 5 \times A}{d/2} = 10 C' = 10 \times 8 = 80 \text{ pF}$$

(iii) (d): If a dielectric medium of dielectric constant K is filled completely between the plates then capacitance increases by K times.

$$(iv) (b): C = \frac{\epsilon_0 A}{d} = 1 \text{ pF} \quad \dots(i)$$

$$C' = \frac{x\epsilon_0 A}{(2d)} = 2 \text{ pF} \quad \dots(ii)$$

Divide (ii) by (i), $x/2 = 2/1 \Rightarrow x = 4$

(v) (c): As capacitance, $C_o = \frac{\epsilon_o A}{d}$

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

9. (i) (b): As, $C_1 = 2 \mu\text{F}$, $C_2 = 4 \mu\text{F}$

In series combination, the equivalent capacitance will

$$\text{be, } C = \frac{C_1 C_2}{C_1 + C_2} = \left(\frac{2 \times 4}{2 + 4}\right) \mu\text{F} = \frac{4}{3} \mu\text{F}$$

Potential difference applied, $V = 6 \text{ V}$

$$\text{Energy stored in the system, } U = \frac{1}{2} CV^2 \\ = \frac{1}{2} \times \frac{4}{3} \times 10^{-6} \times (6)^2 \text{ J} = 24 \mu\text{J}$$

(ii) (b): The energy stored in a capacitor is

$$U = \frac{1}{2} CV^2 = \frac{1}{2} \times (10 \times 10^{-6}) (10)^2 = 500 \mu\text{J}$$

(iii) (b): When the gap between the plates is completely filled with dielectric of dielectric constant K , then potential is

$$V = \frac{Qd}{A\epsilon_0 K} \quad \dots(i)$$

and electric field is

$$E = \frac{Q}{A\epsilon_0 K} \quad \dots(ii)$$

From equations (i) and (ii), both electric field and potential decrease.

$$(iv) (b): \text{Work done} = U_f - U_i = \frac{1}{2} \frac{q^2}{C_f} - \frac{1}{2} \frac{q^2}{C_i}$$

$$= \frac{q^2}{2} \left[\frac{1}{C_f} - \frac{1}{C_i} \right] = \frac{(5 \times 10^{-6})^2}{2} \left[\frac{1}{2 \times 10^{-6}} - \frac{1}{5 \times 10^{-6}} \right] \\ = 3.75 \times 10^{-6} \text{ J}$$

(v) (b) : Here $r = 18 \text{ cm} = 18 \times 10^{-2} \text{ m}$, $q = 5 \times 10^{-6} \text{ C}$

$$\text{As } C = 4\pi\epsilon_0 r = \frac{18 \times 10^{-2}}{9 \times 10^9} = 2 \times 10^{-11} \text{ F}$$

Energy of charged conductor is

$$U = \frac{q^2}{2C} = \frac{(5 \times 10^{-6})^2 \text{ C}}{2 \times 2 \times 10^{-11} \text{ F}} = 0.625 \text{ J}$$

10. (i) (d): In polar molecule the centres of positive and negative charges are separated even when there is no external field. Such molecule have a permanent dipole moment. Ionic molecule like HCl is an example of polar molecule.

(ii) (c) : As $F_m = \frac{F_0}{K}$

\therefore The maximum force decreases by K times.

(iii) (b)

(iv) (b): A polar molecule is one in which the centre of gravity for positive and negative charges are separated.

(v) (a)

11. (c) : If two points P and Q in an electric field are separated by an infinitesimal distance Δx and have a potential difference ΔV between then, $E = \frac{-\Delta V}{\Delta x}$.

Here negative sign implies that \vec{E} has got a direction opposite to the potential gradient *i.e.* in the direction of \vec{E} the potential decreases *i.e.* positive charge always move from a higher potential point to a lower potential point.

12. (d): The whole charge of a conductor can be transferred to another isolated conductor, if it is placed inside the hollow insulated conductor and connected with it.

13. (c) : Earth is a good conductor of very large size. When some small charge is given to earth, its potential does not change. Hence potential of earth is assumed to be zero. It is just like sea level which does not alter materially when water is added to it or removed from it. Thus, the potential of all other bodies are measured with reference to the earth. For this, if the connection of a charged body to the ground by a metallic conductor would cause electrons to flow to that body from ground, the body is at positive potential. Conversely, is also true. In either case the conductor is neutralized and brought to zero potential. In fact the atmosphere does possess significant electric field.

14. (a): Capacitance of parallel plate capacitor is $C = \frac{\epsilon_0 A}{d}$. Thus distance decreases and capacitance of capacitor increases.

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

$$C = \frac{q}{V} \quad \dots (i)$$

Electric field intensity becomes $\frac{1}{K}$ times [as $K = E_0/E$], therefore potential V also becomes $1/K$ times.

Hence, from equation (i) capacity becomes K times. Thus electric field decreases and capacitance increases when condenser is filled with insulated medium of some dielectric constant.

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

$$C = \frac{\epsilon_0 A}{d - t[1 - 1/K]}$$

For metals, $K = \infty$, $\therefore C = \frac{\epsilon_0 A}{d - t}$.

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.

17. (d): The potential of a conductor depends upon the charge given to it and there exist a potential difference between two adjacent conductors.

18. (a): The dielectric molecules are polarised, producing an opposite electric field. Thus the effective electric field and hence the potential difference between the plates is reduced and consequently the capacitance is increased ($\because C = Q/V$).

19. (b): When the plates of a capacitor are moved further apart, the capacitance gets decreased. As battery remains connected, hence charge $q (= CV)$ on the plates is decreased and energy $U = [1/2 CV^2]$ also decreases. Some charge from the plates flows to the battery *i.e.* some energy of capacitor is transferred to the battery. Work done against electrostatic attraction between plates is used in the transference of energy and is dissipated in the form of heat energy in connection wires.

20. (c): A charged capacitor, after removing the battery, does not discharge itself. If this capacitor is touched by someone, he may feel shock due to large charge still present on the capacitor. Hence it should be handled cautiously otherwise this may cause a severe shock.

21. (b): When large amount of charges are placed on capacitor a high potential difference is established between its conducting components. If this potential difference is above what is called breakage potential, an electric discharge results, destroying the capacitor. If the capacitor contains an insulator between its conducting components, the insulator will be burnt at the atomic/molecular level. A capacitor subjected to voltage exceeding the breakage potential cannot be recovered. It should be discarded and replaced.

22. (c): The capacitance C with dielectric between the plates is given as

$$C = \frac{\epsilon_0 KA}{d}$$

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

$$C' = \frac{\epsilon_0 3KA}{\frac{d}{2}} \Rightarrow C' = \frac{6\epsilon_0 KA}{d} = 6C$$

The capacitance C depends only on the geometrical configuration (shape, size, separation) of the system of two conductors.

23. (c): Let two capacitors be connected in series. If $+q$ charge is installed on left plate of the first capacitor then $-q$ charge is induced on right plate of this capacitor. This charge comes from electron drawn from the left plate of second capacitor. Thus there will be equal charge $+q$ on the left plate of second capacitor and $-q$ charge induced on the right plate of second capacitor. Thus each capacitor has same charge (q) when connected in series. Capacitance is

quantity dependent on construction of capacitor and independent of charge.

24. (d): On increasing the charge, potential increases. But capacity of a capacitor is fixed by geometry of condenser $\left(C = \frac{\epsilon_0 A}{d}\right)$. Capacitance is independent of charge.

25. (a): If two points on a conductor were at different potentials, charge would flow from higher potential to lower potentials, till their potentials become equal. A surface on which the potential has the same value everywhere is called an equipotential surface.

26. (d): Electric potential of a charged conductor depends not only on the amount of charge and volume but also on the shape of the conductor. Hence if their shapes are different, they may have different electric potential.

27. (a): Inside the charged metallic sphere every point is at the same electric potential, hence $W = q\Delta V = 0$. But outside the sphere, there exists a potential gradient at every point, hence $W \neq 0$.

28. (b): If a material contain polar molecules, they will generally be in random orientations when no electric field is applied. An applied electric field will polarize the material by orienting the dipole moment of polar molecules.

29. (d): If electric field is used for detecting the electron beam, then very high voltage will have to be applied and very long tube will have to be taken.

30. (a)