CHAPTER

2

Electrostatic Potential and Capacitance

A Quick Recapitulation of the Chapter

1. **Electrostatic Potential** The electrostatic potential at any point in an electric field is given by

$$V = \frac{\text{Work done}(W)}{\text{Charge}(q)}$$

Its SI unit is volt (V) and 1 V = 1 J/C.

2. **Electrostatic Potential Difference** The electrostatic potential difference between two points in an electric field is given by

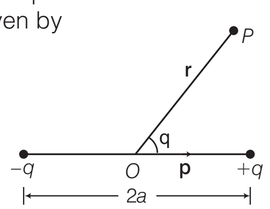
$$V_B - V_A = \frac{W_{AB}}{q_0} = -\int_A^B \mathbf{E} \cdot d\mathbf{l}$$

where, W_{AB} is work done in taking charge q_0 from A to B against the electrostatic force.

3. Electrostatic potential due to a point charge q at any point P lying at a distance r from it is given by

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

4. Electrostatic potential due to an electric dipole at any point P whose position vector is $\mathbf{r}$ w.r.t. mid-point of dipole is given by



$$V = \frac{1}{4\pi\varepsilon_0} \cdot \frac{p\cos\theta}{r^2} \quad \text{or} \quad V = \frac{1}{4\pi\varepsilon_0} \cdot \frac{\mathbf{p} \cdot \hat{\mathbf{r}}}{|\mathbf{r}|^2}$$

where, θ is the angle between $\mathbf{r}$ and $\mathbf{p}$.

5. Electrostatic potential at any point P due to a system of n point charges $q_1, q_2, \ldots, q_n$ whose position vectors are $\mathbf{r}_1, \mathbf{r}_2, \ldots, \mathbf{r}_n$ respectively, is given by

$$V = \frac{1}{4\pi\varepsilon_0} \sum_{i=1}^{n} \frac{q_i}{|\mathbf{r} - \mathbf{r}_i|}$$

where, $\mathbf{r}$ is the position vector of point P w.r.t. the origin.

6. Electrostatic potential due to a thin charged spherical shell carrying charge q and radius R respectively, at any point P lying
   (i) inside the shell is $V = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q}{R}$
   (ii) on the surface of shell is $V = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q}{R}$
   (iii) outside the shell is $V = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q}{r}$ for $r > R$

where, r is the distance of point P from the centre of the shell.

7. A surface which have same electrostatic potential at every point on it, is known as **equipotential surface**.

8. **Relationship between Electric Field and Potential Gradient**

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

where, negative sign indicates that the direction of electric field is from higher potential to lower potential, *i.e.,* in the direction of decreasing potential.

9. The work done against electrostatic force gets stored as potential energy. This is called **electrostatic potential energy**.

   i.e., $\Delta U = U_B - U_A = W_{AB}$

10. Electrostatic potential energy of a system of two point charges is given by

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

   where, q_1 and q_2 are value of charges and r is separation between the point charges.

   Putting the values of charge with their signs.

11. **Potential Energy in an External Field**

   (i) **Potential energy of a single charge in external field**
   Potential energy of a single charge q at a point with position vector $\mathbf{r}$, in an external field is $qV(\mathbf{r})$,
   where $V(\mathbf{r})$ is the potential at the point due to external electric field E.

   (ii) **Potential energy of a system of two charges in an external field**

$$U = q_1 V(\mathbf{r}_1) + q_2 V(\mathbf{r}_2) + \frac{q_1 q_2}{4\pi\varepsilon_0 \mathbf{r}_{12}}$$

   where, q_1 and q_2 = two point charges at position vectors $\mathbf{r}_1$ and $\mathbf{r}_2$, respectively
   $V(\mathbf{r}_1)$ = potential at $\mathbf{r}_1$ due to the external field
   $V(\mathbf{r}_2)$ = potential at $\mathbf{r}_2$ due to the external field

12. Potential energy of a dipole in a uniform electric field

$$\mathbf{E} = -\mathbf{p} \cdot \mathbf{E}$$

13. The process which involves the making of a region free from any electric field is known as **electrostatic shielding.**

14. When a polar or non-polar dielectric develops a net dipole moment in the presence of an external electric field, the dipole moment per unit volume is called polarisation and is denoted by $\mathbf{p}$.

15. For linear isotropic dielectrics

$$\mathbf{p} = \chi_e \mathbf{E}$$

   where, χ_e is a constant characteristic of the dielectric and is known as the electric susceptibility of the dielectric medium.

16. A combination of two conductors placed close to each other is called **capacitor.**

   Capacity of conductor $C = \frac{\text{Charge}}{\text{Potential}} = \frac{q}{V}$

   In SI system, the unit of capacity is farad.

17. Surface charge density of the plate of a capacitor,

$$\sigma = \frac{q}{A}$$

18. Intensity of the electric field between the plates of a capacitor

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

19. Potential difference between the plates

$$V = Ed = \frac{qd}{A\varepsilon_0}$$

   where, d is the distance between the conductor plates.

20. Capacity of the capacitor in air or vacuum is given by

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

21. If the medium between the plates of a capacitor is filled with a dielectric, then new capacitance is given by

$$C = KC_0$$

   where, C_0 = Capacitance with air
   K = dielectric constant of the dielectric.

22. When a dielectric fully occupies the intervening region between the plates of a capacitor, the dielectric is polarised by the field, the effect is equivalent to two charged sheets having surface charge densities $+\sigma p$ and $-\sigma p$. The electric field in the dielectric is then

$$E = \frac{\sigma - \sigma p}{\varepsilon_0}.$$

23. For capacitors in series combination, the equivalent capacitance C_s is given by

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

   In the parallel combination, the equivalent capacitance C_p is given by

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

   where, C_1, C_2, C_3 are individual capacitances.

24. The energy U stored in a capacitor of capacitance C, with charge q and voltage V is

$$U = \frac{1}{2}qV = \frac{1}{2}CV^2 = \frac{q^2}{2C}$$

25. The electrostatic energy density (energy per unit volume) in a region with electric field E is

$$U = \frac{1}{2}\varepsilon_0 E^2$$

26. A van de Graft generator consists of a large spherical conducting shell (a few metre in diameter).

   Through a moving belt and suitable brushes, charge is continuously transferred to the shell and potential difference of the order of million volts (6 or 8 million volts) is built up which can be used to accelerate charged particles.

Objective Questions Based on NCERT Text

Topic 1
Electrostatic Potential

1. Work done by an external force in bringing a unit positive charge from infinity to a point is
(a) equal to the electrostatic potential (V) at that point
(b) equal to the negative of work done by electrostatic forces
(c) Both (a) and (b)
(d) Neither (a) nor (b)

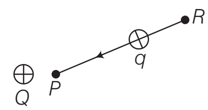
2. If δW is the work done in bringing a infinitesimal small test charge δq from infinity to a point P, then potential at point P is
(a) $\frac{\delta W}{\delta q}$
(b) $-\frac{\delta W}{\delta q}$
(c) $\delta W \cdot \delta q$
(d) None of these

3. To find the value of potential at a point, the external force at every point of the path is to be equal and opposite to the
(a) work done
(b) electrostatic force on the test charge at that point
(c) Both (a) and (b)
(d) Neither (a) nor (b)

4. For $Q < 0, V < 0$, work done (by the external force) per unit positive test charge in bringing it from infinity to the point is negative. This is equivalent to
(a) work done by electrostatic force in bringing the unit positive charge from infinity to the point P is positive
(b) work done by the electrostatic force in bringing the unit positive charge from infinity to the point P is negative
(c) Both (a) and (b)
(d) Neither (a) nor (b)

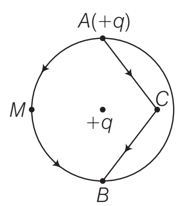
5. The electrostatic potential of a uniformly charged thin spherical shell of charge Q and radius R at a distance r from the centre is
(a) $\frac{Q}{4\pi\varepsilon_0 r}$ for points outside and $\frac{Q}{4\pi\varepsilon_0 R}$ for points inside the shell
(b) $\frac{Q}{4\pi\varepsilon_0 r}$ for both points inside and outside the shell
(c) zero for points outside and $\frac{Q}{4\pi\varepsilon_0 r}$ for points inside the shell
(d) zero for both points inside and outside the shell

6. Work done by external forces in moving a charge q from R to P as shown in figure is



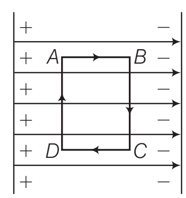
(a) $-\int_R^P \mathbf{F}_E \cdot d\mathbf{r}$
(b) $\int_R^P \mathbf{F}_E \cdot d\mathbf{r}$
(c) $\int_R^P 2\mathbf{F}_E \cdot d\mathbf{r}$
(d) $\int_R^P \frac{\mathbf{F}_E}{2} \cdot d\mathbf{r}$

7. If a point charge $(+q)$ is taken along two different paths say AMB (path 1) and ACB (path 2) such that A, M and B lie on the circle and $+q$ (another charge) is placed at the centre, then which the given statements holds true for work done along the two paths.



(a) $W_{AMB} > W_{ACB}$
(b) $W_{ACB} > W_{AMB}$
(c) $W_{ACB} = W_{AMB}$
(d) None of these

8. A uniform electric field E exists between two charged plates. What would be the work done in moving a charge q along the closed path $ABCDA$?



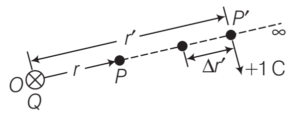
(a) $\oint \mathbf{E} \cdot d\mathbf{l}$
(b) $-\oint \mathbf{E} \cdot d\mathbf{l}$
(c) Zero
(d) None of these

9. If 100 J of work has to be done in moving an electric charge 4 C from a place where potential is -10 V to another place where potential is V volt, find the value of V.
(a) 5 V
(b) 10 V
(c) 25 V
(d) 15 V

10. The potential difference between a cloud and the Earth is 10^7 V. Calculate the amount of energy dissipated when the charge of 100 C is transferred from the cloud to the ground due to lightning bolt.

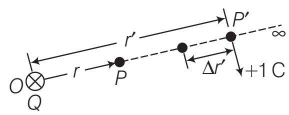
(a) zero (b) 10^9 J
(c) 60 J (d) 10^7 J

11. In the given figure, total work done (W) by the external force from $r' = \infty$ to $r' = r$ is



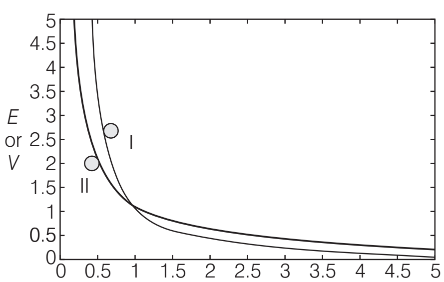
(a) $-\dfrac{Q}{4\pi\varepsilon_0 r}$ (b) $\dfrac{Q}{4\pi\varepsilon_0 r}$
(c) $\dfrac{2Q}{4\pi\varepsilon_0 r}$ (d) $-\dfrac{2Q}{4\pi\varepsilon_0 r}$

12. In the given figure, work done against this force from r' to $r' - \Delta r'$ is



(a) $\dfrac{Q}{4\pi\varepsilon_0 r'^2}\Delta r'$ (b) $\dfrac{2Q}{4\pi\varepsilon_0 r'^2}\Delta r'$
(c) $-\dfrac{2Q}{4\pi\varepsilon_0 r'^2}\Delta r'$ (d) $-\dfrac{Q}{4\pi\varepsilon_0 r'^2}\Delta r'$

13.



The above figure shows the variation of potential V or electric field with r for a point charge Q. Which of the given curves represent E *versus* r or V *versus* r?

(a) I→ E *versus* r, II→ V *versus* r
(b) I→ V *versus* r, II→ V *versus* r
(c) Both represent E *versus* r
(d) None of the above

14. Calculate the potential at a point P due to a charge of 4×10^{-7} C located 9 cm away

(a) 8×10^{-5} V (b) 8×10^{4} V
(c) 4×10^{4} V (d) 4×10^{-4} V

15. With reference to above question (14), the work done in bringing a charge of 2×10^{-9} C from infinity to the point P is

(a) 4×10^{-4} J (b) 6×10^{-4} J
(c) 8×10^{-5} J (d) 8×10^{5} J

16. A hollow metal sphere of radius 10 cm is charged such that the potential on its surface becomes 80 V. The potential at the centre of the sphere is

(a) 80 V (b) 800 V (c) 8 V (d) zero

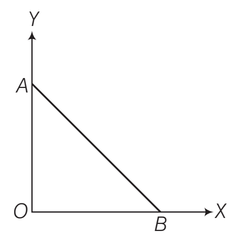
17. A charge $2Q$ is placed at each corner of a cube of side a. The potential at the centre of the cube is

(a) $\dfrac{8Q}{\pi\varepsilon_0 a}$ (b) $\dfrac{4Q}{4\pi\varepsilon_0 a}$ (c) $\dfrac{8Q}{\sqrt{3}\,\pi\varepsilon_0 a}$ (d) $\dfrac{2Q}{\pi\varepsilon_0 a}$

18. The potential of a large liquid drop when eight liquid drops are combined is 20 V . Then, the potential of each single drop was

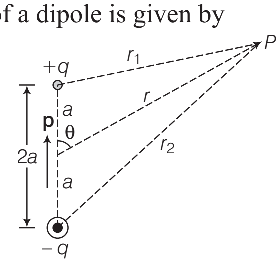
(a) 10 V (b) 7.5 V (c) 5 V (d) 2.5 V

19. As per this diagram, a point charge $+q$ is placed at the origin O. Work done in taking another point charge $-Q$ from the point A [coordinates $(0, a)$] to another point B [coordinate $(a,0)$] along the straight path AB is



(a) zero (b) $\left(\dfrac{-qQ}{4\pi\varepsilon_0 a^2}\right)\sqrt{2}a$
(c) $\left(\dfrac{qQ}{4\pi\varepsilon_0 a^2}\right)\cdot\dfrac{a}{\sqrt{2}}$ (d) $\left(\dfrac{qQ}{4\pi\varepsilon_0}\dfrac{1}{a^2}\right)\sqrt{2}a$

20. With reference to the figure given below, the electric potential of a dipole is given by



(a) $\dfrac{2\mathbf{p}\cdot\hat{\mathbf{r}}}{4\pi\varepsilon_0 r^2}$ (b) $\dfrac{\mathbf{p}\cdot\hat{\mathbf{r}}}{8\pi\varepsilon_0 r^2}$
(c) $\dfrac{1}{4\pi\varepsilon_0}\dfrac{\mathbf{p}\cdot\hat{\mathbf{r}}}{r^2}$ (d) $\dfrac{1}{4\pi\varepsilon_0}\dfrac{\mathbf{p}\cdot\hat{\mathbf{r}}}{r}$

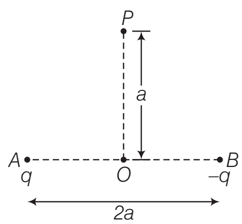
21. Two charges 3×10^{-8} C and -2×10^{-8} C located 15 cm apart. At what point on the line joining the two charges is the electric potential zero?

(a) 9 cm (b) 45 cm
(c) 18 cm (d) Both (a) and (b)

22. A solid conducting sphere having a charge Q is surrounded by an uncharged concentric hollow spherical shell. Let the potential difference between the surface of the solid sphere and that of the outer surface of hollow shell be V. What will be the new potential difference between the same two surfaces if the shell is given a charge $-3Q$?

(a) V (b) -3 V (c) 2 V (d) 4 V

23. In the figure given alongside, O is the centre of line joining AB. Two charges of opposite nature and same magnitude are placed at A and B respectively.



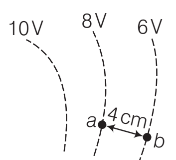
The potential at point P is

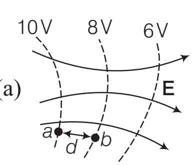
(a) $\frac{2kq}{a\sqrt{2}}$ (b) zero
(c) $\frac{kq}{a\sqrt{2}}$ (d) cannot be determined

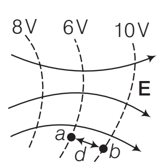
24. For a uniform electric field E, along the X-axis, the equipotential surfaces

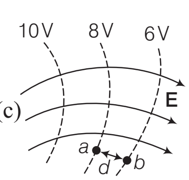
(a) planes perpendicular to the X-axis
(b) planes parallel to the YZ-plane
(c) Both (a) and (b)
(d) Neither (a) nor (b)

25. Three equipotential surfaces are shown in figure. Which of the following is correct one for the corresponding field lines?



(a)


(b)


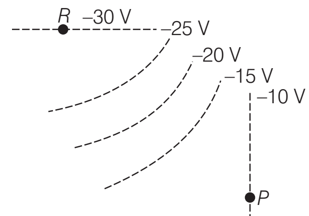
(c)


(d) None of these

26. In the above question, the field strength at a point a,where the distance between the surfaces is 4 cm, is

(a) 50 Vm^{-1} (b) 5 Vm^{-1} (c) 15 Vm^{-1} (d) 55 Vm^{-1}

27. Figure shows equipotential surfaces.



What is the direction of electric field **E** at P and R?

(a) At P, E is to the left. At R, E is upward
(b) At P, E is to the right. At R, E is downward
(c) At P, E is to downward. At R, E is to the left
(d) At P, E is to upward. At R, E is to the right

28. Equipotentials surface between two equal and oppose charges passing through the middle point is

(a) a plane (b) curved surface
(c) Both (a) and (b) (d) None of these

29. The electric potential at a certain distance from a point charge is 600 V and the electric field is 200 NC^{-1}. The distance of the point charge (in metres) is

(a) 2 (b) 3 (c) 1 (d) 0

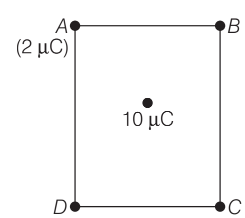
30. In a Millikan drop experiment, a drop of diameter 10^{-4} cm with a density of 900 kgm^{-3} is observed. The capacitor plates are 2 cm apart. A potential of 72 V applied across the plates keeps the drop in balance. How many electronic charges are there on the drop?

(a) 1 (b) 8 (c) 4 (d) 2

31. Work done in moving a test charge over an equipotential surface?

(a) No (b) Yes (c) Constant (d) Zero

32. What is the work done in moving a 2μC point charges from corner A to corner B of a square $ABCD$ in figure when a 10μC charge exists at the centre of the square?

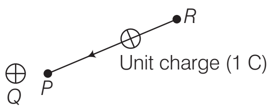


(a) Zero (b) 5
(c) 2 (d) 20

33. If a charged spherical conductor of radius 10 cm has potential V at a point distant 5 cm from its centre, then the potential at a point distant 15 cm from the centre will be

(a) $\frac{1}{3}V$ (b) $\frac{2}{3}V$ (c) $\frac{3}{2}V$ (d) V

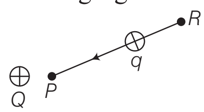
Topic 2
Electrostatic Potential Energy

34. 

Potential energy difference between points R and P is equal to

(a) $\Delta U = -W_{RP}$ (b) $\Delta U = W_{RP}$
(c) $\Delta U = 2W_{RP}$ (d) $\Delta U = 4\,W_{RP}$

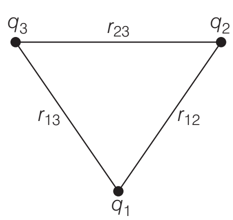
35. Consider the following figure as shown below.



Work done by external force in bringing a unit positive charge from point R to P is

(a) $-\left(\frac{U_P - U_R}{q}\right)$ (b) $-\left(\frac{U_R - U_P}{q}\right)$
(c) $\left(\frac{U_R - U_P}{2q}\right)$ (d) $\left(\frac{U_P - U_R}{q}\right)$

36. The total potential energy of a system of three charges q_1, q_2 and q_3 located at r_1, r_2 and r_3 respectively is that



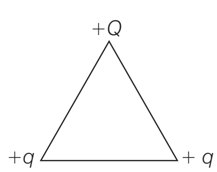
(a) $\frac{1}{4\pi\varepsilon_0}\left(\frac{q_1q_2}{r_{12}} + \frac{q_1q_3}{r_{13}} + \frac{q_2q_3}{r_{23}}\right)$

(b) $\frac{1}{4\pi\varepsilon_0}\left(\frac{q_1q_2}{r_{12}} - \frac{q_1q_3}{r_{13}} + \frac{q_2q_3}{r_{23}}\right)$

(c) $\frac{1}{4\pi\varepsilon_0}\left(\frac{q_1q_2}{r_{12}} + \frac{q_1q_3}{r_{13}} - \frac{q_2q_3}{r_{23}}\right)$

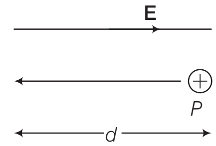
(d) $\frac{1}{4\pi\varepsilon_0}\left(\frac{q_1q_2}{r_{12}} - \frac{q_1q_3}{r_{13}} - \frac{q_2q_3}{r_{23}}\right)$

37. Three charges are placed at the vertex of an equilateral triangle of side l as shown in figure. For what value of Q, the electrostatic potential energy of the system is zero?



(a) $-q$ (b) $q/2$ (c) $-2q$ (d) $-q/2$

38. In the figure, proton moves a distance d in a uniform electric field E as shown in the figure. Does the electric field do a positive or negative work on the proton? Does the electric potential energy of the proton increase or decrease?

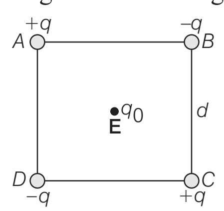


(a) Negative, increase (b) Positive, decrease
(c) Negative, decrease (d) Positive, increase

39. Work done in moving a charge from one point to other inside a uniformly charged conducting sphere is

(a) always zero (b) non-zero
(c) may be zero (d) None of these

40. Four charges are arranged at the corners of a square $ABCD$ of side d, as shown in the figure. The work required to put together this arrangement is



(a) $\frac{-q^2}{4\pi\varepsilon_0 d}(4-\sqrt{2})$ (b) $\frac{-q^3}{4\pi\varepsilon_0 d}(4-\sqrt{2})$

(c) $\frac{-q^4}{4\pi\varepsilon_0 d}(4-\sqrt{2})$ (d) $\frac{q^2}{4\pi\varepsilon_0 d}(4-\sqrt{2})$

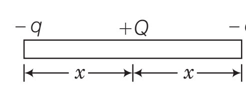
41. An electric dipole of length 1cm is placed with the axis making an angle of 30° to an electric field of strength 10^4 N/C. If it experiences a torque of $10\sqrt{2}$ Nm, the potential energy of the dipole is

(a) 0.245 J (b) 2.45 J (c) 24.5 J (d) 245.0 J

42. Two charges of equal magnitude q are placed in air at a distance $2a$ apart and third charge $-2q$ is placed at mid-point. The potential energy of the system is (ε_0 = permittivity of free space)

(a) $-\frac{q^2}{8\pi\varepsilon_0 a}$ (b) $-\frac{3q^2}{8\pi\varepsilon_0 a}$ (c) $-\frac{5q^2}{8\pi\varepsilon_0 a}$ (d) $-\frac{7q^2}{8\pi\varepsilon_0 a}$

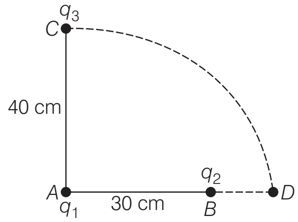
43. Three charges $-q$, $+Q$ and $-q$ are placed in a straight line as shown.



If the total potential energy of the system is zero, then the ratio q/Q is

(a) 2 (b) 5.5 (c) 4 (d) 1.5

44. Two charges q_1 and q_2 are placed 30 cm apart, as shown in the figure. A third charge q_3 is moved along the arc of a circle of radius 40 cm from C to D. The change in the potential energy of the system is $\frac{q_3}{4\pi\varepsilon_0}k$, where k is

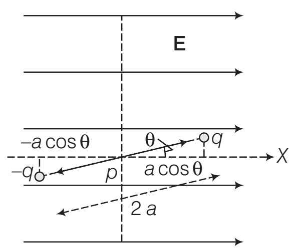


(a) $8q_2$ (b) $8q_1$ (c) $6q_2$ (d) $6q_1$

45. Three point charges $+q_1, -2q$ and $-2q$ are placed at the vertices of an equilateral triangle of side a. The work done by some external force to increase their separation to $2a$ will be

(a) $\frac{1}{4\pi\varepsilon_0}\frac{2q^2}{a}$ (b) $\frac{1}{4\pi\varepsilon_0}\frac{q^2}{2a}$ (c) $\frac{1}{4\pi\varepsilon_0}\frac{\delta q}{a^2}$ (d) zero

46. Suppose an external torque τ_{ext} is applied on dipole and rotates it in the plane of paper from angle θ_0 to an angle θ_1 at an infinitesimal angular speed and without angular acceleration. The amount of work done by the external torque will be given by



(a) $pE(\cos\theta_1 - \cos\theta_0)$ (b) $-2\,pE(\cos\theta_1 - \cos\theta_0)$
(c) $pE(\cos\theta_0 - \cos\theta_1)$ (d) $-2\,pE(\cos\theta_0 - \cos\theta_1)$

47. Determine the electrostatic potential energy of a system consisting of two charges 7μC and -2μC (and with no external field) placed at (− 9 cm, 0, 0) and (9 cm, 0, 0), respectively

(a) 0.7 J (b) − 0.7 J
(c) 70 J (d) − 70 J

48. According to Q.no. 47, how much work is required to separate the two charges infinitely away from each other?

(a) 7 J (b) − 7 J (c) 0.7 J (d) 70 J

49. Suppose that the same system of charges is now placed in an external electric field $E = A\,(1/r^2)$; $A = 9\times10^5$ cm^{-2}. What would the electrostatic energy of the configuration be?

(a) 49 J (b) 49.3 J
(c) − 49.3 J (d) 45 J

50. A molecule of a substance has a permanent electric dipole moment of magnitude 10^{-29} Cm. A mole of this substance is polarised (at low temperature) by applying a strong electrostatic field of magnitude 10^6 Vm^{-1}. The direction of the field is suddenly changed by an angle of 60°. Estimate the heat released by the substance in aligning its dipoles along the new direction of the field.

(a) − 3 J (b) 3 J (c) − 6 J (d) 6 J

51. An electric dipole, made up of positive and negative charges each of 3.5 μC and placed at a distance 4.2 cm apart is placed in an electric field of 5.87×10^5 NC^{-1}. What will be the maximum torque which the field can exert on the dipole? Also, obtain the work that must be done to turn the dipole from 0° to 180°.

(a) 85.26×10^{-3} Nm^{-1}, 1.70×10^{-1} J
(b) 75.26×10^{-3} Nm^{-1}, 1.70×10^{-1} J
(c) 85.26×10^{-3} Nm^{-1}, 3.70×10^{-3} J
(d) 55.26×10^{-3} Nm^{-1}, 1.70×10^{-3} J

52. What happens when a conductor is placed in an external electric field?

(a) The free charge carriers move and charge distribution in the conductor adjusts itself in such a way that the electric field due to induced charge opposes the external field within the conductor
(b) In the static situation, the two fields cancel each other and the electrostatic field in the conductor is zero
(c) Both (a) and (b)
(d) Neither (a) nor (b)

53. Which of the following is/are the example of non-polar molecules?

(a) Oxygen (b) Hydrogen
(c) Nitrogen (d) All (a), (b) and (c)

54. The examples of polar molecules are

(a) HCl (b) H_2O
(c) NH_3 (d) All (a), (b) and (c)

55. The total dipole moment of dielectric with polar molecules in absence of an external electric field is

(a) zero (b) negative
(c) infinite (d) None of these

56. The extent of polarisation depends on

(a) the dipole potential energy in the external field tending to align the dipoles with the field
(b) thermal energy tending to disrupt the alignment
(c) Both (a) and (b)
(d) Neither (a) nor (b)

57. For linear isotropic dielectric, the polarisation is

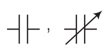
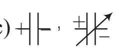
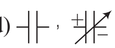
(a) $\mathbf{p} = \chi_e\,\mathbf{E}$ (b) $\mathbf{p} = -\chi_e\,\mathbf{E}$
(c) $\mathbf{p} = 2\chi_e\,\mathbf{E}$ (d) $\mathbf{p} = \frac{\chi_e}{\mathbf{E}}$

58. When a dielectric is placed in an electric field, the electric field inside a dielectric
(a) increases (b) decreases
(c) constant (d) zero

59. When **P** is normal to the surface, the polarisation is numerically equal to the
(a) surface density of the induced charge
(b) dipole moment
(c) Both (a) and (b)
(d) Neither (a) nor (b)

60. The dielectric constant of helium at $0° C$ and 1 atmospheric pressure is 1.00074. Find the dipole moment induced in each helium atom when the gas is in an electric field of intensity 10 Vm^{-1}.
(a) 2.4×10^{40} C - m
(b) 2.4×10^{-39} C-m
(c) 2.6×10^{-39} C-m
(d) 1.5×10^{40} C-m

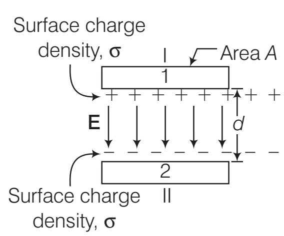
Topic 3
Capacitance and Van de Graaff Generator

61. The symbols of a capacitor with fixed capacitance and with variable capacitance is
(a)  (b)  (c)  (d) 

62. The maximum electric field that a dielectric medium of a capacitor can withstand without break down (of its insulating property) is called its
(a) polarisation (b) capacitance
(c) dielectric strength (d) None of these

63. A parallel-plate capacitor has circular plates of radius 8 cm and plate separation 1 mm. What will be the charge on the plates if a potential difference of 100 V is applied?
(a) 1.78×10^{-8} C (b) 1.78×10^{-5} C
(c) 4.3×10^{4} C (d) 2×10^{-9} C

64. Let A be the area of each plate and d the separation between them. The two plates have charges Q and $-Q$. Since, d is much smaller than the linear dimension of the plates ($d^2 << A$), plate 1 has surface charge density $\sigma = Q/A$ and plate 2 has a surface charge density $-\sigma$. The electric field in outer region I (region above the plate 1)

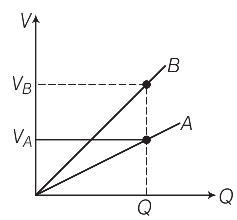


(a) $\frac{\sigma}{2\varepsilon_0}$ (b) $-\frac{\sigma}{2\varepsilon_0}$ (c) zero (d) $\frac{2\sigma}{4\varepsilon_0}$

65. What is the value of capacitance if the very thin metallic plate is introduced between two parallel plates of area A and separated at distance d?
(a) $\varepsilon_0 A/d$ (b) $\frac{2\varepsilon_0 A}{d}$ (c) $\frac{4\varepsilon_0 A}{d}$ (d) $\frac{\varepsilon_0 A}{2d}$

66. The plates of a parallel plate capacitor are not exactly parallel. The surface charge density
(a) is lower at the closer end
(b) will not uniform
(c) each plate will have the same potential at every point
(d) Both (b) and (c)

67. The graph shows the variation of voltage V across the plates of two capacitors A and B *versus* increase of charge Q stored in them. Which of the capacitors has higher capacitance?



(a) Capacitor A (b) Capacitor B
(c) Both (a) and (b) (d) None of these

68. A parallel plate air capacitor has a capacitance $18 \mu F$. If the distance between the plates is tripled and a dielectric medium is introduced, the capacitance becomes $72 \mu F$. The dielectric constant of the medium is
(a) 4 (b) 9 (c) 12 (d) 2

69. If dielectric constant and dielectric strength be denoted by K and X respectively, then a material suitable for use as a dielectric in a capacitor must have
(a) high K and high X (b) high K and low X
(c) low K and high X (d) low K and low X

70. Taking earth to be a metallic spheres. Its capacity will approximately be
(a) 6.4×10^{6} F (b) 700 F
(c) $711 \mu F$ (d) 700 pF

71. The plates in a parallel plates capacitor are separated by a distance d with air as the medium between the plates. In order to increase the capacity by 66% a dielectric slab of thickness $\frac{3d}{5}$ is introduced between the plates. What is the dielectric constant of the dielectric slab?

(a) 1.5 (b) 1.66
(c) 3 (d) 5

72. In a parallel plate capacitor the separation between the plates is 3 mm with air between them. Now, a dielectric of dielectric constant 2 is introduced between the plates due to which the capacity increases. In order to bring its capacity of the original value the separation between the plates must be made

(a) 1.5 mm (b) 2.5 mm
(c) 4 mm (d) 6 mm

73. The capacitance of a parallel plate capacitor with air a medium is $3\,\mu F$ with the introduction of dielectric medium between the plates, the capacitance becomes $15\,\mu F$. The permittivity of the medium is

(a) $5\ C^2\ N^{-1}m^{-2}$
(b) $15\ C^2 N^{-1}m^{-2}$
(c) $0.44\times 10^{-10}\ C^2\ N^{-1}m^{-2}$
(d) $8.845\times 10^{-11}\ C^2\ N^{-1}m^{-2}$

74. A capacitor connected to a 10 V battery collects a charge of $40\,\mu C$ with air as dielectric and $100\,\mu C$ with a given oil as dielectric. The dielectric constant of the oil is

(a) 1.5 (b) 2.0
(c) 2.5 (d) 3.0

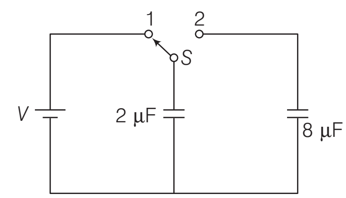
75. Two capacitors C_1 and C_2 are charged to 120 V and 200 V respectively. It is found that by connecting them together the potential on each one can be made zero. Then, **[JEE Main 2013]**

(a) $5C_1 = 3C_2$ (b) $3\,C_1 = 5C_2$
(c) $3C_1 + 5C_2 = 0$ (d) $9\,C_1 = 4C_2$

76. A slab of material of dielectric constant K has the same area as the plates of a parallel plate capacitor but has a thickness $(3/4)d$, where d is the separation of the plates. How is the capacitance changed when the slab is inserted between the plates?

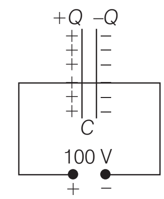
(a) $\frac{4K}{K+3}C_0$
(b) $\frac{K+3}{4K}C_0$
(c) $\frac{K-3}{4K}C_0$
(d) $\frac{4K}{K-3}C_0$

77. A capacitor of $2\,\mu F$ is charged as shown in the figure. When the switch S is turned to position 2, the percentage of its stored energy dissipated is **[NEET 2016]**



(a) 20% (b) 75% (c) 80% (d) 0%

78. A 900 pF capacitor is charged by 100 V battery in the figure. How much electrostatic energy is stored by the capacitor?



(a) 45×10^{-6} J (b) 4.5×10^{6} J
(c) 4.5×10^{-6} J (d) 0.45×10^{5} J

79. Three capacitors each of capacity $4\,\mu F$ are to the connected in such a way that the effective capacitance is $6\,\mu F$. This can be done by

(a) connecting two in series and one in parallel
(b) connecting two in parallel and one in series
(c) connecting all of them in series
(d) connecting all of them in parallel

80. A gang capacitor is formed by interlocking nine plates with each other. The distance between the consecutive plates is 0.885 cm and the overlapping area of the plate is 5 cm^2. The capacity of the unit is

(a) 1.06 pF (b) 4 pF
(c) 6.36 pF (d) 12.72 pF

81. A parallel plate capacitor is connected to a 5V battery and charged. The battery is then disconnected and a glass slab is introduced between the plates. Then, the quantities that decrease are

(a) charge and potential difference
(b) charge and capacitance
(c) capacitance and potential difference
(d) energy stored and potential difference

82. When a series combination of two uncharged capacitors is connected to a 12 V battery, $173\,\mu J$ of energy is drawn from the battery. If one of the capacitors has a capacitance of $4\mu F$, the capacitance of the other capacitor (in μF) is

(a) 8 (b) 4 (c) 2 (d) 6

83. A parallel plate capacitor has the space between its plates filled by the two slabs of thickness $\frac{d}{2}$ each and dielectric constants K_1 and K_2, d is the plate separation of the capacitor. The capacity of the capacitor is

(a) $\frac{2\varepsilon_0 d}{A}\left(\frac{K_1+K_2}{K_1K_2}\right)$

(b) $\frac{2\varepsilon_0 A}{d}\left(\frac{K_1K_2}{K_1+K_2}\right)$

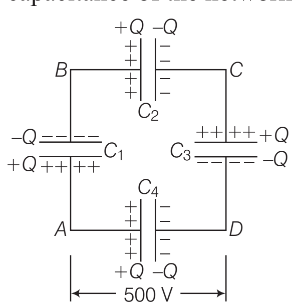
(c) $\frac{2\varepsilon_0 A}{A}(K_1+K_2)$

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

84. Across each of two capacitors of capacitance 1μF, a potential difference of 10 V is applied. Then, positive plate of one is connected to the negative plate of the other and negative plate of one is connected to the positive plate of the other. After contact

(a) charge on each is zero
(b) charge on each is same but non-zero
(c) charge on each is different but non-zero
(d) None of the above

85. A network of four 10μF capacitors is connected to a 500 V supply as shown in figure. Determine the equivalent capacitance of the network.

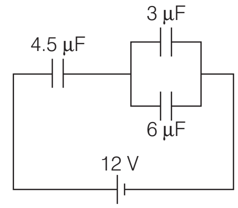


(a) 12μF
(b) 13.3μF
(c) 11.5μF
(d) 14μF

86. A number of condensers, each of the capacitance 1μF and each one of which gets punctured, if a potential difference just exceeding 500 V is applied are provided.
In arrangement suitable for giving capacitance of 2μF across which 3000 V may be applied requires at least

(a) 6 component capacitors
(b) 12 component capacitors
(c) 72 component capacitors
(d) 2 component capacitors

87. In the circuit shown in the figure, the potential difference across the 4.5 μF capacitor is



(a) $\frac{8}{3}$ V (b) 4 V (c) 6 V (d) 8 V

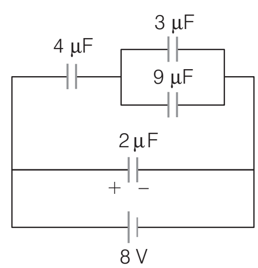
88. A series combination of n_1 capacitors, each of value C_1, is charged by a source of potential difference 4V. When another parallel combination of n_2 capacitors, each of value C_2, is charged by a source of potential difference V, it has the same (total) energy stored in it, as the first combination has. The value of C_2 in terms of C_1 is

(a) $\frac{2C_1}{n_1n_2}$ (b) $16\frac{n_1}{n_2}$ (c) $2\frac{n_2}{n_1}C_1$ (d) $\frac{16C_1}{n_1n_2}$

89. A parallel plate capacitor is made of two circular plates separated by a distance of 5 mm and with a dielectric of dielectric constant 2.2 between them. When the electric field in the dielectric is 3×10^4 V/m, the charge density of the positive plate will be closed to **[JEE Main 2014]**

(a) 6×10^{-7} Cm^{-2}
(b) 3×10^{-7} Cm^{-2}
(c) 3×10^{4} Cm^{-2}
(d) 6×10^{4} Cm^{-2}

90. A combination of capacitors is setup as shown in the figure. The magnitude of the electric field due to a point charge Q (having a charge equal to the sum of the charges on the 4μF and 9μF capacitors), at a point distance 30 m from it, would equal to **[JEE Main 2016]**



(a) 240 N/C
(b) 360 N/C
(c) 420 N/C
(d) 480 N/C

91. A parallel plate air capacitor of capacitance C_0 is connected to a cell of emf V and then disconnected from it. A dielectric slab of dielectric constant K, which can just fill the air gap of the capacitor, is now inserted in it.

Which of the following is incorrect?

(a) The potential difference between the plates decreases K times

(b) The energy stored in the capacitor decreases K times

(c) The change in energy $\frac{1}{2}C_0V^2(K-1)$

(d) The change in energy $\frac{1}{2}C_0V^2\left(\frac{1}{K}-1\right)$

92. A capacitor is charged by a battery and the energy stored is U. The battery is now removed and the separation distance between the plates is doubled. The energy stored now is

(a) $U/2$ (b) U (c) $2U$ (d) $4U$

93. The potential energy of a charged parallel plate is U_0. If a slab of dielectric constant K is inserted between the plates, then the new potential energy will be

(a) $\frac{U_0}{K}$ (b) U_0K^2 (c) $\frac{U_0}{K^2}$ (d) U_0^2K

94. A parallel plate capacitor has a uniform electric field (Vm^{-1}) in the space between the plates. If the distance between the plates is d(m) and area of each plate is $A(m^2)$ the energy (joule) stored in the capacitor, is

(a) $\frac{1}{2}\varepsilon_0E^2$ (b) ε_0EAd (c) $\frac{1}{2}\varepsilon_0E^2Ad$ (d) E^2Ad/ε_0

95. A small sphere of radius r_1 having charge q_1 is enclosed by a spherical shell of radius r_2 having charge q_2. Which charge will necessarily flow from the sphere to the shell, when connected

(a) q_1 (b) q_2

(c) Both (a) and (b) (d) May be q_2

96. Van de Graaff generator is used to

(a) store electrical energy

(b) build up high voltages of few million volts

(c) decelerate charged particle like electrons

(d) Both (a) and (b) are correct

97. Which of the following statement(s) is/are true about the principle of Van de Graaff generator?

(a) The action of sharp points

(b) The charge given to a hollow conductor is transferred to outer surface and is distributed uniformly over it

(c) It is used for accelerating uncharged particle

(d) Both (a) and (b) are true

98. In a Van de Graaff type generator, a spherical metal shell is to be at a 1.5×10^6 V. The dielectric strength of the gas surrounding the electrode is $5\times10^7\ Vm^{-1}$. What is minimum radius of the spherical shell required?

(a) 0.3 cm (b) 0.03 cm (c) 30 cm (d) 3 m

Special Format Questions

I. Assertion and Reason

Directions (Q. Nos. 99-108) *In the following questions, a statement of assertion is followed by a corresponding statement of reason. Of the following statements, choose the correct one.*

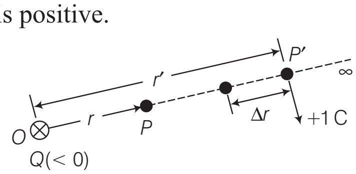
(a) Both Assertion and Reason are correct and Reason is the correct explanation of Assertion.

(b) Both Assertion and Reason are correct but Reason is not the correct explanation of Assertion.

(c) Assertion is correct but Reason is incorrect.

(d) Assertion is incorrect but Reason is correct.

99. Assertion Work done by the electrostatic force in bringing the unit positive charge from infinity to the point P is positive.



Reason For $Q<0$, the force on unit positive charge is attractive, so that the electrostatic force and the displacement (from infinity to P) are in the same direction.

100. Assertion A and B are two conducting spheres of same radius. A being solid and B hollow. Both are charged to the same potential. Then, charge on A = charge on B.

Reason Potential on both are same.

101. Assertion There is no potential difference between any two points on the equipotential surface.

Reason No work is required to move a test charge on the equipotential surface from one point to other.

102. Assertion The expression of potential energy $U=\frac{1}{4\pi\varepsilon_0}\frac{q_1q_2}{r_{12}}$, is unaltered whatever way the charges are brought to the specified locations.

Reason Path-independence of work for electrostatic force.

103. **Assertion** In the absence of an external electric field, the dipole moment per unit volume of a polar dielectric is zero.

Reason The dipoles of a polar dielectric are randomly oriented.

104. **Assertion** Polar molecules have permanent dipole moment.

Reason In polar molecules, the centre of positive and negative charges coincides even when there is no external field.

105. **Assertion** Charge on all the condensers connected in series is the same.

Reason Capacitance of capacitor is directly proportional to charge on it.

106. **Assertion** An electron moves from a region of lower potential to a region of higher potential.

Reason An electron has a negative charge.

107. **Assertion** A parallel plate capacitor is connected across a battery through a key. A dielectric slab of dielectric constant K is introduced between the plates. The energy which is stored becomes K times.

Reason The surface density of charge on the plate remains constant or unchanged.

108. **Assertion** If three capacitors of capacitances $C_1 < C_2 < C_3$ are connected in parallel, and in series then their equivalent capacitances.

$$C_p > C_s$$

Reason $\dfrac{1}{C_p} = \dfrac{1}{C_1} + \dfrac{1}{C_2} + \dfrac{1}{C_3}$

II. Statement Based Questions Type I

■ **Directions** (Q. Nos. 109-113) *In the following questions, a statement I is followed by a corresponding statement II. Of the following statements, choose the correct one.*

(a) Both Statement I and Statement II are correct and Statement II is the correct explanation of Statement I.
(b) Both Statement I and Statement II are correct but Statement II is not the correct explanation of Statement I.
(c) Statement I is correct but Statement II is incorrect.
(d) Statement I is incorrect but Statement II is correct.

109. **Statement I** For a charged particle moving from point P to point Q, the net work done by an electrostatic field on the particle is independent of the path connecting point P to point Q.

Statement II The net work done by a conservative force on an object moving along a closed loop is zero.

110. **Statement I** A capacitor can be given only a limited quantity of charge.

Statement II Charge stored by a capacitor depends upon the shape and size of the plates of capacitor and the surrounding medium.

111. **Statement I** Capacity of a parallel plate capacitor increases when distance between the plates is decreased.

Statement II Capacitance of a capacitor is directly proportional to distance between them.

112. **Statement I** The capacity of a conductor, under given circumstance, remains constant irrespective of the charge present on it.

Statement II Capacity depends on size and shape of conductor and also on the medium.

113. **Statement I** A charged capacitor is disconnected from a battery. Now if its plates are separated further, the potential energy will fall.

Statement II Energy stored in a capacitor is equal to the work done in charging it.

Statement Based Questions Type II

114. I. In a metal, the outer (valence) electrons part away from their atoms and are free to move.
II. The valence electrons are within the metal but not free to leave the metal.
III. The free electrons form a kind of gas; they collide with each other and with the ions and move randomly in different directions.

(a) I and II are correct, III may be correct
(b) I and III are correct, II may be correct
(c) I, II and III are incorrect
(d) I, II and III are correct

115. I. In metals, the positive ions made up of the nuclei and the bound electrons remain held in their fixed positions.
II. In electrolytic conductors, the charge carriers are both positive and negative ions.

(a) I is correct, II may be correct
(b) II is correct, I is incorrect
(c) I and II are incorrect
(d) I and II are correct

116. I. The molecules of a substance may be polar or non-polar.
II. In a non-polar molecule, the centres of positive and negative charge coincide.
III. The non-polar molecule has no permanent (or intrinsic) dipole moment.
(a) I, II are correct, III may be correct
(b) I and III are correct, II may be correct
(c) II and III are correct, I is incorrect
(d) I, II and III are correct

117. I. In an external electric field, the positive and negative charges of a non-polar molecule are displaced in opposite directions.
II. In non-polar molecules displacement stops when the external force on the constituent charges of the molecule is balanced by the restoring force.
III. The non-polar molecule develops an induced dipole moment.
(a) I, II are III are correct
(b) I, II and III are incorrect
(c) I and II are correct, III is incorrect
(d) I and III are correct, II is incorrect

118. I. Electrostatic force is conservative.
II. Van de Graaff generator is a machine that can build up high voltages of the order of a few million volts.
III. In Van de Graaff generator, electric fields are used to accelerate charged particle to high energies.
Which of the following statement(s) is/are correct?
(a) I and II are correct, III may be correct
(b) I and III are correct, II may be correct
(c) I, II and III are correct
(d) II and III are correct, I may be correct

III. Matching Type

119. Match the following columns.

Column I	Column II
A. 1 keV	1. 1.6×10^{-7} J
B. 1 MeV	2. 1.6×10^{-10} J
C. 1 GeV	3. 1.6×10^{-16} J
D. 1 TeV	4. 1.6×10^{-13} J

	A	B	C	D
(a)	4	2	3	1
(b)	3	4	2	1
(c)	2	3	4	1
(d)	1	4	3	2

120. Match the following columns and choose the correct options from codes given below. Consider the large plates, each of area A, separated by a distance d. The charge on the plates is $\pm Q$, corresponding to the charge density $\pm\sigma$ (with $\sigma = Q/A$).

Column I	Column II
A. Electric field between the plates E_0	1. $\varepsilon_0 A/d$
B. Potential difference V_0	2. σ/ε_0
C. The capacitance C_0	3. $E_0 d$

	A	B	C		A	B	C
(a)	1	2	3	(b)	2	3	1
(c)	3	2	1	(d)	3	1	2

121. Match the following columns and choose the correct options from code given below. Consider a dielectric inserted between the plates fully occupying the intervening region. The surface charge densities on the charged plates are $\pm\sigma$.

Column I	Column II
A. Electric field E	1. $Qd/A\varepsilon_0 K$
B. Potential difference across the plates V	2. $(\sigma - \sigma_p)/\varepsilon_0$
C. The capacitance C, with dielectric between the plates	3. C/C_0
D. Dielectric constant of the substance (K)	4. $\varepsilon_0 KA/d$

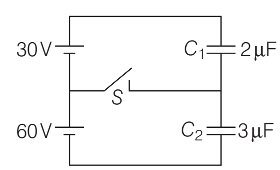
	A	B	C	D		A	B	C	D
(a)	1	2	3	4	(b)	2	1	4	3
(c)	3	4	1	2	(d)	4	2	3	1

122. A capacitor C_1 of capacitance C is charged to a potential difference V_0. The terminals of the charged capacitor are then connected to an uncharged capacitor C_2 of capacitance $C/2$.

Column I	Column II
A. Final energy of capacitor C_1	1. $-(1/6)\,CV_0^2$
B. Final energy of capacitor C_2	2. $(1/6)\,CV_0^2$
C. Final energy of the system	3. $(1/3)\,CV_0^2$
D. Change in energy on joining the capacitors	4. $(2/9)\,CV_0^2$
	5. $(1/9)\,CV_0^2$

	A	B	C	D		A	B	C	D
(a)	1	2	3	5	(b)	4	5	3	1
(c)	5	4	3	1	(d)	1	2	3	4

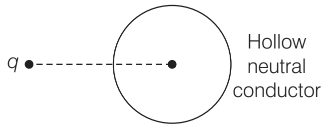
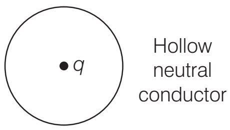
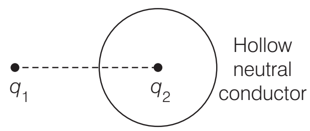
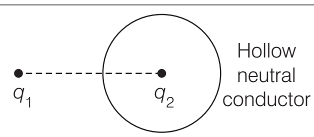
123. Match the entries of Column I with the entries of Column II and choose the correct option from the codes given below.



Column I	Column II
A. 108 μC	1. Charge on both the capacitors (S open)
B. 180 μC	2. Charge on both the capacitors (S closed)
C. 60 μC	3. Charge on C_1 (S closed)
D. 240 μC	4. Charge on C_2 (S closed)

	A	B	C	D		A	B	C	D
(a)	1	2	3	4	(b)	4	3	2	1
(c)	1	4	3	2	(d)	1	3	2	4

124. Match the entries of Column I with entries of Column II.

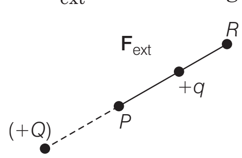
	Column I		Column II
A.		1.	**E** inside the conductor is zero.
B.		2.	| **E** | inside the conductor is constant but not zero.
C.		3.	| **E** | inside the conductor is varying.
D.		4.	Potential inside the conductor is same as that of conductor.
		5.	Potential inside the conductor is varying.

	A	B	C	D
(a)	1, 4	3, 5	3, 5	3, 5
(b)	4, 1	3, 4	2, 3	4, 2
(c)	1, 4	3, 5	2, 3	3, 4
(d)	3, 5	2, 3	4, 1	1, 4

IV. Passage Based Questions

■ **Directions** (Q. Nos. 125-127) *Answer the following questions are based on the given figure followed by a paragraph. Choose the correct option from those given below.*

A test charge $+q$ is taken from point R to point P against repulsive electrostatic force by the application of an extended force $\mathbf{F}_{\text{ext}}$ as shown figure.



125. If the change in potential energy of charge q from R to P is 3 J, then work done by electric field is

(a) 3 J (b) zero
(c) $-$ 3 J (d) Cannot be determined

126. If potential energy at P is 5 J and the change in potential is 2 J, then the potential energy at R is

(a) $-$ 3 J (b) + 3 J
(c) zero (d) Cannot be determined

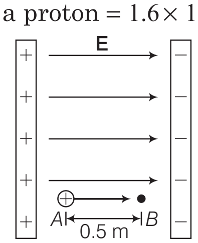
127. If the test charge is moved back to R from P, then total work done by electric field is

(a) 3 J (b) zero
(c) Cannot be determined (d) None of these

■ **Directions** (Q. Nos. 128-131) *Answer the following questions are based on the given figure followed by a paragraph. Choose the correct option from those given below.*

Potential difference (ΔV) between two points A and B separated by a distance x, in a uniform electric field $\mathbf{E}$ is given by $\Delta V = -Ex$, where x is measured parallel to the field lines. If a charge q_0 moves from A to B 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 8.0×10^4 Vm^{-1} directed along the positive X-axis. The proton undergoes a displacement of 0.50 m in the direction of E.

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



With the help of the passage given above, choose the most appropriate alternative for each of the following questions.

128. As the proton moves from A to B, 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

129. The change in electric potential of the proton between the points A and B is

(a) 4.0×10^4 V (b) -4.0×10^4 V
(c) 6.4×10^{-19} V (d) -6.4×10^{-19} V

130. The change in electric potential energy of the proton for displacement from A to B is

(a) -6.4×10^{-19} J
(b) 6.4×10^{-19} J
(c) -6.4×10^{-15} J
(d) 6.4×10^{-15} J

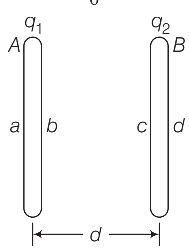
131. The velocity (v_B) of the proton after it has moved 0.50 m starting from rest is

(a) 1.6×10^8 ms^{-1} (b) 2.77×10^6 ms^{-1}
(c) 2.77×10^4 ms^{-1} (d) 1.6×10^6 ms^{-1}

■ **Directions** (Q. Nos. 132-136) *Answer of the following questions are based on the given figure followed by a paragraph. Choose those correct option from these given below.*

The electric field due to a plane sheet of charge having charge q and area A is given by $E = \frac{q}{2\varepsilon_0 A}$. Further, with usual notation, in case of a parallel-plate capacitor,

$$E = \frac{q}{\varepsilon_0 A}, V = \frac{qd}{\varepsilon_0 A} \quad \text{and} \quad C = \frac{\varepsilon_0 A}{d}$$



Let us now consider that the charges given to the two plates A and B of a parallel-plate capacitor are different, *i.e.*, q_1 and q_2 as shown in figure.

With the help of the paragraph given above, choose the most appropriate alternative for each of the following questions.

132. The charges on the surfaces a and b of the plate A are

(a) $\frac{q_1 + q_2}{2}, \frac{q_1 - q_2}{2}$ (b) $\frac{q_1 - q_2}{2}, \frac{q_2 - q_1}{2}$

(c) $\frac{q_1 + q_2}{2}, \frac{q_1 + q_2}{2}$ (d) $\frac{q_1 + q_2}{2}, \frac{q_2 - q_1}{2}$

133. The charges on the surfaces c and d of the plate B, are

(a) $\frac{q_1 - q_2}{2}, \frac{q_2 - q_1}{2}$ (b) $\frac{q_2 - q_1}{2}, \frac{q_1 + q_2}{2}$

(c) $\frac{q_1 + q_2}{2}, \frac{q_1 + q_2}{2}$ (d) $\frac{q_1 + q_2}{2}, \frac{q_2 - q_1}{2}$

134. The electric field between the two plates A and B, is

(a) $\frac{q_1 + q_2}{2\varepsilon_0 A}$ (b) $\frac{q_1 - q_2}{2\varepsilon_0 A}$ (c) $\frac{q_2 - q_1}{2\varepsilon_0 A}$ (d) $\frac{q_1 + q_2}{\varepsilon_0 A}$

135. The potential difference between the two plates A and B, is

(a) $\frac{(q_1 + q_2) d}{2\varepsilon_0 A}$ (b) $\frac{(q_2 - q_1) d}{2\varepsilon_0 A}$

(c) $\frac{(q_1 - q_2) d}{2\varepsilon_0 A}$ (d) $\frac{(q_1 + q_2) d}{\varepsilon_0 A}$

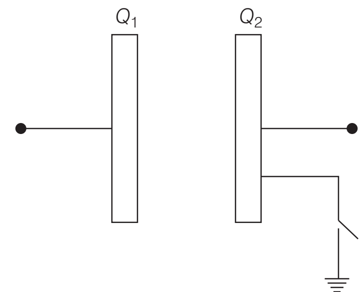
136. The capacitance of the capacitor is given by

(a) $\frac{\varepsilon_0 A}{2d}$ (b) $\frac{\varepsilon_0 A}{d}$

(c) $\frac{2\varepsilon_0 A}{d}$ (d) $\frac{2(q_1 + q_2)\varepsilon_0 A}{(q_1 - q_2) d}$

V. More than One Option Correct

137. The two plates of a parallel plate capacitors charges Q_1 and Q_2 are given. The capacity of the capacitor is C. When the switch is closed, mark the correct statement(s). Assuming both Q_1, Q_2 to be positive.



(a) The charge flown through switch is zero.
(b) The charge flown through switch is $Q_1 + Q_2$
(c) Potential difference across the capacitor plates is $\frac{Q_1}{C}$.
(d) The charge of the capacitor is Q_1.

138. A parallel plate capacitor is charged and the charging battery is then disconnected.

If the plates of the capacitor are moved further apart by means of insulating handles, then which of the following is correct?

(a) The charge on the capacitor increases
(b) The voltage across the plates increases
(c) The capacitance increases
(d) The electrostatic energy stored in the capacitor increases

139. A 900 pF capacitor is charged by 100 V battery.

(a) The charge on the capacitor is 9×10^{-8} C
(b) The energy stored by the capacitor is 4.5×10^{-6} J
(c) If capacitor is disconnected from the battery and connected to another 900 pF capacitor, then energy stored by the system is 2.25×10^{-6} J
(d) None of the above

140. If a charged conductor is enclosed by a hollow charged conducting shell (assumed concentric and spherical in shape), and they are connected by a conducting wire, then which of the following statement (s) would be correct?

(a) Potential difference between two conductors becomes zero.
(b) If charge on inner conductor is q and on outer conductor is $2q$, then finally charge on outer conductor will be $3q$.
(c) The charge on the inner conductor is not totally transferred to the outer conductor.
(d) If charge on the inner conductor is q and charge on the outer conductor is zero, then finally charge on each conductor will be $q/2$.

NCERT & NCERT Exemplar Questions

NCERT

141. Two charges 5×10^{-8} C and -3×10^{-8} C are located 16 cm apart. At what point(s) from +ve charge on the line joining the two charges is the electric potential zero? Take the potential at infinity to be zero.

(a) 6 cm, 30 cm (b) 8 cm, 40 cm
(c) 10 cm, 40 cm (d) 30 cm, 40 cm

142. A regular hexagon of side 10 cm has a charge 5 μC at each of its vertices. Calculate the potential at the centre of the hexagon.

(a) 3.7×10^{-6} V
(b) 2.7×10^{-6} V
(c) 2.7×10^{-4} V
(d) 3.7×10^{-4} V

143. A parallel plate capacitor with air between the plates has a capacitance of 8 pF (1 pF = 10^{-12} F). What will be the capacitance, if the distance between the plates is reduced by half and the space between them is filled with a substance of dielectric constant 6?

(a) 24 pF (b) 96 pF (c) 8 pF (d) 12 pF

144. Three capacitors each of capacitance 9 pF are connected in series. What is the potential difference across each capacitor, if the combination is connected to a 120 V supply?

(a) 40 V (b) 60 V (c) 80 V (d) 50 V

145. In a parallel plate capacitor with air between the plates, each plate has an area of 6×10^{-3} m^2 and the distance between the plates is 3 mm. If this capacitor is connected to a 100 V supply, what is the charge on each plate of the capacitor?

(a) 1.77×10^{-9} C (b) 2.77×10^{-9} C
(c) 1×10^{-8} C (d) 4.7×10^{-6} C

146. A 600 pF capacitor is charged by a 200 V supply. Then, it is disconnected from the supply and is connected to another uncharged 600 pF capacitor. How much electrostatic energy is lost in the process?

(a) 12×10^{-6} J (b) 8×10^{-6} J
(c) 6×10^{-6} J (d) 4×10^{-6} J

147. A charge of 8 mC is located at the origin. Calculate the work done in taking a small charge of -2×10^{-9} C from a point $P(0, 0, 3)$ (in cm) to a point Q (0, 4, 0) (in cm), *via* a point R (0, 6, 9) (in cm).

(a) 2.4 J (b) 1.2 J (c) 2 J (d) 3.6 J

148. A cube of side b has a charge q at each of its vertices. Determine the potential due to this charge array at the centre of the cube.

(a) $\frac{4\sqrt{3}q}{\pi\varepsilon_0 b}$ (b) $\frac{3q}{\pi\varepsilon_0 b}$ (c) $\frac{4q}{\sqrt{3}\pi\varepsilon_0 b}$ (d) zero

149. Two tiny spheres carrying charges 1.5 μC and 2.5 μC are located 30 cm apart. Find the potential at a point 10 cm from this mid-point in a plane normal to the line and passing through the mid-point.

(a) 10^5 V (b) 2×10^5 V
(c) 2×10^8 V (d) zero

150. In a hydrogen atom, the electron and proton are bound at a distance of about 0.53 Å.
What is the potential energy of the system in eV, taking the zero of the potential energy at infinite separation of the electron from proton?

(a) + 27.16 eV (b) – 27.16 eV
(c) 13.58 eV (d) – 13.58 eV

NCERT Exemplar

151. A positively charged particle is released from rest in an uniform electric field. The electric potential energy of the charge

(a) remains a constant because the electric field is uniform
(b) increases because the charge moves along the electric field
(c) decreases because the charge moves along the electric field
(d) decreases because the charge moves opposite to the electric field

152. Figure shows some equipotential lines distributed in space. A charged object is moved from point A to point B.

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

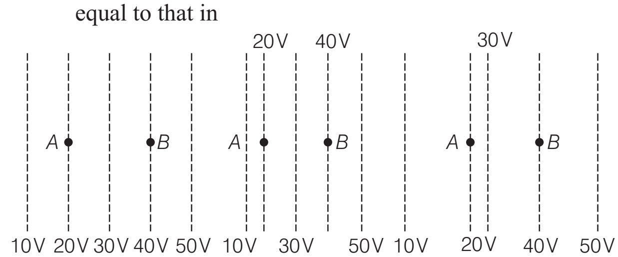


Fig. (i) Fig. (ii) Fig. (iii)

153. The electrostatic potential on the surface of a charged conducting sphere is 100 V. Two statements are made in this regard 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 independant

154. Equipotentials at a great distance from a collection of charges whose total sum is not zero are approximately

(a) spheres

(b) planes

(c) paraboloids

(d) ellipsoids

155. Equipotential surfaces

(a) are closer in regions of large electric fields compared to regions of lower electric fields

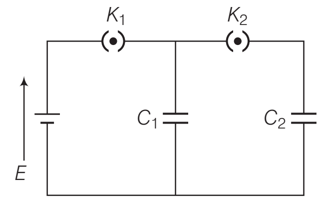
(b) will be more crowded near sharp edges of a conductor

(c) will be more crowded near regions of large charge densities

(d) will always be equally spaced

156. In the circuit shown in figure initially key K_1 is closed and key K_2 is open. Then, K_1 is opened and K_2 is closed (order is important).

[Take Q_1' and Q_2' as charges on C_1 and C_2 and V_1 and V_2 as voltages respectively.]



Then,

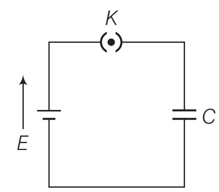
(a) charge on C_1 gets redistributed such that $V_1 = V_2$

(b) charge on C_1 gets redistributed such that $Q_1' = Q_2'$

(c) charge on C_1 gets redistributed such that $C_1V_1 + C_2V_2 = C_1E$

(d) charge on C_1 gets redistributed such that $Q_1' + Q_2' = Q$

157. A parallel plate capacitor is connected to a battery as shown in figure. Consider two situations.



I. Key K is kept closed and plates of capacitors are moved apart using insulating handle.

II. Key K is opened and plates of capacitors are moved apart using insulating handle.

Choose the correct option(s).

(a) In I Q remains same but C changes

(b) In II V remains same but C changes

(c) In I V remains same and hence Q changes

(d) In II Q remains same and hence V changes

Answers

1.	(a)	**2.**	(a)	**3.**	(b)	**4.**	(a)	**5.**	(a)	**6.**	(a)	**7.**	(c)	**8.**	(c)	**9.**	(d)	**10.**	(b)	**11.**	(b)	**12.**	(d)	**13.**	(a)	**14.**	(c)	**15.**	(c)
16.	(a)	**17.**	(c)	**18.**	(c)	**19.**	(a)	**20.**	(c)	**21.**	(d)	**22.**	(a)	**23.**	(b)	**24**	(c)	**25.**	(c)	**26.**	(a)	**27.**	(a)	**28.**	(a)	**29.**	(a)	**30.**	(b)
31.	(d)	**32.**	(a)	**33.**	(b)	**34.**	(b)	**35.**	(d)	**36.**	(a)	**37.**	(d)	**38.**	(a)	**39.**	(a)	**40.**	(a)	**41.**	(c)	**42.**	(d)	**43.**	(c)	**44.**	(a)	**45.**	**(d)**
46.	(c)	**47.**	(b)	**48.**	(c)	**49.**	(b)	**50.**	(b)	**51.**	(a)	**52.**	(c)	**53.**	(d)	**54.**	(d)	**55.**	(a)	**56.**	(c)	**57.**	(a)	**58.**	(b)	**59.**	(a)	**60.**	(b)
61.	(a)	**62.**	(c)	**63.**	(a)	**64.**	(c)	**65.**	(a)	**66.**	(d)	**67.**	(a)	**68.**	(c)	**69.**	(a)	**70.**	(c)	**71.**	(c)	**72.**	(d)	**73.**	(c)	**74.**	(c)	**75.**	(b)
76.	(a)	**77.**	(c)	**78.**	(c)	**79.**	(a)	**80.**	(b)	**81.**	(d)	**82.**	(d)	**83.**	(b)	**84.**	(c)	**85.**	(b)	**86.**	(c)	**87.**	(d)	**88.**	(d)	**89.**	(a)	**90.**	(c)
91.	(d)	**92.**	(c)	**93.**	(a)	**94.**	(c)	**95.**	(a)	**96.**	(b)	**97.**	(d)	**98.**	(c)	**99.**	(a)	**100.**	(a)	**101.**	(a)	**102.**	(a)	**103.**	(a)	**104.**	(c)	**105.**	(c)
106.	(a)	**107.**	(c)	**108.**	(c)	**109.**	(a)	**110.**	(a)	**111.**	(c)	**112.**	(a)	**113.**	(d)	**114.**	(d)	**115.**	(d)	**116.**	(d)	**117.**	(a)	**118.**	(c)	**119.**	(b)	**120.**	(b)
121.	(b)	**122.**	(b)	**123.**	(c)	**124.**	(c)	**125.**	(c)	**126.**	(b)	**127.**	(b)	**128.**	(a)	**129.**	(b)	**130.**	(c)	**131.**	(b)	**132.**	(a)	**133.**	(b)	**134.**	(b)	**135.**	(c)
136.	(b)	**137.**	(b,c,d)	**138.**	(b,d)	**139.**	(a,b,c)	**140.**	(a,b)	**141.**	(c)	**142.**	(b)	**143.**	(b)	**144.**	(a)	**145.**	(a)	**146.**	(c)	**147.**	(b)	**148.**	(c)	**149.**	(b)	**150.**	(b)

Hints *and* Explanations

1. (*a*) Considering potential to be zero at infinity. Work done by an external force in bringing a unit positive charge from infinity to a point without acceleration

= − Work done by electrostatic forces

= Electrostatic potential (V) at that point

2. (*a*) The electrostatic potential (V) at any point in a region with electrostatic field is the work done in bringing a unit positive charge (without acceleration) from infinity to that point.

3. (*b*) The external force at every point of the path is to be equal and opposite to the electrostatic force on the test charge at that point.

4. (*a*) Work done by the electrostatic force in bringing the unit positive charge from infinity to the point P is positive.

5. (*a*) If charge on a conducting sphere of radius R is Q, then potential outside the sphere.

$$V_{\text{out}} = \frac{1}{4\pi\varepsilon_0}\cdot\frac{Q}{r}$$

At the surface of sphere, $V_s = \dfrac{1}{4\pi\varepsilon_0}\cdot\dfrac{Q}{R} = V_{\text{inside}}$

6. (*a*) Thus, work done by external forces in moving a charge q from R to P is

$$W_{RP} = \int_R^P \mathbf{F}_{\text{ext}}\cdot d\mathbf{r} = -\int_R^P \mathbf{F}_E\cdot d\,\mathbf{r}$$

7. (*c*) Electrostatic force is a conservative force depending only on the initial and the final points and is independent of the path taken to go from one point to the other.

So, $\quad W_{ACB} = W_{AMB}$

8. (*c*) Electric field is a conservative field, no work is done in moving the charge q along the closed path $ABCDA$ in a uniform electric field (as $\oint \mathbf{E}\cdot d\,\mathbf{l} = 0$).

9. (*d*) Here, $W_{AB} = 100$ J, $q_0 = 4$ C

$$V_A = -10\text{ V},\ V_B = V$$

Since, $V_B - V_A = \dfrac{W_{AB}}{q_0}$, by external force

$$V - (-10V) = \frac{100\text{ J}}{4\text{ C}} = 25\text{ V}$$

or $\quad V = 25\text{ V} - 10\text{ V} = 15\text{ V}$

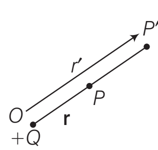
10. (*b*) Here, $q = 100$ C

Potential difference between the cloud and the Earth,

$$V = 10^7\text{ V}$$

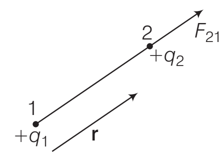
Energy dissipated, $W = qV = 100\,C\times 10^7\,V = 10^9$ J

11. (*b*)



Electrostatic force between any two positive charges q_1 and q_2 separated by a distance r is given by

$$\mathbf{F}_{21} = \frac{q_1 q_2}{4\pi\varepsilon_0 r^2}\hat{\mathbf{r}} \quad \ldots\text{(i)}$$



Here, $\mathbf{F}_{21}$ is the electrostatic force on 2 due to 1 which along the vector $\mathbf{r}$. Also, $\mathbf{r}$ is the unit vector along $\mathbf{r}$ and $r = |\,\mathbf{r}\,|$.

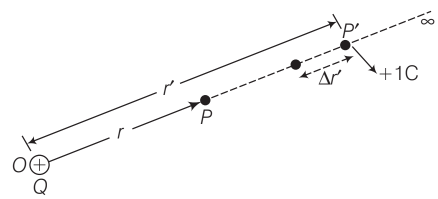
From Eq. (i), in this case $q_1 = +Q$ and $q_2 = +1$ C

$$\Rightarrow \quad \mathbf{F} = \frac{Q\times 1}{4\pi\varepsilon_0 (r')^2}\hat{\mathbf{r}}' \quad \ldots\text{(ii)}$$

Total work done (W) by the external force is obtained by integrating Eq. (ii) from $r' = \infty$ to $r' = r$

$$W = -\int_\infty^r \frac{Q}{4\pi\varepsilon_0 r'^2}\,dr' = \left.\frac{Q}{4\pi\varepsilon_0 r'}\right|_\infty^r = \frac{Q}{4\pi\varepsilon_0 r}$$

12. (*d*) Consider a point charge Q at the origin in the figure.



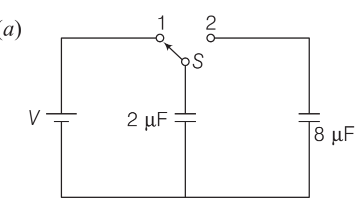
At some intermediate point P' on the path, the electrostatic force on a unit positive charge is

$$\frac{Q\times 1}{4\pi\varepsilon_0 r'^2}\hat{\mathbf{r}}' \quad \ldots\text{(i)}$$

where, $\hat{\mathbf{r}}'$ is the unit vector along OP'. Work done against this force from $\hat{\mathbf{r}}'$ to $\hat{\mathbf{r}}' - \Delta\hat{\mathbf{r}}'$ is

$$\Delta W = -\frac{Q}{4\pi\varepsilon_0 r'^2}\Delta r'$$

13. (*a*)



$$E = \frac{KQ}{r^2} \Rightarrow E \propto \frac{1}{r^2} \Rightarrow V = \frac{KQ}{r} \Rightarrow V \propto \frac{1}{r}$$

So, for $0 < r < 1$, the curve E will be above V and for $r > 1$, the curve E will be below V at $r = 1$, $E = V$

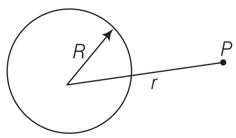
14. (*c*) $V = \dfrac{1}{4\pi\varepsilon_0}\cdot\dfrac{Q}{r} = 9\times 10^9\text{ Nm}^{-2}\text{ C}^{-2}\times\dfrac{4\times 10^{-7}\text{ C}}{0.09\text{ m}}$

$$= 4\times 10^4\text{ V}$$

15. (*c*) Work done $= q\,(V_B - V_A)$, since $V_A = 0$ (point at infinity)

$\Rightarrow W = qV_B = qV$ or $W = 2\times 10^{-9}\,C\times 4\times 10^4\text{ V} = 8\times 10^{-5}$ J

16. (*a*) The potential at the centre of the sphere is 80 V because it remains same at each point under the metallic hollow sphere as on surface.



$$V(r) = \begin{cases} \dfrac{Q}{4\pi\varepsilon_0 r}; & r > R \\ \dfrac{Q}{4\pi\varepsilon_0 R}; & r \le R \end{cases}$$

17. (*c*) Let V_1 be the potential at the centre of the cube due to one charge

$$V_1 = \frac{1}{4\pi\varepsilon_0}\frac{2Q}{x} \quad \text{and} \quad x = \frac{a\sqrt{3}}{2}$$

Potential due to all eight corners of the cube

$$\Rightarrow \quad V = 8\,V_1 = 8\left[\frac{1}{4\pi\varepsilon_0}\frac{2Qx_2}{\sqrt{3}a}\right] = \frac{32Q}{4\pi\varepsilon_0\sqrt{3}\times a} = \frac{8Q}{a\sqrt{3}\pi\varepsilon_0}$$

18. (*c*) Volume of eight drops = Volume of a big drop

$$\therefore \qquad \left(\frac{4}{3}\pi r^3\right)\times 8 = \frac{4}{3}\pi R^3 \quad \Rightarrow \quad 2r = R \qquad \text{...(i)}$$

According to charge conservation,

$$8q = Q \qquad \text{...(ii)}$$

Potential of one small drop $(V') = \dfrac{q}{4\pi\varepsilon_0 r}$

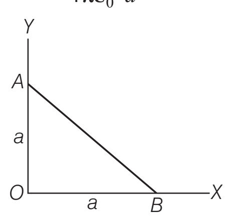
Similarly, potential of big drop $(V) = \dfrac{Q}{4\pi\varepsilon_0 R}$

Now, $\qquad \dfrac{V'}{V} = \dfrac{q}{Q}\times\dfrac{R}{r}$

$\Rightarrow \qquad \dfrac{V'}{20} = \dfrac{q}{8q}\times\dfrac{2r}{r}$ [from Eqs. (i) and (ii)]

$\therefore \qquad V' = 5\,\text{V}$

19. (*a*) Potential at A, $V_A = \dfrac{1}{4\pi\varepsilon_0}\dfrac{q}{a}$



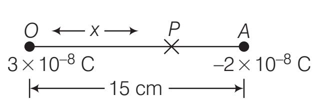
Potential at B, $V_B = \dfrac{1}{4\pi\varepsilon_0}\cdot\dfrac{q}{a}$

Thus, work done in causing a test charge $-Q$ from A to B.

$$W = (V_A - V_B)\times(-Q) = 0$$

20. (*c*) The electric potential of a dipole is given by $\dfrac{1}{4\pi\varepsilon_0}\cdot\dfrac{\mathbf{p}\cdot\mathbf{r}}{r^2}$.

21. (*d*)



$$\frac{1}{4\pi\varepsilon_0}\left[\frac{3\times 10^{-8}}{x\times 10^{-2}} - \frac{2\times 10^{-8}}{(15-x)\times 10^{-2}}\right] = 0$$

where, x in cm, *i.e.*, $\dfrac{3}{x} - \dfrac{2}{15-x} = 0$

Which gives $x = 9$ cm

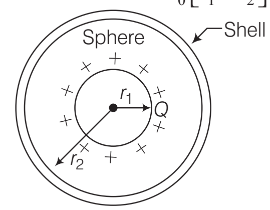
If x lies on the extended line OA, the required condition is

$$\frac{3}{x} - \frac{2}{x-15} = 0$$

Which gives $x = 45$ cm

Thus, electric potential is zero at 9 cm and 45 cm away from the positive on the side of the negative charge.

22. (*a*) Initially, $V_{\text{sphere}} - V_{\text{shell}} = \dfrac{Q}{4\pi\varepsilon_0}\left[\dfrac{1}{r_1} - \dfrac{1}{r_2}\right] = V$



$$V_0 = \frac{1}{4\pi\varepsilon_0}\left(-\frac{3Q}{r_2}\right)$$

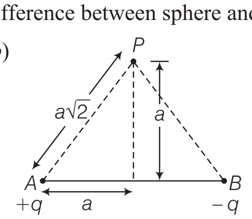
So that now, $\qquad V'_{\text{sphere}} = \dfrac{1}{4\pi\varepsilon_0}\left(\dfrac{Q}{r_1}\right) + V_0$

and $\qquad V'_{\text{shell}} = \dfrac{1}{4\pi\varepsilon_0}\left(\dfrac{Q}{r_2}\right) + V_0$

Hence, $\qquad V'_{\text{sphere}} - V'_{\text{shell}} = \dfrac{Q}{4\pi\varepsilon_0}\left(\dfrac{1}{r_1} - \dfrac{1}{r_2}\right) = V$

i.e., if any charge is given to an external shell, the potential difference between sphere and shell will not change.

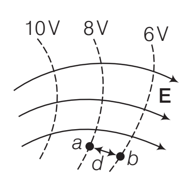
23. (*b*)



$$V_P = V_A + V_B = \left(\frac{Kq}{a\sqrt{2}}\right) + \left(\frac{-Kq}{a\sqrt{2}}\right) = \text{zero}$$

24. (*c*) For a uniform electric field **E** say, along the X-axis, the equipotential surfaces are planes normal to the X-axis, *i.e.*, planes parallel to the YZ-plane.

25. (*c*) The field lines are perpendicular to the equipotential surfaces.



26. (*a*) In the vicinity, $V_a - V_b \approx E_d$

$$\Rightarrow \qquad E \approx \frac{V_a - V_b}{d} = \frac{8\text{V} - 6\text{V}}{4\times 10^{-2}\ \text{m}} = 50\ \text{Vm}^{-1}$$

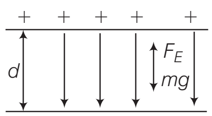
27. (*a*) Electric field lines are perpendicular to the equipotential surfaces and point in the direction of decreasing potential. At P, electric field **E** is to the left. At R, **E** is upward.

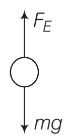
28. (*a*) Equipotential surface between two equal and opposite charges passing through L middle point will be a plane. On this surface potential will be zero on all points on the surface.

29. (*b*) As electric field, $E = \dfrac{V}{r}$

The distance of point charge, $r = \dfrac{V}{E} = \dfrac{600\text{ V}}{200\text{ NC}^{-1}} = 3\text{ m}$

30. (*b*)





$\because \quad V = Ed \Rightarrow E = (V/d)$

In equilibrium, $F_E = mg$

$\Rightarrow \quad qE = mg \quad \Rightarrow \quad (ne)E = V \times \rho g$

$(ne)E = \dfrac{4}{3}\pi r^3 \times \rho \times g$

$$\Rightarrow \quad n = \frac{\left(\frac{4}{3}\pi r^3 \rho g\right)}{E \times (e)} = \frac{\left(\frac{4}{3}\pi r^3 \rho g\right)}{(V/d) \times e}$$

$$= \frac{\frac{4}{3} \times (3.14) \times \left(\frac{10^{-6}}{2}\right)^3 \times 900 \times 10}{3600 \times 1.6 \times 10^{-19}} = 8.17 = 8$$

31. (*d*) Potential difference between any two points on an equipotential surface is zero, *i.e.,* $\Delta V = 0$

Work done in moving the test charge (q_0)

i.e., $\quad W = q_0\, \Delta V = 0$

32. (*a*) For $(V_A - V_B) = 0$

[Potential at A and B due to 10 μC charge are equal]

Thus, work done $W_{AB} = q\,(V_B - V_A) = 0$

33. (*b*) Potential inside the sphere will be same as that on its surface.

Given, $R = 10$ cm

For inside the sphere,

$$V_1(r) = \frac{KQ}{R} = \frac{KQ}{10} = V \qquad (\text{for } r \le R) \quad \ldots\text{(i)}$$

For outside the sphere,

$$V_2(r) = \frac{KQ}{r} = \frac{KQ}{15} \qquad (\text{for } r > R) \quad \ldots\text{(ii)}$$

From Eqs. (i) and (ii), we get

$$\frac{V_1(r)}{V_2(r)} = \frac{15}{10} = \frac{3}{2} \quad \text{or} \quad V_2(r) = \frac{2}{3}V_1(r) = \frac{2V}{3}$$

34. (*b*) The potential energy difference, $\Delta U = U_P - U_R = W_{RP}$

35. (*d*) Work done by external force in bringing a unit positive charge from point R to P

$$= V_P - V_R = \left(\frac{U_P - U_R}{q}\right)$$

where, V_P and V_R are the electrostatic potentials at P and R, respectively.

36. (*a*) The potential energy of a system of three charges q_1, q_2 and q_3 located at $\mathbf{r}_1$, $\mathbf{r}_2$, and $\mathbf{r}_3$ respectively. To bring q_1 first from infinity to $\mathbf{r}_1$, no work is required. Next we bring q_2 from infinity to $\mathbf{r}_2$. As before, work done in this step is

$$q_2 V_1(\mathbf{r}_2) = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r_{12}} \quad \ldots\text{(i)}$$

The charges q_1 and q_2 produce a potential, which at any point P is given by

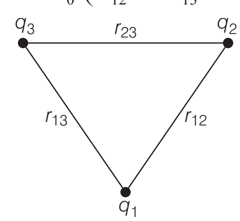
$$V_{1,2} = \frac{1}{4\pi\varepsilon_0}\left(\frac{q_1}{q_{1p}} + \frac{q_2}{q_{2p}}\right) \quad \ldots\text{(ii)}$$

Work done next in bringing q_3 from infinity to the point $\mathbf{r}_3$ is $q_3\, V_{12}$ times at $\mathbf{r}_3$

$$q_3 V_{12}(\mathbf{r}_3) = \frac{1}{4\pi\varepsilon_0}\left(\frac{q_1 q_3}{r_{13}} + \frac{q_2 q_2}{r_{23}}\right) \quad \ldots\text{(iii)}$$

The total work done in assembling the charges at the given locations is obtained by [Eqs. (i) and (iii)]

$$U = \frac{1}{4\pi\varepsilon_0}\left(\frac{q_1 q_2}{r_{12}} + \frac{q_1 q_3}{r_{13}} + \frac{q_2 q_3}{r_{23}}\right) \quad \ldots\text{(iv)}$$



37. (*d*) Potential energy of the system, $U = \dfrac{KQq}{l} + \dfrac{Kq^2}{l} + \dfrac{KqQ}{l} = 0$

$$\Rightarrow \quad \frac{Kq}{l} \times [(Q + q + Q)] = 0 \Rightarrow Q = -q/2$$

38. (*a*) Since, the proton is moving against the direction of electric field, so work is done on the proton against electric field. It implies that electric field does negative work on the proton. Again, proton is moving in electric field from low potential region to high potential region hence, its potential energy increases.

39. (*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.

40. (*a*) $W = U = -\dfrac{Kq^2}{d} \times 4 + \dfrac{Kq^2}{\sqrt{2}d} \times 2 = -\dfrac{q^2}{4\pi\varepsilon_0 d}(4 - \sqrt{2})$

41. (*c*) As, $\tau = pE\sin\theta$

$\Rightarrow 10\sqrt{2} = p \times 10^4 \sin\theta$

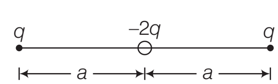
As, $\quad p = 2\sqrt{2} \times 10^{-3}$

A is $\quad U = pE\cos\theta$

$\quad U = 2\sqrt{2} \times 10^{-3} \times 10^4 \cos 30°$

$\therefore$ Potential energy, $U = 24.5$ J

42. (*d*) Potential energy of the system,



$$U = \frac{1}{4\pi\varepsilon_0}\left[\frac{q_1 q_2}{r_{12}} + \frac{q_1 q_3}{r_{13}} + \frac{q_2 q_3}{r_{23}}\right]$$

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

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

$$= \frac{1}{4\pi\varepsilon_0}\left[\frac{-4q^2}{a} + \frac{q^2}{2a}\right] = \frac{-7q^2}{8\pi\varepsilon_0 a}$$

43. (*c*) Potential energy of the system,

$$-\frac{KqQ}{x} - \frac{KQq}{x} + \frac{Kq^2}{2x} = 0$$

$$\Rightarrow \quad \frac{-4KqQ + Kq^2}{2x} = 0$$

$$\Rightarrow \quad Kq^2 = 4KQq \quad \Rightarrow \quad \frac{q}{Q} = 4$$

44. (*a*) When charge q_3 is at C, then potential energy of the system is

$$U_C = \frac{1}{4\pi\varepsilon_0}\left\{\left(\frac{q_1 q_3}{0.4} + \frac{q_2 q_3}{0.5}\right) + \frac{q_1 q_2}{0.3}\right\}$$

Similarly, when charge q_3 is at D, then

$$U_D = \frac{1}{4\pi\varepsilon_0}\left\{\left(\frac{q_1 q_3}{0.4} + \frac{q_2 q_3}{0.1}\right) + \frac{q_1 q_2}{0.3}\right\}$$

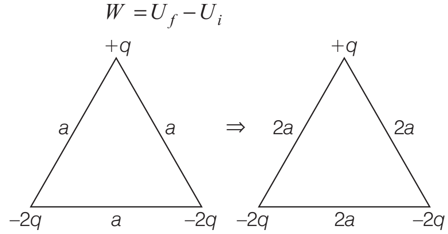
Here, change in potential energy

$$\frac{q_3}{4\pi\varepsilon_0} k = \frac{1}{4\pi\varepsilon_0}\left(\frac{q_2 q_3}{0.1} - \frac{q_2 q_3}{0.5}\right)$$

$$\Rightarrow \quad k = q_2\,(10 - 2) = 8q_2$$

45. (*d*) Work done in increasing the separation from a to $2a$ is

$$W = U_f - U_i$$



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

$$= \frac{1}{4\pi\varepsilon_0}[-2q^2 - 2q^2 + 4q^2] = 0$$

Similarly, U_f is also zero.

Hence, $\quad W = 0$

46. (*c*) The amount of work done by the external torque will be given by

$$W = \int_{\theta_0}^{\theta_1} \tau_{\text{ext}}\,(\theta)\,d\theta = \int_{\theta_0}^{\theta_1} pE\sin\theta d\theta = pE\,(\cos\theta_0 - \cos\theta_1)$$

47. (*b*) The electrostatic potential energy due to system of two charges is given as $U = \frac{Kq_1 q_2}{r_{12}}$

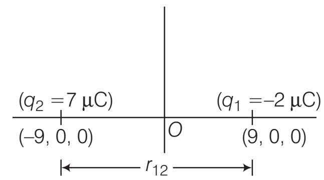
$$U = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r} = 9\times10^9 \times \frac{7\times(-2)\times10^{-12}}{0.18} = -0.7\text{ J}$$

48. (*c*) Work done is change in potential energy in bringing the charge from infinity to the present configuration.

$$W = U_2 - U_1 = 0 - U$$
$$= 0 - (-0.7) = 0.7\text{ J}$$

49. (*b*) The mutual interaction of energy of the two charges remains unchanged. In addition, there is the energy of interaction of the two charges with the external electric field.

In the presence of external electric field, we first find the potentials at 1 and 2, respectively using



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

$$\Rightarrow \quad \int_{\infty}^{r_1} \frac{A}{r^2}dr = -\int_0^{V_1} dV \quad \Rightarrow \quad \frac{A}{r_1} = V_1$$

or $\quad V_1 = A/r_1 \quad$ and $\quad V_2 = A/r_2$

Total electrostatic energy of system,

$$= q_1V_1 + q_2V_2 + \frac{kq_1 q_2}{r_{12}}$$

$$= A\left(\frac{-2\,\mu\text{C}}{0.09}\right) + A\left(\frac{7\,\mu\text{C}}{0.09}\right) + \frac{-9\times10^{-9}\times7\times2\times10^{-12}}{0.18}$$

$$= \frac{A\,(5\,\mu\text{C})}{0.09} - 0.7\text{ J} = 50\text{ J} - 0.7\text{ J} = 49.3\text{ J}$$

50. (*b*) Here, the dipole moment of each molecule = 10^{-29} C-m

1 mole of the substance contains 6×10^{23} molecules. Therefore total dipole moment of all molecules,

$$p = 6\times10^{23}\times10^{-29}\text{ C-m} = 6\times10^{-6}\text{ C-m}$$

Initial potential energy,

$$U = -pE\cos\theta = -6\times10^{-6}\times10^6\cos60° = -3\text{ J}$$

Final potential energy (when $\theta = 0°$),

[finally p and E are aligned in the same direction]

$$U_f = -6\times10^{-6}\times10^6\cos0° = -6\text{ J}$$

Change in potential energy = – 6J – (– 3J) = –3 J

So, there is a loss in potential energy. This must be the energy released by the substances in the form of heat in aligning its dipole. When field is changed in direction the energy of dipole in initial position is enhanced from – 6J to – 3J.

51. (*a*) When a dipole is placed in an electric field **E**, force exerted $\tau = pE\sin\theta$, where p = dipole moment and θ is the angle which makes dipole with the field.

$$\tau_{\max} = pE\sin90°,\ i.e.,\ \tau_{\max} = pE$$

$$\Rightarrow \quad \tau_{\max} = q\times2l\times E = (3.5\times10^{-6})\times4.2 \times10^{-2}\times5.8\times10^5$$

$$= 85.26\times10^{-3}\text{ Nm}^{-1}$$

Work done in rotating the dipole from an angle θ_0 to θ,

$$W = \int_{\theta_0}^{\theta} pE\sin\theta\,d\theta = pE\,[\cos\theta_0 - \cos\theta]$$

$$W = pE\,(\cos\theta° - \cos 180°)$$

where, $\theta_0 = 0°$ and $\theta = 180°$

$$\Rightarrow \quad W = 2pE$$
$$= 2 \times q \times 2l \times E$$
$$= 2 \times (3.5 \times 10^{-6}) \times (4.2 \times 10^{-2}) \times 5.8 \times 10^{5}$$
$$= 1.76 \times 10^{-1}\,\text{J}$$

52. (*c*) The free charge carriers move and charge distribution in the conductor adjusts itself in such a way that the electric field due to induced charges opposes the external field within the conductor. This happens until in the static situation, the two fields cancel each other and the net electrostatic field in the conductor is zero.

53. (*d*) Oxygen and hydrogen and nitrogen are the examples of non-polar molecules.

54. (*d*) HCl and H_2O and NH_3 are the examples of polar molecules.

55. (*a*) In the absence of any external field, the different permanent dipoles are oriented randomly due to thermal agitation; so the total dipole moment is zero. When an external field is applied, the individual dipole moment tends to align with the field.

56. (*c*) The extent of polarisation depends on the relative strength of two mutually opposite factors : the dipole potential energy in the external field tending to align the dipoles with the field and thermal energy tending to disrupt the alignment. There may be, in addition, the 'induced dipole moment' effect as for non-polar molecules, but generally the alignment effect is more important for polar molecules.

57. (*a*) For linear isotropic dielectric $\mathbf{p} = \chi_e \mathbf{E}$ (Direction of $\mathbf{p}$ and $\mathbf{E}$ are same).

where, χ_e is a constant characteristic of the dielectric and is known as the electric susceptibility of the dielectric medium and it is possible to relate χ_e to the molecular properties of the substance.

58. (*b*) An electric field (E_i) is induced inside the dielectric in a direction opposite to the external field (E_0) due to polarisation. On account of this, the net electric field (E) inside the slab is less than the external field as $E = E_0 - E_i$.

59. (*a*) When **P** is normal to the surface, the polarisation is numerically equal to the surface density of the induced charge.

60. (*b*) As $P = \varepsilon_0 \chi_e E$ and $\varepsilon_r = 1 + \chi_e \Rightarrow P = \varepsilon_0 (\varepsilon_r - 1) E$

If n is the number of helium atoms/m^3 and P is the dipole moment per atom, then

$$P = np$$

or
$$p = \frac{P}{n} = \frac{\varepsilon_{0r} (\varepsilon_r - 1) E}{n} \quad \ldots\text{(i)}$$

Since, at NTP, 1 atom (6.02×10^{23} atoms) of a gas occupies a volume of 22.4 litre (*i.e.*, 22.4×10^{-3} m^3).

$$n = \frac{6.02 \times 10^{23}}{22.4 \times 10^{-3} \text{m}^3} = 2.69 \times 10^{25} / \text{m}^3 \quad \ldots\text{(ii)}$$

From Eqs. (i) and (ii), we get

$$p = \frac{(8.85 \times 10^{-12} \text{C}^2 / \text{Nm}^2\ (1.000074 - 1)\ (100\ \text{V/m})}{2.69 \times 10^{25} / \text{m}^3}$$
$$= 2.4 \times 10^{-39}\ \text{C-m}$$

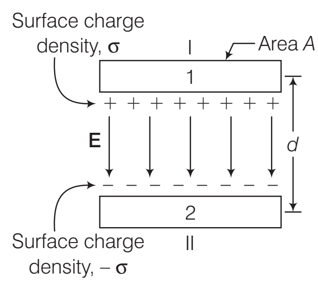
61. (*a*) The symbol of a capacitor with fixed capacitance and with variable capacitance is –| |– and –| |–. For fixed capacitance, the capacitance value (C) remains same but for variable capacitance C can be changed as per our requirement within the given range.

62. (*c*) The maximum electric field that a dielectric medium can withstand without break down (of its insulating property) is called its dielectric strength; for air it is about 3×10^6 Vm^{-1}. For a separation between conductors of the order of 1 cm or so, this field corresponds to a potential difference of 3×10^4 V between the conductors. Thus, for a capacitor to store a large amount of charge without leaking, its capacitance should be high enough so that the potential difference and hence the electric field do not exceed the break down limits. Put differently, there is a limit to the amount of charge can be stored on a given capacitor without significant leaking.

63. (*a*) $C = \dfrac{\varepsilon_0 A}{d} = \dfrac{8.85 \times 10^{-12} \times 3.14 \times 0.08 \times 0.08}{1 \times 10^{-3}}$

$$q = CV = \frac{8.85 \times 10^{-12} \times 3.14 \times .08 \times .08 \times 100\ \text{V}}{1 \times 10^{-3}}$$
$$= 1.78 \times 10^{-8}\ \text{C}$$

64. (*c*)



The electric field in outer region I (region above the plate 1) is

$$E = \frac{\sigma}{2\varepsilon_0} - \frac{\sigma}{2\varepsilon_0} = 0$$

Outer region II (region below the plate 2),

$$E = \frac{\sigma}{2\varepsilon_0} - \frac{\sigma}{2\varepsilon_0} = 0$$

65. (*a*) When a metallic slab is inserted between the plates, capacitance $(C) = \dfrac{\varepsilon_0 A}{d - t}$. Here, $t = 0$ as plate is very thin.

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

66. (*d*) Being a conductor, each plate have the same potential at each point. So, potential gradient will be highest at closest end. As $E \propto \sigma$, so surface charge density σ is higher at the closer end.

67. (*a*) From the given graphs, find the voltages, V_A and V_B, on capacitors A and B corresponding to charge Q on each of the capacitors. Clearly,

$$V_A = \frac{Q}{C_A} \quad \text{and} \quad V_B = \frac{Q}{C_B} \quad \text{or} \quad \frac{V_B}{V_A} = \frac{Q/C_B}{Q/C_A} = \frac{C_A}{C_B}$$

Since, $V_B > V_A$, $C_A > C_B$ *i.e.*, the capacitor A has the higher capacitance.

68. (*c*) $$C_0 = \frac{\varepsilon_0 A}{d} = 18 \quad \ldots\text{(i)}$$

$$C = \frac{K\varepsilon_0 A}{3d} = 72 \quad \ldots\text{(ii)}$$

On dividing Eq. (ii) by Eq. (i), we get

$$\frac{K}{3} = \frac{72}{18} = 4$$

$\therefore$ Dielectric constant, $K = 12$

69. (*a*) The material suitable for use as dielectric must have high dielectric strength X and large dielectric constant K.

70. (*c*) Capacity, $C = 4\pi\varepsilon_0 R = \dfrac{6.4\times 10^6}{9\times 10^9} = 711\,\mu\text{F}$

71. (*c*) The capacity in air, $C = \dfrac{\varepsilon_0 A}{d}$

The capacity when dielectric slab of dielectric constant K is introduced between the plates.

$$C' = \frac{\varepsilon_0 A}{(d - t + t/k)}$$

$$\therefore \quad \frac{C}{C'} = \frac{(d - t + t/k)}{d}$$

Given, $$C' = \frac{166}{100} C$$

$$\Rightarrow \quad \frac{100}{166} = \frac{1}{K} = \frac{(d - t + t/k)}{d}; \text{ Putting } t = \frac{3d}{5}$$

$$\Rightarrow \quad K = 3$$

72. (*d*) Given, initial separation $d = 3$ mm

Let new separation between the plates is d'.

$$\therefore \quad \frac{C'd'}{k} = Cd$$

Given, $$C' = C$$

$$\Rightarrow \quad d' = kd$$

$$\Rightarrow \quad d' = (2)(3) = 6 \text{ mm}$$

73. (*c*) Capacitance of a parallel plate capacitor with air is $C = \dfrac{\varepsilon_0 A}{d}$.

Capacitance of a same parallel plate capacitor with the introducing of a dielectric medium $C' = \dfrac{K\varepsilon_0 A}{d}$

where, K is the dielectric constant of a medium.

$$\therefore \quad \frac{C'}{C} = K = \frac{15}{3} = 5$$

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

or $$\varepsilon = K\varepsilon_0 = 5\times 8.854\times 10^{-12}$$

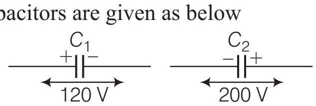
$$= 0.4427\times 10^{-10}\ \text{C}^2\ \text{N}^{-1}\ \text{m}^{-2}$$

74. (*c*) $q = CV$, As V is constant, therefore $q \propto C$.

Here, C becomes $\dfrac{100}{40} = 2.5$ times

$$\therefore \quad K = 2.5$$

75. (*b*) Two capacitors are given as below



For potential to be made zero after connection, the charge of both capacitors are equal.

$$\therefore \quad q_1 = q_2$$

$$C_1 V_1 = C_2 V_2$$

or $$120\,C_1 = 200 C_2 \Rightarrow 3C_1 = 5C_2$$

76. (*a*) Let $E_0 = V_0/d$ be the electric field between the plates when there is no dielectric and the potential difference is V_0. If the dielectric is now inserted, the electric field in the dielectric will be $E = E_0/K$. The potential difference will be

$$V = E_0\left(\frac{1}{4}d\right) + \frac{E_0}{K}\left(\frac{3}{4}d\right)$$

$$= E_0 d\left(\frac{1}{4} + \frac{3}{4K}\right) = V_0 \cdot \frac{K+3}{4K}$$

The potential difference decreases by the factor $\dfrac{(K+3)}{4K}$ while the free charge Q_0 on the plates remains unchanged. The capacitance thus increases.

$$C = \frac{Q_0}{V} = \frac{4K}{K+3}\frac{Q_0}{V_0} = \frac{4K}{K+3}C_0$$

77. (*c*) Stored energy in the capacitor can be given as

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

When the switch S is connected to point 2, energy dissipated on connected across 8 μF will be

$$= \frac{1}{2}\left(\frac{C_1 C_2}{C_1 + C_2}\right)V^2$$

$$= \frac{1}{2}\left(\frac{2\times 8}{10}\right)V^2 = \frac{1}{2}\times\frac{16}{10}\times V^2$$

$$\text{Therefore ,\% loss of energy} = \left(\frac{\frac{1}{2}\times\frac{16}{20}V^2\times 100}{\frac{1}{2}\times 2\times V^2}\right) = 80\%$$

78. (*c*) The charge on the capacitor is

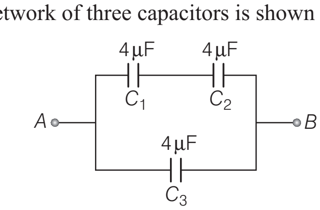
$$q = CV = 900\times 10^{-12}\ \text{F}\times 100\ \text{V} = 9\times 10^{-8}\,\text{C}$$

The energy stored by the capacitor is

$$= (1/2)\,CV^2 = (1/2)\,qV$$

$$= 1/2\times 9\times 10^{-8}\,\text{C}\times 100\ \text{V} = 4.5\times 10^{-6}\ \text{J}$$

79. (a) The network of three capacitors is shown below.

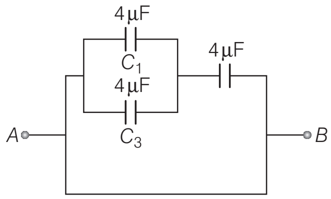


Here, C_1 and C_2 are in series and the combination of two is in parallel with C_3.

$$C_{\text{net}} = \frac{C_1 C_2}{C_1 + C_2} + C_3$$

$$= \left(\frac{4\times 4}{4+4}\right) + 4 = 2 + 4 = 6\,\mu\text{F}$$

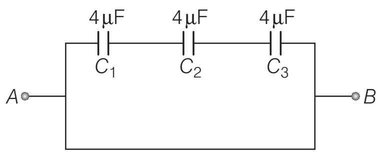
(ii) The corresponding network is shown in figure.



Here, C_1 and C_2 are in parallel and this combination is in series with C_3.

So, $C_{net} = \frac{(C_1 + C_2) \times C_3}{(C_1 + C_2) + C_3} = \frac{(4 + 4) \times 4}{(4 + 4) + 4} = \frac{32}{12} = \frac{8}{3}$ μF

(iii) The corresponding network is shown in figure.

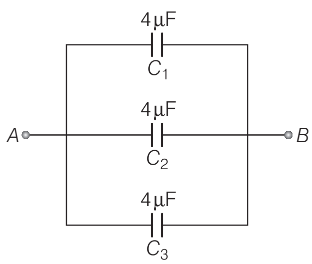


All of three are in series.

So, $\frac{1}{C_{net}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} = \frac{1}{4} + \frac{1}{4} + \frac{1}{4} = \frac{3}{4}$

$\therefore \quad C = \frac{4}{3}$ μF

(iv) The corresponding network is shown.



$C_{net} = C_1 + C_2 + C_3 = 4 + 4 + 4 = 12\,\mu F$

80. (*b*) According to the question, the given arrangement of nine plates is equivalent to the parallel combination of 8 capacitors.

The capacity of each capacitor,

$$C = \frac{\varepsilon_0 A}{d} = \frac{8.854 \times 10^{-12} \times 5 \times 10^{-4}}{0.885 \times 10^{-2}} = 0.5 \text{ pF}$$

Hence, the capacity of 8 capacitors $= 8C = 8 \times 0.5 = 4$ pF

81. (*d*) The quantities energy stored and potential difference decreases, because $U = \frac{1}{2}\frac{q^2}{KC}$ and $V = \frac{q}{KC}$ decreases. On inserting a dielectric, the capacitance increase (KC_0), where C_0 is the capacitance when no glass slab is present and K is dielectric constant, As 'C' increase, U and V both decreases as they are inversely related to C. q is constant here.

82. (*d*) As, $C_S = \left(\frac{4C}{4 + C}\right)$ μF (C is capacitance of other capacitor)

and $\frac{1}{2} C_s V^2 = 173$ μJ

$\Rightarrow \quad \frac{1}{2}\left(\frac{4C}{4 + C}\right)(12)^2 = 173$

$\Rightarrow \quad \frac{4C}{4 + C} = \frac{2 \times 173}{144} = 2.4$

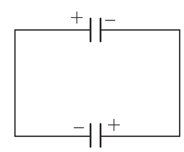
Hence, $C = 6$ μF

83. (*b*) $C_1 = \frac{K_1 \varepsilon_0 A}{d/2} = \frac{2K_1 \varepsilon_0 A}{d}$ and $C_2 = \frac{2K_2 \varepsilon_0 A}{d}$

$\therefore \quad \frac{1}{C_s} = \frac{1}{C_1} + \frac{1}{C_2} = \frac{d}{2K_1 \varepsilon_0 A} + \frac{d}{2K_2 \varepsilon_0 A} = \frac{d}{2\varepsilon_0 A}\left(\frac{K_1 + K_2}{K_1 K_2}\right)$

$\Rightarrow$ Capacity, $C_s = \frac{2\varepsilon_0 A}{d}\left(\frac{K_1 K_2}{K_1 + K_2}\right)$

84. (*a*) Each capacitor will have equal charges. When they are joined as described, they will be in parallel combination. The positive charge will cancel out negative charge of each other. So, net charge in each capacitor will be zero.



85. (*b*) In the given network, C_1, C_2 and C_3 are connected in series. The effective capacitance C' of these capacitors is given by

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

For $C_1 = C_2 = C_3 = 10\,\mu F$, $C' = (10/3)\mu F$

The network has C' and C_4 connected in parallel.

Thus, the equivalent capacitance C of the network is

$$C = C' + C_4 = \left(\frac{10}{3} + 10\right) = 13.3\,\mu F$$

86. (*c*) Minimum number of conductors in each row $\frac{3000}{500} = 6$

If C_s is capacity of 6 conductors in a row, then

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

$\Rightarrow \quad C_s = \frac{1}{6}$ μF

Let there be m such rows in parallel.

Total capacity $= m \times C_s$

$$2 = m \times \frac{1}{6}$$

$\therefore \quad m = 12$

Total number of capacitors $= 6 \times 12 = 72$

87. (*d*) The total capacity of capacitor

$$C = \frac{9 \times 4.5}{13.5} = 3\mu F$$

Charge, $\quad q = CV = 3 \times 12 = 36\,\mu C$

Potential difference across 4.5μF, $V = \frac{36}{4.5} = 8$ V

88. (*d*) **Case I** When the capacitors are joined in series,

$$U_{series} = \frac{1}{2}\frac{C_1}{n_1}(4V)^2$$

Case II When the capacitors are joined in parallel,

$$U_{\text{parallel}} = \frac{1}{2}(n_2 C_2)V^2$$

Given, $U_{\text{series}} = U_{\text{parallel}}$

or $\frac{1}{2}\frac{C_1}{n_1}(4V)^2 = \frac{1}{2}(n_2 C_2)V^2$

$\Rightarrow$ $$C_2 = \frac{16\,C_1}{n_1 n_2}$$

89. (*a*) When free space between parallel plates of capacitor,

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

When dielectric is introduced between parallel plates of capacitor, $E' = \frac{\sigma}{K\varepsilon_0}$

Electric field inside dielectric

$$\frac{\sigma}{K\varepsilon_0} = 3 \times 10^4$$

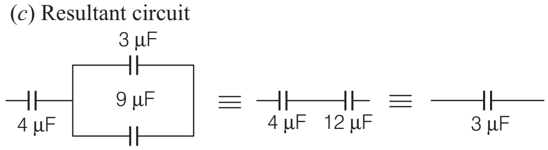
where, K = dielectric constant of medium = 2.2

ε_0 = permittivity of free space = 8.85×10^{-12}

$\Rightarrow$ $\sigma = 2.2 \times 8.85 \times 10^{-12} \times 3 \times 10^4$

$= 6.6 \times 8.85 \times 10^{-8} = 5.841 \times 10^{-7} = 6 \times 10^{-7}\ \text{C/m}^2$

90. (*c*) Resultant circuit



As, charge on 3 μF = 3 μF × 8 V = 24 μC

∴Charge on 4 μF = Charge on 12 μF = 24 μC

Charge on 3 μF = 3 μF × 2 V = 6 μC

Charge on 9 μF = 9 μF × 2 V = 18 μC

Charge on 4 μF + charge on 9 μF = (24 + 18) μC = 42 μC

∴ Electric field at a point distant 30 m

$$= \frac{9 \times 10^9 \times 42 \times 10^{-6}}{30 \times 30}$$

$= 420\ \text{N/C}$

91. (*d*) Initial energy, $U_i = \frac{1}{2}C_0 V^2$

Final energy, $U_f = \frac{1}{2}(KC_0)(V/K)^2$

or $$U_f = \frac{1}{K}\left(\frac{1}{2}C_0 V^2\right)$$

Change in energy $= U_f - U_i = \frac{1}{2}C_0 V^2 (1/K - 1)$

92. (*c*) Energy stored, $U = 1/2\ qV$

As the distance d is increased between the two plates.

Now, stored energy,

$$U' = \frac{1}{2}qV' = \frac{1}{2}q[q/C] = \frac{1}{2}\frac{q^2 d}{\varepsilon_0 A} \Rightarrow U' \propto d$$

Hence, $U' = 2U$

93. (*a*) The new potential energy will be U_0/K.

$\because$ $$U_0 = \frac{Q_0^2}{2C_0} \quad \ldots\text{(i)}$$

On insertion of dielectric, $U_{\text{new}} = \frac{Q_0^2}{2KC_0}$ …(ii)

From Eqs. (i) and (ii), we get $U_{\text{new}} = U_0/K$

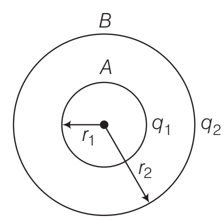
[$\because Q_0$ = constant (considered)]

94. (*c*) The energy stored in the capacitor,

$$U = \frac{1}{2}CV^2 = \frac{1}{2}\left(\frac{A\varepsilon_0}{d}\right)(Ed)^2 \quad \left(\because C = \frac{A\varepsilon_0}{d} \text{ and } V = Ed\right)$$

$$= \frac{1}{2}\varepsilon_0 E^2 Ad$$

95. (*a*) When connected $V_A = V_B$, hence q_1 will flow to outer surface of B



V_B = Potential due to its own charge q_2 + potential due to charge q_1 on A

$$= \frac{1}{4\pi\varepsilon_0}\left(\frac{q_2}{r_2} + \frac{q_1}{r_2}\right)$$

Potential on the inner sphere A due to its own charge,

i.e., $$V_1 = \frac{1}{4\pi\varepsilon_0}\frac{q_1}{r_1}$$

As the potential at every point inside charged sphere is the same as that on its surface, the potential on the inner sphere (A) due to charge q_2 on sphere B, *i.e.*,

$$V_2 = \frac{1}{4\pi\varepsilon_0}\frac{q_2}{r_2}$$

Total potential on the inner sphere A, *i.e.*,

$$V_A = \frac{1}{4\pi\varepsilon_0}\left(\frac{q_1}{r_1} + \frac{q_2}{r_2}\right)$$

Thus, $$(V_A - V_B) = \frac{q_1}{4\pi\varepsilon_0}\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$$

As $r_1 < r_2$, $\frac{1}{r_1} > \frac{1}{r_2}$ or $\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$ is positive, further, since q_1 is positive, $V_A > V_B$

Thus, when the two spheres are connected by a wire, charge q_1 on A will flow entirely to B, irrespective of the charge q_2 already present on B.

96. (*b*) Van de Graaff generator is a machine that can build up high voltage of the order of a few million volts. The resulting large electric fields are used to accelerate charged particle, (electron, proton ions) to high energies needed for experiments to probe the small scale structure of matter.

97. (*d*) Both (a) and (b) are correct.

98. (*c*) Maximum permissible field strength, $E = (1/10)$ of the dielectric strength of the gas

$$= (1/10)(5 \times 10^7 \text{ Vm}^{-1}) = 5 \times 10^6 \text{ Vm}^{-1}$$

Potential on the surface of the sphere = 1.5×10^6 V

In case of charged spherical cell (having a charged) electric field (E) and electric potential (V) at a point on its surface is given by

$$E = K\, q/r^2 \quad \text{and} \quad V = K\, q/r$$

$$E = V/r \quad \text{or} \quad r = V/E$$

When E is maximum, r is minimum and as such minimum value of r is given by

$$r = \frac{1.5 \times 10^6 \text{ V}}{5 \times 10^6 \text{ V/m}} = 0.3 \text{ m} = 30 \text{ cm}$$

99. (*a*) Assertion and Reason are true and Reason is the correct explanation of Assertion.

100. (*a*) A and B are two conducting spheres of same radius. A being solid and B hollow. Both are charged to the same potential. Then, charge on A = Charge on B. Because potentials on both are same.

101. (*a*) The proof of this statement is simple. There is no potential difference between any two points on the surface and no work is required to move a test charge on the surface because work done = potential difference × charge.

102. (*a*) The potential energy $U = \dfrac{1}{4\pi\varepsilon_0} \dfrac{q_1 q_2}{r_{12}}$ is unaltered whatever way the charges are brought to the specified locations, because of path independence of work for electrostatic force.

103. (*a*) There are polar and non-polar dielectric materials. The molecules of a polar dielectric have a permanent dipole moment. However, due to random orientations net dipole moment is zero. If there is no external electric field, there is no polarisation.

104. (*c*) The molecules of a substance may be polar or non-polar. In a non-polar molecule, the centre of positive and negative charges coincides. On the other hand, a polar molecule is one is which the centres of positive and negative charges are separated, even when there is no external field. Such molecules have a permanent dipole moment.

105. (*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.

106. (*a*) Electric field is set up from higher potential to lower potential. An electron is negatively charged and moves opposite to the direction of electric field, *i.e.*, from lower potential to higher potential.

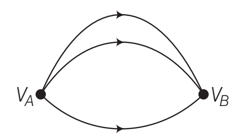
107. (*c*) The reason is false as $\sigma' = \dfrac{q'}{A} = \dfrac{C'V'}{A} = \dfrac{(KC)V}{A} = \dfrac{Kq}{A} = K\sigma$

(as $C' = KC$, $V' = V$ and $CV = q$)

108. (*c*) Assertion is true as capacitance in parallel is greater than capacitance is series. Reason is false as $C_p = C_1 + C_2 + C_3$.

109. (*a*) Work done = Potential difference $(V_B - V_A) \times q$ (the charge) where V_A and V_B depend only on the initial and final positions and not on path in figure. Electrostatic force is a conservative force. Since work done in moving charge along a closed loop is zero it is a conservative force. So, statement I is also correct.

If the loop is completed, no net work is done as the initial and the final potentials are the same.



For used path : $W = 2\Delta V = 0$ $\quad (\because \Delta V = 0)$

110. (*a*) The maximum amount of charge we can give to a capacitor depends upon on the geometrical factors as well as environmental factors.

111. (*c*) Capacitance is inversely proportional to distance between the plates.

112. (*a*) Capacitance of a capacitor does not depend upon charge but it depends upon geometrical factors.

113. (*d*) Battery is disconnected from the capacitor,

So, Q = constant

$$\text{Energy} = \frac{Q^2}{2C} = \frac{Q^2 d}{2\varepsilon_0 A} \Rightarrow \text{Energy} \propto d$$

114. (*d*) In a metal, the outer (valence) electrons part away from their atoms and are free to move. These electrons are free within the metal but not free to leave the metal. The free electrons form a kind of 'gas'. They collide with each other and with the ions and move randomly in different directions.

115. (*d*) In metals, the positive ions made up of the nuclei and the bound electrons remain held in their fixed positions. In electrolytic conductors, the charge carriers are both positive and negative ions.

116. (*d*) The molecules of a substance may be polar or non-polar. In a non-polar molecule, the centres of positive and negative charges coincide. The molecule then has no permanent (or intrinsic) dipole moment. Examples of non-polar molecules are oxygen (O_2) and hydrogen (H_2) molecules which, because of their symmetry, have no dipole moment.

117. (*a*) In an external electric field, the positive and negative charges of a non-polar molecule are displaced in opposite directions. The displacement stops when the external force on the constituent charges of the molecule is balanced by the restoring force (due to internal fields in the molecule). The non-polar molecule thus develops an induced dipole moment. The dielectric is said to be polarised by the external field.

118. (*c*) Statements I, II and III are correct.

119. (*b*) 1 keV = 10^3 eV = 1.6×10^{-16} J, 1 MeV = 10^6 eV

= 1.6×10^{-13} J, 1 GeV = 10^9 eV = 1.6×10^{-10} J

and 1 TeV = 10^{12} eV = 1.6×10^{-7} J

120. (*b*) Two large plates, each of area A, separated by a distance d. The charge on the plates $\pm Q$, corresponding to the charge density $\pm \sigma$ (with $\sigma = Q/A$). When there is vacuum between the plates,

$$E_0 = \frac{\sigma}{\varepsilon_0}$$

and the potential difference V_0 is $V_0 = E_0 d$

The capacitance C_0 in this case is $C_0 = \frac{Q}{V_0} = \varepsilon_0 \frac{A}{d}$

121. (*b*) Consider a dielectric is inserted between the plates fully occupying the intervening region. The dielectric is polarised by the field, the effect is equivalent to two charged sheets (at the surfaces of the dielectric normal to the field) with surface charge densities σ_p and $-\sigma_p$. The electric field in the dielectric then corresponds to the case when the net surface charge density on the plates is $\pm(\sigma - \sigma_p)$. *i.e.,*

$$E = \frac{\sigma - \sigma_p}{\varepsilon_0} \qquad \text{...(i)}$$

so that the potential difference across the plates is

$$V = Ed = \frac{\sigma - \sigma_p}{\varepsilon_0} d \qquad \text{...(ii)}$$

For linear dielectric, we except σ_p to be proportional to E_0, *i.e.*, to σ. Thus, $(\sigma - \sigma_p)$ is proportional to σ and we can write

$$\sigma - \sigma_p = \frac{\sigma}{K} \qquad \text{...(iii)}$$

where, K is a constant characteristic of the dielectric. Clearly, $K > 1$, then we have

$$V = \frac{\sigma d}{\varepsilon_0 K} = \frac{Qd}{A\varepsilon_0 K} \qquad \text{...(iv)}$$

The capacitance C with dielectric between the plates is

$$C = \frac{Q}{V} = \frac{\varepsilon_0 KA}{d} \qquad \text{...(v)}$$

The product $\varepsilon_0 K$ is called the permittivity of the medium and is denoted by ε.

$$\varepsilon = \varepsilon_0 K \qquad \text{...(vi)}$$

For vacuum $K = 1$ and $\varepsilon = \varepsilon_0$; ε_0 is called the permittivity of the vacuum. The dimensionless ratio

$$K = \frac{\varepsilon}{\varepsilon_0} \qquad \text{...(vii)}$$

is called the dielectric constant of the substance. As remarked before, from Eq. (iii), it is clear that K is greater than 1.

From equations, $(C_0 = \varepsilon_0 \frac{A}{d})$ and $C = \frac{\varepsilon_0 KA}{d}$,

$$K = \frac{C}{C_0} \qquad \text{...(viii)}$$

122. (*b*) A → 4; B → 5; C → 3; D → 1

As, $\quad \frac{Q_1}{C_1} = \frac{Q_2}{C_2}, Q_2 = \left(\frac{C_2}{C_1}\right) Q_1 = \frac{(C/2)}{C} Q_1 = \frac{Q_1}{2}$

Further, as $\quad Q = Q_1 + Q_2 = Q_1 + \frac{Q_1}{2} = \frac{3}{2} Q_1$

$$Q_1 = \frac{2}{3} Q \text{ and } Q_2 = \frac{1}{3} Q$$

$$U_1 = \frac{Q_1^2}{2C_1} = \frac{\left(\frac{2}{3}Q\right)^2}{2C} = \frac{2}{9}\left(\frac{Q^2}{C}\right) = \frac{2}{9}\left(\frac{C^2 V_0^2}{C}\right)$$

$$= \frac{2}{9} CV_0^2 \qquad (\text{as } Q = CV_0) \ (A \to 4)$$

$$(B \to 5)\, U_2 = \frac{Q_2^2}{2C_2} = \frac{\left(\frac{1}{3}Q\right)^2}{2(C/2)} = \frac{1}{9}\left(\frac{Q^2}{C}\right) = \frac{1}{9} CV_0^2$$

$$(C \to 3)\, U_{\text{final}} = U_1 + U_2 = \frac{1}{3} CV_0^2$$

$$(D \to 1)\, U_{\text{initial}} = \frac{Q^2}{2C} = \frac{(CV_0)^2}{2C} = \frac{1}{2} CV_0^2$$

Change in energy, $\Delta U = -\frac{1}{6} CV_0^2$

123. (*c*) A → 1; B → 4; C → 3; D → 2

(i) When S is open, then

$$C_{\text{eq}} = \frac{C_1 C_2}{C_1 + C_2} = \frac{(2\mu\text{F})\,(3\mu\text{F})}{(2\mu\text{F} + 3\mu\text{F})} = \frac{6}{5}\mu\text{F}$$

Charge (q) on both the capacitors will be the same (as these are in series), *i.e.*,

$$q = C_{\text{eq}}\, V = \left(\frac{6}{5}\mu\text{F}\right)(30 + 60)\,V = 108\,\mu\text{C}$$

(ii) When S is closed, charge on C_1, *i.e.*,

$$q_1 = C_1 V_1 = (2\mu\,\text{F})\,(30\,\text{V}C) = 60\,\mu\text{C}$$

Charge on C_2, *i.e.*, $q_2 = C_2 V_2 = (3\mu\text{F})(60\text{ V}) = 180\,\mu\text{C}$

Charge on C_1 and $C_2 = 60\,\mu\text{C} + 180\,\mu\text{C} = 240\,\mu\text{C}$

124. (*c*) (A) → 1, 4 (B) → 3, 5 (C) → 3, 5 (D) → 3, 5.

(A) Due to q, charge will be induced on the conductor such that net field due to q and induced charge becomes zero at any point inside the conductor.
Since, $E = 0$ everywhere inside the conductor, so potential is constant inside and same as that of surface of conductor.

(B) Due to q, field and potential both will vary inside.

(C) Due to q_2, field and potential both will vary inside. Because inside charge system has nothing to do with outside system.

(D) Same as that of (c).

125. (*c*) Work done by external force,

$$W_{RP} = U_P - U_R = 3\text{ J}$$

∴ Work done by electric field $= -W_{RP} = -3$ J

(direction of force and displacement opposite)

126. (*b*) According to the question,

$$U_P - U_R = 2 \quad \Rightarrow \quad 5 - U_R = 2$$

$$\therefore \qquad U_R = 3\text{ J}$$

127. (*b*) Electrostatic force is a conservative force. So, work done by an electrostatic field in moving a charge from one point to another depends only on initial and final points and is independent of path. Here, initial and final points are same, so work done will be zero.

128. (*a*) Potential energy of the proton decreases as it moves in the direction of the electric field. In the direction of electric field potential decreases, hence, $\Delta U = q(V_f - V_i) = -$ ve
i.e., potential energy decreases.

129. (*b*) $\Delta V = -E\Delta x = -(8.0\times 10^4 \text{ V/m})(0.50 \text{ m}) = -4\times 10^4 \text{ V}$

130. (*c*) $\Delta U = q_0 \Delta V = (1.6\times 10^{-19} \text{C})(-4.0\times 10^4 \text{V}) = -6.4\times 10^{-15} \text{ J}$

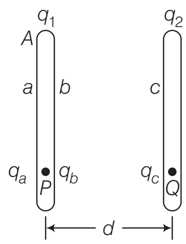
131. (*b*) As, $\Delta K = -\Delta U = 6.4\times 10^{-15}$ J

(from conservation of energy)

$$\Delta K = \frac{1}{2}mv_B^2 \quad \text{or} \quad v_B = \sqrt{\frac{2\Delta K}{m}}$$

$$= \sqrt{\frac{2(6.4\times 10^{-15}\text{J})}{(1.66\times 10^{-27} \text{ kg})}} = 2.77\times 10^6 \text{ ms}^{-1}$$

132. (*a*) At the point p, the electric field due to charge q_a is towards right whereas it will be towards left due to charges q_b, q_c and q_d. Since, the resultant electric field at a point inside a conductor is zero,



$$\frac{q_a}{2\varepsilon_0 A} - \frac{q_b}{2\varepsilon_0 A} - \frac{q_c}{2\varepsilon_0 A} - \frac{v_d}{2\varepsilon_0 A} = 0$$

or $\quad q_a = q_b + q_c + q_d$

$$= (q_1 - q_a) + (q_2 - q_d) + q_d = q_1 - q_a + q_2$$

where, $\quad q_a = \dfrac{q_1 + q_2}{2}$

and $\quad q_b = q_1 - q_a = q_1 - \dfrac{q_1 + q_2}{2} = \dfrac{q_1 - q_2}{2}$

133. (*b*) Since, the electric field at Q is zero.

$$\frac{q_a}{2\varepsilon_0 A} + \frac{q_b}{2\varepsilon_0 A} + \frac{q_c}{2\varepsilon_0 A} - \frac{q_d}{2\varepsilon_0 A} = 0$$

where, $\quad q_d = \dfrac{q_1 + q_2}{2}$ and $q_c = q_2 - q_d$

$\therefore \quad q_c = \dfrac{q_2 - q_1}{2}$

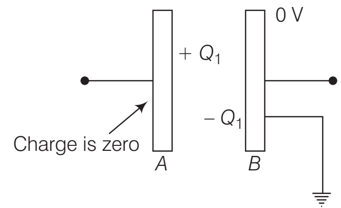
134. (*b*) The charges on the inner surfaces (q_b, q_c) which are equal and opposite are responsible for creating the electric field between the plates of the capacitor.

Thus, $\quad E = \dfrac{\sigma}{\varepsilon_0} = \dfrac{(q_1 - q_2)}{2\varepsilon_0 A}$

135. (*c*) $V = Ed = \dfrac{(q_1 - q_2)}{2\varepsilon_0 A}\times d$

136. (*b*) Capacitance, $C = \dfrac{q_b}{V} = \dfrac{\left(\dfrac{q_1 - q_2}{2}\right)}{\dfrac{(q_1 - q_2)d}{2\varepsilon_0 A}} = \dfrac{\varepsilon_0 A}{d}$

137. (*b, c, d*) When we earth plate B, whole of its charge will go to earth. Now charge of plate A will induce charge $-Q$, and $+Q_1$ on inner side and outer side of plate B. Again Q_1 charge of plate B will go to earth. $-Q_1$ charge will not go to earth. It will be bounded to $+Q$, charge of plate A (see fig.)



So, it is clear that $\dfrac{Q_1 + Q_2}{2}$ charge goes from 2nd plate to earth.

Charge of capacitor is Q_1 and hence its potential is $\dfrac{Q_1}{C}$.

138. (*b, d*) Battery is disconnected, hence charge remains conserved. The plates are pulled apart, so capacity will decrease so there is increase of voltage. Now, capacity decreases, hence energy will increase as charge is constant. $\left(E = \dfrac{Q^2}{2c}\right)$

Thus, (b) and (d) are correct.

139. (*a, b, c*)

(i) The charge on the capacitor is

$$q = CV = 900\times 10^{-12} \text{ F}\times 100 \text{ V} = 9\times 10^{-8} \text{C}$$

(ii) The energy stored by the capacitor is

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

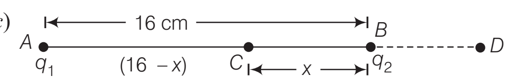
$$= (1/2)\times 9\times 10^{-8} \text{ C}\times 100 \text{ V} = 4.5\times 10^{-6} \text{J}$$

(iii) In the steady situation, the two capacitors have their positive plates at the same potential and their negative plates at the same potential. Let the common potential difference be V'. The charge on each capacitor is then $q' = CV'$. By charge conservation $q' = Q/2$. This implies $V' = V/2$. The total energy of the system is

$$= 2\times \frac{1}{2}Q'V' = \frac{1}{2}QV = 2.25\times 10^{-6} \text{J}$$

140. (*a, b*) This question is based on the working principal of a van de Graaff generator.

141. (*c*)



The potential at point C due to charge q_1,

$$V_A = \frac{1}{4\pi\varepsilon_0}\cdot\frac{q_1}{AC} = \frac{9\times 10^9\times 5\times 10^{-8}}{(16-x)\times 10^{-2}} \quad \ldots\text{(i)}$$

The potential at point C due to charge q_2,

$$V_B = \frac{1}{4\pi\varepsilon_0}\cdot\frac{q_2}{BC} = \frac{-9\times 10^9\times 3\times 10^{-8}}{x\times 10^{-2}} \quad \ldots\text{(ii)}$$

$$\Rightarrow \frac{9\times 10^9\times 5\times 10^{-8}}{(16-x)\times 10^{-2}} + \left(\frac{-9\times 10^9\times 3\times 10^{-8}}{x\times 10^{-2}}\right) = 0$$

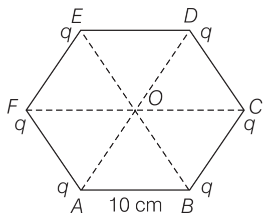
$$\Rightarrow \quad \frac{5}{16-x} - \frac{3}{x} = 0 \quad \Rightarrow \quad x = 6 \text{ cm}$$

$\therefore$ Distance from $q_1 = 16 - 6 = 10$ cm

Similarly at point D $\dfrac{k\times 5\times 10^{-8}}{16 + x_1} = \dfrac{k\times 3\times 10^{-8}}{x_1} \Rightarrow x_1 = 24$ cm

Distance from $q_1 = 16 + 24 = 40$ cm

142. (*b*)



i.e., $OA = OB = OC = OD = OE = OF = 10\,\text{cm}$

Potential at point O = Sum of potential at centre O due to individual point charges

$\therefore\ V_O = V_A + V_B + V_C + V_D + V_E + V_F \qquad \left(\because V = \frac{1}{4\pi\varepsilon_0}\cdot\frac{q}{r}\right)$

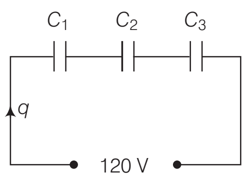
$V_O = V_A \times 6 = 2.7 \times 10^{-6}\ \text{V}$

143. (*b*) $C_0 = \frac{\varepsilon_0 A}{d} = 8\ \text{pF}$

$$C = \frac{K\varepsilon_0 A}{d'} = \frac{6\varepsilon_0 A \times 2}{d} = 96\ \text{pF}$$

144. (*a*) $\frac{1}{C_s} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} = \frac{1}{9} + \frac{1}{9} + \frac{1}{9}$

$$\frac{1}{C_s} = \frac{3}{9} \quad \Rightarrow \quad C_s = 3\ \text{pF}$$



Charge, $q = C_s V = 3 \times 120 = 360\ \text{pC}$

Potential difference across C_1, $(V_1) = \frac{q}{C_1} = \frac{360}{9} = 40\ \text{V}$

$$= V_2 = V_3$$

145. (*a*) $C = \frac{\varepsilon_0 A}{d} = \frac{8.854 \times 10^{-12} \times 6 \times 10^{-3}}{3 \times 10^{-3}}$

$C = 1.77 \times 10^{-11}\ \text{F}$

When the capacitor is connected to a 100 V supply, charge on each plate of the capacitor $q = CV = 1.77 \times 10^{-11} \times 100$

$$q = 1.77 \times 10^{-9}\ \text{C}$$

146. (*c*) Given, capacitance of capacitor $C_1 = 600\ \text{pF} = 600 \times 10^{-12}\ \text{F}$ and supply voltage $V_1 = 200\ \text{V}$

$C_2 = 600\ \text{pF} = 600 \times 10^{-12}\ \text{F}$ and $V_2 = 0$

Loss in energy $(E) = \frac{C_1 C_2 (V_1 - V_2)^2}{2(C_1 + C_2)}$

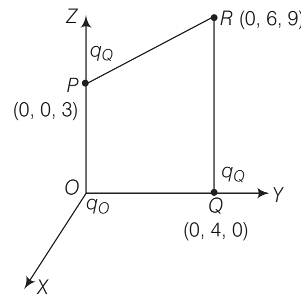
$$\Rightarrow \qquad E = \frac{600 \times 10^{-12} \times 600 \times 10^{-12} (200 - 0)^2}{2(600 + 600) \times 10^{-12}}$$

$$= 6 \times 10^{-6}\ \text{J}$$

Thus, the 6×10^{-6} J amount of electrostatic energy is lost in the sharing of charges.

147. (*b*) Charge at origin O is $q_O = 8\ \text{mC} = 8 \times 10^{-3}\ \text{C}$

Charge q_P at point $P = -2 \times 10^{-9}\ \text{C}$



Distance $OP = r_P = 3\ \text{cm} = 0.03\ \text{m}$

Distance $OQ = r_Q = 4\ \text{cm} = 0.04\ \text{m}$

Work done in bringing the charge q_P from P to Q

$= q_P \times$ Potential difference between P and Q

$$W_{PQ} = q_P\,(V_Q - V_P)$$

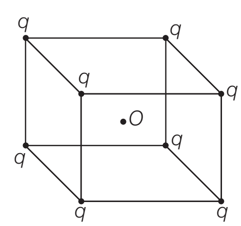
$$= -2 \times 10^{-9}\left(\frac{1}{4\pi\varepsilon_0}\cdot\frac{q_O}{OQ} - \frac{1}{4\pi\varepsilon_0}\cdot\frac{q_O}{OP}\right)$$

$$W_{pq} = -2 \times 10^{-9}\left(\frac{9 \times 10^9 \times 8 \times 10^{-3}}{0.04} - \frac{9 \times 10^9 \times 8 \times 10^{-3}}{0.03}\right)$$

$$= 1.2\ \text{J}$$

148. (*c*) Length of the main diagonal of the cube

$$= \sqrt{b^2 + b^2 + b^2} = \sqrt{3}b$$



Distance of centre O from each of the vertices is r,

$$r = \frac{b\sqrt{3}}{2}$$

Potential at point O due to one charge is $V = \frac{1}{4\pi\varepsilon_0}\cdot\frac{q}{r}$

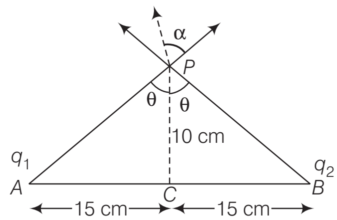
Potential at point O due to all charges placed at the vertices of the cube,

$$V' = 8V = \frac{8 \times 1 \times q}{4\pi\varepsilon_0 \cdot r}$$

$$= \frac{8q \times 2}{4\pi\varepsilon_0 \cdot b\sqrt{3}} = \frac{4q}{\sqrt{3}\pi\varepsilon_0 b}$$

149. (*b*) The distance from point P to point A is equal to the distance from point P to point B.

($BC = AC = 15\ \text{cm} = 0.15\ \text{cm}$, $PC = 10\ \text{cm} = 0.1\ \text{m}$)



$\therefore \quad PA = PB = \sqrt{(0.10)^2 + (0.15)^2} = 0.18$ m

Potential at point P

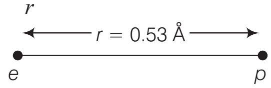
$V_P =$ Potential at point P due to charge q_1 + Potential at point P due to charge q_2

$$V_P = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q_1}{PA} + \frac{1}{4\pi\varepsilon_0} \cdot \frac{q_2}{PB}$$

$$= 9 \times 10^9 \left(\frac{1.5 \times 10^{-6}}{0.18} + \frac{2.5 \times 10^{-6}}{0.18} \right)$$

$$= \frac{9 \times 10^9}{0.18} \times 10^{-6} \times 4 = 2 \times 10^5 \text{ V}$$

150. (b) $U = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q_e q_p}{r}$



$$U = \frac{9 \times 10^9 \times 1.6 \times 10^{-19} \times (-1.6) \times 10^{-19}}{0.53 \times 10^{-10}}$$

$$= 43.47 \times 10^{-19} \text{ J} \qquad (\because 1 \text{ eV} = 1.6 \times 10^{-19} \text{ J})$$

$$= \frac{43.47 \times 10^{-19}}{1.6 \times 10^{-19}} = -27.16 \text{ eV}$$

151. (c) **E** always acts along decreasing potential.

The positively charged particle experiences electrostatic force along the direction of electric field, *i.e.*, from high electrostatic potential to low electrostatic potential. Thus, the work is done by the electric field on the positive charge, hence electrostatic potential energy of the positive charge decreases.

152. (c) The work done by a electrostatic force is given by $W_{12} = q(V_2 - V_1)$. Here initial and final potentials are same in all three cases and same charge is moved, so work done is same in all three cases.

154. (b) In this problem, the collection of charges, whose total sum is not zero, with regard to great distance can be considered as a point charge.

Hence, equipotentials will be planes.

155. (a,b,c) The electric field intensity E is inversely proportional to the separation between equipotential surfaces. So, equipotential surfaces are closer in regions of large electric fields.

Since, the electric field intensity is large near sharp edges of charged conductor and near regions of large charge densities. Therefore, equipotential surfaces are closer at such places.

156. (a,d) When K_2 is on the charge stored by capacitor C_1 gets redistributed between C_1 and C_2 till their potentials become same, *i.e.*, $V_2 = V_1$. By law of conservation of charge, the charge stored in capacitor C_1 when key K_1 is closed and key K_2 is opened is equal to sum of charges on capacitors C_1 and C_2 when K_1 is opened and K_2 is closed.

i.e., $\qquad Q'_1 + Q'_2 = Q$

157. (c, d) $C = \frac{\varepsilon_0 A}{d}$, changes as separation changes, hence

$q = CV$, changes

Source is disconnected charge remains same.

$\Rightarrow \qquad V = \frac{Q}{C}$

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