ELECTROSTATIC POTENTIAL AND CAPACITANCE

CHAPTER 02

Electric Potential

- In an electrostatic field, the electric potential (due to some source charges) at a point P is defined as the work done by external agent in taking a unit point positive charge from a reference point (generally taken at infinity) to that point P without changing its kinetic energy.

  Mathematical representation: $V = \lim_{q_0 \to 0} \frac{W}{q_0}$

- **Potential due to a point charge**: From the definition of potential, V=U/q0

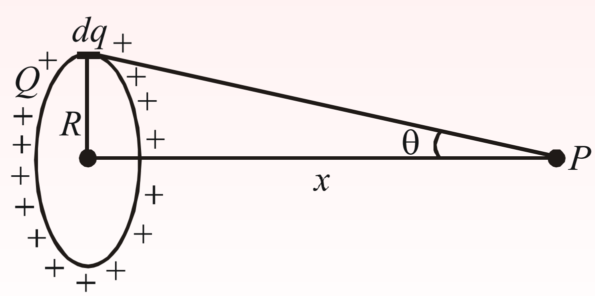
$$V = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q}{r}$$

Here, r is the distance from the point charge q to the point charge q to the point at which the potential is evaluated. If q is positive, the potential that is produces is positive at all points; if q is negative, it produces potential that is negative everywhere. In either case, V is equal to zero at infinity.

- **Potential due to a system of Charges**: Just as the electric field due to a collection of point charges is the vector sum of the fields produced y each charge, the electric potential due to a collection of point charges is the scalar sum of the potential due to each charge.

  Potential due to a ring:

- **Potential at the axis of a ring:** To calculate the potential at a point on the axis which is a distance x from centre of uniformly charged (total charge Q) ring of radius R, consider an element of charge dq on the ring.



Potential at point P due to charge dq will be $dV = \frac{1}{4\pi\varepsilon_0}\frac{dq}{\sqrt{R^2 + x^2}}$

Net potential at point P due to all such element will be: $V = \frac{1}{4\pi\varepsilon_0}\frac{Q}{(R^2 + x^2)^{\frac{1}{2}}}$

- **Potential due to Charged Spherical Surfaces**

  To find the electric potential due to a conducting sphere we should keep in mind the following two points

  1) Electric potential on the surface and at any point inside the sphere is

  $V = \frac{1}{4\pi\varepsilon_0}.\frac{q}{r}$ r= radius of sphere

  2) Electric potential at any point outside the sphere is

  $V = \frac{1}{4\pi\varepsilon_0}.\frac{q}{r}$ r= distance of the point from the centre

Potential Difference

- It refers to the work done per unit charge in moving a charge from one point to another within an electric field.

$$\Delta V = W/Q$$

- **Relation between Electric Field and Potential difference**

  We can use the equation to determine the difference in potential difference between two points if the electric field is known. By inverting this equation, we can write the electric field in terms of the potential.

Since, $V = -\int \vec{E}.d\vec{r}$

Thus, we can write, $E = -\frac{dV}{dr}$

Therefore, the component of the field in any direction is equal to the negative of the rate of change of the electric potential with displacement in that direction

If the field is produced by a point charge, then, $\boxed{\vec{E} = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q}{r^3} \vec{r}}$

and $V = -\int_{\infty}^{r} \vec{E} \cdot d\vec{r}$

so, $V = -\int_{\infty}^{r} \frac{1}{4\pi\varepsilon_0} \cdot \frac{q}{r^3} \vec{r} \cdot d\vec{r}$

i.e., $\boxed{V = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q}{r}}$

Equipotential Surfaces

- If potential of a surface is same throughout, then such surface is known as an equipotential surface.

- **Properties of equipotential surfaces:**

1. Equipotential surfaces can never cross each other.
2. Equipotential surfaces are always perpendicular to the lines of force.
3. If a charge is moved from one point to the other over an equipotential surface, work done will be zero as

   $W_{AB} = -U_{AB} = q(V_B - V_A) = 0 \quad [V_B = V_A]$

Electrostatic Potential Energy

- The Electrostatic potential energy is the work done in taking the charge from reference point to that point without change in kinetic energy.

1. If a point charge q_1 is present in an electric field where potential is V. By definition

   $V = \frac{U}{q_1} \Rightarrow U = q_1 V$

2. The electric potential energy of two-point changes q_1 and q_2 at separation r_{12} is

   $\boxed{U_{12} = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q_1 q_2}{r_{12}}}$

   So, in case of discrete distribution of charges $U = \frac{1}{4\pi\varepsilon_0}\left[\frac{q_1 q_2}{r_{12}} + \frac{q_2 q_3}{r_{13}} + ...\right]$

   and in case of continuous distribution of charge as

   $dU = Vdq$ or

   $U = \int Vdq$

Capacitance

Capacitance is measured by capacitor. The capacitor is a device that store electrical energy. In its most common form, it is an arrangement of two conductors, carrying charges of equal magnitude but of opposite sign, separated by an insulating medium.

It is a scalar quantity

$$\because \quad C = \frac{q}{V} = [M^{-1}L^{-2}T^{4}A^{2}]$$

Its SI unit is coulomb/volt.

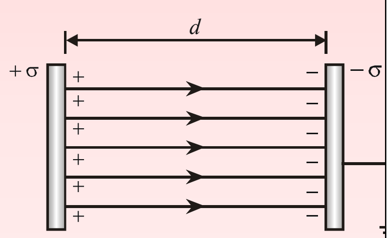
- **Capacitance of a spherical conductor**

The potential at surface of the spherical conductor is $V = \frac{1}{4\pi\varepsilon_o}\frac{Q}{R}$

$$\text{Since } C = \frac{Q}{V}, \quad \text{so} \quad C = 4\pi\varepsilon_o R$$

- **Parallel Plate Capacitor**
- **Parallel plate capacitor with air as an insulator**

A parallel plate capacitor consists of two equal flat parallel metal plates facing each other and separated by distance d.



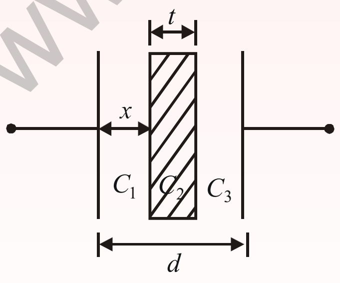
Net electric field between plates, $E = \frac{\sigma}{2\varepsilon} - \frac{(-\sigma)}{2\varepsilon} = \frac{\sigma}{\varepsilon}$

($\sigma = \frac{q}{A}$ is the surface charge density of the plates)

Since $E = \frac{V}{d} = \frac{q}{A\varepsilon}$, so $V = qd/A\varepsilon$

$$\therefore \; C = \frac{q}{V} = \frac{A\varepsilon}{d}$$

- **Capacitor with dielectric slab**



Let a dielectric slab of thickness t dielectric constant K is placed between the plate, at a distance 'x' from one plate.

Let E is a field in a region between the plates filled with air, then field inside dielectric slab is E/K.

Therefore, the potential difference between the plates is $V = E(d-t) + \frac{E}{K}t$

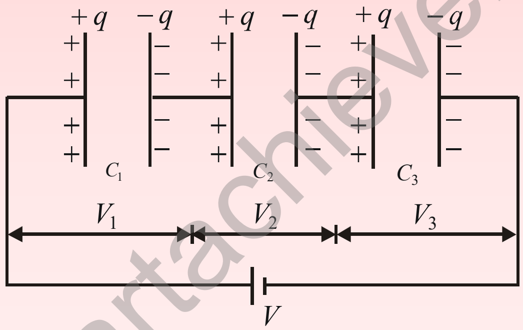
Since, $E = \frac{\sigma}{\varepsilon_o} = \frac{q}{A\varepsilon_o}$ so, $V = \frac{q}{A\varepsilon_o}\left[(d-t) + \frac{t}{K}\right]$

The capacitance of capacitor is $C = \frac{q}{V} = \frac{A\varepsilon_o}{(d-t)+t/K}$

Combination of Capacitors

- **Series arrangement:** Capacitors are said to be in series if charge on each individual capacitor is same, i.e.,

$q = q_1 = q_2 = q_3$

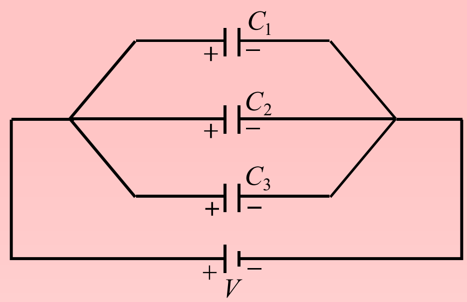


In series as q is same for all capacitors and as $q = CV$ potential divides in the inverse ratio of capacities i.e., $V_1 : V_2 : V_3 :: \frac{1}{C_1} : \frac{1}{C_2} : \frac{1}{C_3}$

Hence, the resultant capacitance is $\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$

If n plates are arranged in series (n–1) capacitors constitute in series and each of value $\frac{\varepsilon_0 A}{d}$, so that $C_R = \frac{\varepsilon_0 A}{d(n-1)}$

- **Capacitors in Parallel:** Capacitors are said to be in parallel if potential across each individual is same and equal



In parallel as V is same for all capacitors and as $q = CV$, charge divides in proportion to capacities i.e., $q_1 : q_2 : q_3 \;::\; C_1 : C_2 : C_3$

Hence, the resultant capacitance is $C = C_1 + C_2 + C_3$

In parallel n plates arranged, $C_R = (n-1)\dfrac{\varepsilon_0 A}{d}$

- **Energy stored in capacitor**

Work required to put a plate at a distance 'd' against attractive force stored in form of electrostatic energy in capacitor

$$w = \int_0^d F dx \quad = -\frac{q^2}{2A\varepsilon_0} d$$

$$w = -\frac{q^2}{2c} \qquad \left(\because C = \frac{A\varepsilon_0}{d}\right)$$

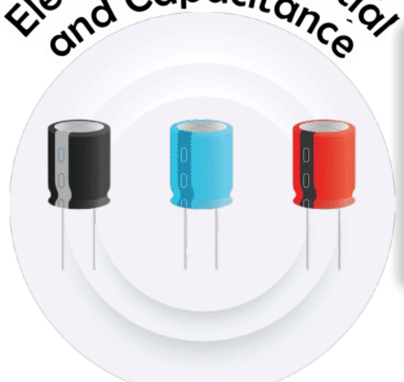
Since electric field is conservative, so potential energy is negative of work done.

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

- **Dielectric Constant**

The ratio of the permittivity of the substance to the permittivity of the free space is defined as dielectric constant. It is denoted by K.

Electrostatic Potential and Capacitance



Electric potential

- Work done per unit test charge by an external agent in moving the test charge from reference point to the desired point. Its SI unit is J/C

$V_0 = W/q_0$.

Electric potential due to a point charge

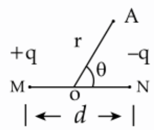
$V_P = Q/4\pi\varepsilon_0 r$

Potential due to a system of charges

$V = \frac{1}{4\pi\varepsilon_0}\sum \frac{Q_i}{r_i}$

Potential due to a dipole

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



Where, $p = qd$

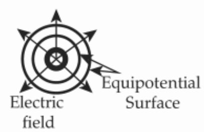
$\theta = \angle AON$

At $\theta = 0°$, $V = \frac{1}{4\pi\varepsilon_0}\frac{p}{r^2}$ [at axial position]

At $\theta = 90°$, $V = 0$ [at equitorial position]

Equipotential surface

- Potential is same at all the points of the surface.
- Component of electric field parallel to an equipotential surface is zero.



Electric potential energy

- It is negative count of work done by the electric force as the configuration of the system changes.
- $Ur_2 - Ur_1 = -W = \frac{q_1 \cdot q_2}{4\pi\varepsilon_0}\left(\frac{1}{r_2} - \frac{1}{r_1}\right)$
- If the separation between charges is 'r', then $U_{(r)} = \frac{q_1 \cdot q_2}{4\pi\varepsilon_0 r}$
- Potential Difference,

$V_B - V_A = \frac{U_B - U_A}{q}$

$U_B - U_A$ = Change in Potential energy

q = Test charge

In 1774, Alessandro Volta wrote treatise "on the forces of attraction of electric fire".

Capacitance, $C = \frac{Q}{V}$

Capacitance of a parallel plate capacitor,
$C = \kappa\varepsilon_0 A/d$, κ = dielectric constant

Parallel grouping of capacitors,
$C = C_1 + C_2 + C_3 + \text{- - - -} + C_n$
for two capacitors, $C = C_1 + C_2$

Energy stored in a capacitor,
$U = \frac{1}{2}CV^2 = \frac{Q^2}{2C} = 1/2\,QV$

Series grouping of capacitors,
$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \text{- - - -} + \frac{1}{C_n}$
For two capacitors, $C = \frac{C_1 C_2}{C_1 + C_2}$

Capacitance when dielectric slab is inserted between the plates
$C = \kappa\varepsilon_0 A/[\kappa d - x(\kappa - 1)]$
where, x = thickness of the slab inserted

Capacitance of a spherical capacitor,
$C = 4\pi\varepsilon_0 / \left(\frac{1}{R_1} - \frac{1}{R_2}\right)$
For isolated sphere,
$C = 4\pi\varepsilon_0 R$

Dielectric

- Force $F = \frac{q_1 q_2}{4\pi\kappa\varepsilon_0 r^2}$, κ = dielectric constant of medium
- A dielectric is an electrical insulator that can be polarized by "application of" electric field.

Conductors & Insulators

Conductors	Insulators
A material which when placed in an electric field, the free electrons move in a direction opposite to the field.	A material in which electrons are tightly bound, and when exposed in an electric field, electrons do not move i.e.,having no free electrons.

Properties of electric field

- Electric field inside a conductor is always zero.
- Electric field is always perpendicular to the charged surface.
- In static state, there will be no additional charge in a conductor.

Potential energy of a dipole

$dU = pE\sin\theta d\theta$

If we choose P.E. of dipole to be zero when $\theta = 90°$, then

$U_\theta - U_{90°} = \int_{90°}^{\theta} pE\sin\theta\, d\theta$

If it is rotated through angle θ against the torque,

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

Trace the Mind Map

- First Level
- Second Level
- Third Level

PRACTICE QUESTIONS

1. The electric potential at point A is 20 V and at B is -40 V. Find the work done by an electrostatic force in moving an electron slowly from B to A.
   a) 9.6×10^{-19} J b) $- 9.6 \times 10^{-19}$ J c) 4.8×10^{-19} J d) $- 4.8 \times 10^{-19}$ J

2. A hollow metallic sphere of radius R is given a charge Q. Then, the potential at the centre
   a) Zero b) $\frac{1}{4\pi\varepsilon_0}.\frac{Q}{R}$ c) $\frac{1}{4\pi\varepsilon_0}.\frac{2Q}{R}$ d) $\frac{1}{4\pi\varepsilon_0}.\frac{Q}{2R}$

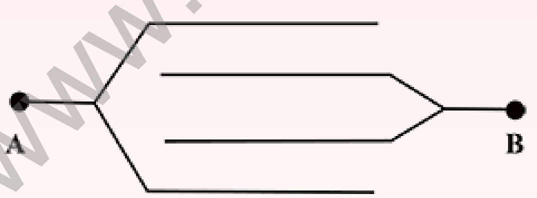
3. An electric field of 10 N/C exists along the x-axis in space. Calculate the potential difference $V_Q - V_P$ where the points P and Q are given by P= (0,0); Q= (4m,2m).
   a) 20V b) 30V c) 40 V d) 50V

4. A conducting sphere of radius 10 cm is charged to 10 μC. Another uncharged sphere of radius 20 cm is allowed to touch it for some time. After that if the spheres are separated, then surface density of charges, on the spheres will be in the ratio of
   a) 1:4 b) 1:3 c) 2:1 d) 1:1

5. A parallel plate capacitor with air between the plates has a capacitance of 9pF. The separation between its plates is 'd'. The space between the plates is now filled with two dielectrics. One of the dielectrics has
   dielectric constant K_1=3 and thickness d/3 while the other one has electric constant K_2=6 and thickness 2d/3. Capacitance of the capacitor now is

   a) 45 pF b) 40.5 pF c) 20.25 pF d) 1.8 pF

6. Four metallic plates each with a surface area of one side A are placed at a distance d from each other. The plates are connected as shown in the circuit diagram. Then the capacitance of the system between a and b is



   a) $\frac{3\epsilon_0 A}{d}$ b) $\frac{2\epsilon_0 A}{d}$ c) $\frac{2\epsilon_0 A}{3d}$ d) $\frac{3\epsilon_0 A}{2d}$

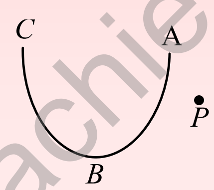
7. A soap bubble is charged to a potential of 16V. Its radius is, then doubled. The potential of the bubble now will be
   a)16V b)4V c)8V d)2V

8. The electric potential inside a conducting sphere
   c) Increases from centre to surface c) Remains constant from centre to surface
   d) Decreases from centre to surface d) Is zero at every point inside

9. Two parallel conducting plates of a capacitor of capacitance C containing charges Q and-- 2Q at a distance d apart. Find out potential difference between the plates of capacitors.
   a) 2Q b)3Q c)3Q/2C d)4Q

10. A slab of material of dielectric constant K has the same area as the plates of a parallel plate capacitor but has a thickness ¾ d where d is the separation of the plates. The ratio of capacitance C (in the presence of dielectric) to the Capacitance C_0 (in the absence of the dielectric) is
    a) 3K/K+4 b) 3K/4 c) 4K/K+3 d) 4K/3

11. In the following diagram the work done in moving a point charge from point *P* to point *A, B* and *C* is respectively as W_A, W_B and W_C then



a) $W_A = W_B = W_C$ b) $W_A = W_B = W_C = 0$ c) $W_A > W_B > W_C$ d) $W_A < W_B < W_C$

12. The charges Q, -q and -q are placed at the vertices of an equilateral triangle of side $10cm$. The potential at the midpoint in between −q and -q, if q=5μC is:

    a)-6.4×10^5 V b) -12.8×10^4 V c) 6.4×10^5 V d) -12.8×10^5 V

13. The potential energy of system of two equal negative point charges of 2μC each held 1m apart in air is ($k = 9 \times 10^9$ SI unit)
    a) 36J b) 3.6×10^{-3} J c)3.6 J d) 3.6×10^{-2} J

14. The plate separation in a parallel plate condenser is d and plate area is A. If it is charged to V volt and battery is disconnected then the work done in increasing the plate separation to 2d will be
    a) $\frac{3\epsilon_0 A V^2}{2d}$ b) $\frac{\epsilon_0 A V^2}{d}$ c) $\frac{2\epsilon_0 A V^2}{d}$ d) $\frac{\epsilon_0 A V^2}{2d}$

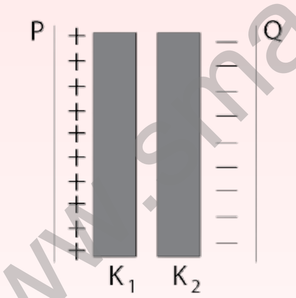
15. Force acting upon a charged particle kept between the plates of a charged condenser is F. If one plate on the condenser is removed, then the force acting on the same particle will become
 a) 0 b) F/2 c) F d) 2F

16. A parallel- plate capacitor is charged from a cell and then isolated from it. The separation between the plates is now increased.
 a) The force of attraction between the plates will decrease.
 b) The field in the region between the plates will not change
 c) The energy stored in the capacitor will increase
 d) The potential difference between the plates will decrease

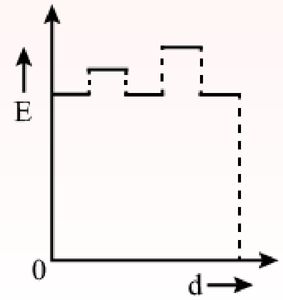
17. A capacitor of capacitance C is charged to a potential difference V from a cell and then disconnected from it. A charge +Q is now given to its positive plate. The potential difference across the capacitor is now
 a) V b) V+ Q/C c) V + Q/2C d) V- Q/C

18. To form a composite 10 μF, 200 V capacitor from a supply of identical capacitors marked 10 μF,50 V, we require a minimum number of capacitors
 a) 8 b) 16 c) 24 d) 32

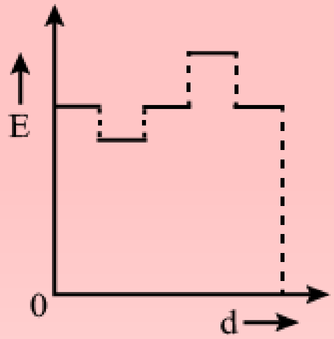
19. Two thin dielectric slabs of dielectric constants K1 and K2(K1<K2) are inserted between plates of a parallel plate capacitor, as shown in the figure. The variation of electric field 'E' between the plates with distance 'd' as measured from plate P is correctly shown by:



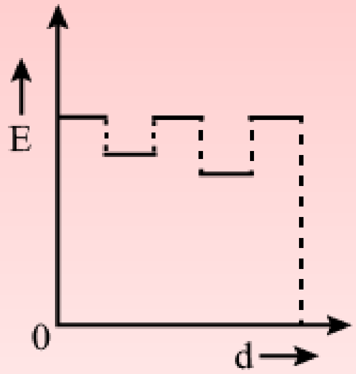
a)



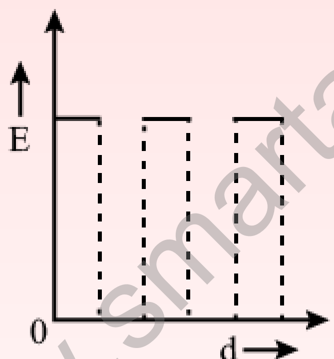
b)



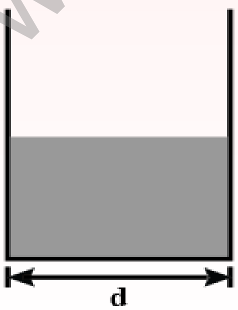
c)



d)



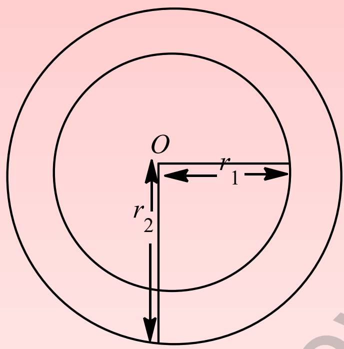
20. A parallel plate air capacitor has a capacitance C. When it is half filled with a dielectric of dielectric constant 5, the percentage increase in the capacitance will be



a) 400% b) 66.6% c) 33.3% d) 200%

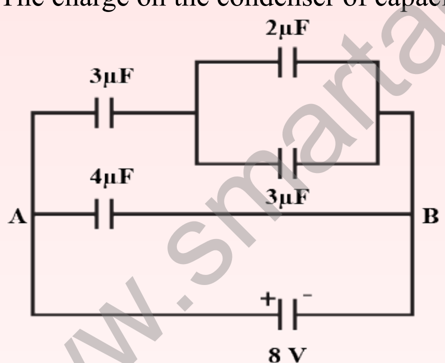
21. The capacitance C of a capacitor is
    a) Independent of the charge and potential of the capacitor
    b) Dependent of the charge and potential of the capacitor
    c) Independent of the geometrical configuration of the capacitor
    d) Independent of the dielectric medium between the two conducting surfaces of the capacitor

22. In the given figure, a hollow spherical capacitor is shown. The electric field will not be zero at



a) 45 V b)60 V c)35 V d)90V

23. The charge on the condenser of capacitance 2μF in the following circuit will be



a) 4.5 μC b) 6.0 μC c) 7 μC d) 30 μC

24. The minimum number of condensers each of capacitance of 2 μF, in order to obtain resultant capacitance of 5 μF will be

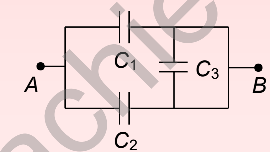
a) 4 b) 5 c) 6 d) 10

25. Identify the wrong statement.
   a) The electrical potential energy of a system of two protons shall increase if the separation between the two is decreased.
   b) The electrical potential energy of a proton-electron system will increase if the separation between the two is decreased.
   c) The electrical potential energy of a proton-electron system will increase if the separation between the two is increased.
   d) The electrical potential energy of system of two electrons shall increase if the separation between the two is decreased.

26. When two conductors of charges and potentials C_1, V_1 and C_2, V_2 respectively are joined, the common potential will be.

a) $\frac{C_1V_1 + C_2V_2}{V_1 + V_2}$ b) $\frac{C_1V_1^2 + C_2V_2^2}{V_1^2 + V_2^2}$ c) $C_1 + C_2$ d) $\frac{C_1V_1 + C_2V_2}{C_1 + C_2}$

27. The equivalent capacitance of the combination of three capacitors, each of capacitance *C* shown in figure between points *A* and *B* is



a) 3C/2 b) C/2 c) 1/3C d)2C

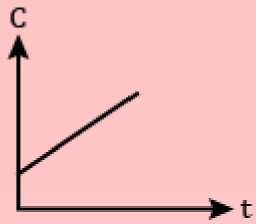
28. Electric potential at the centre of a charged hollow metal sphere is.

a) Zero b) Twice as that on the surface

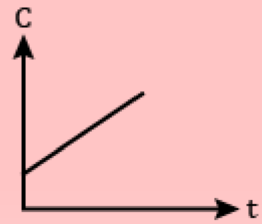
c) Half of that on the surface d) Same as that on the surface

29. A parallel-plate capacitor has a dielectric slab in it. The slab just fills the space inside the capacitor. The capacitor is charged by a battery and then the battery is disconnected. Now, the slab is pulled out slowly at t=0. If at time t, the capacitance of the capacitor is C and potential difference between the plates of the capacitor is V, then which of the following graphs is/are correct.

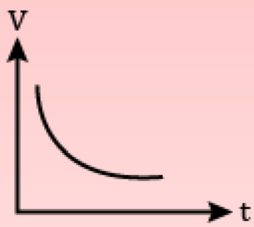
a)



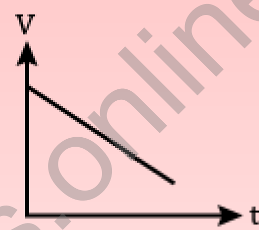
c)



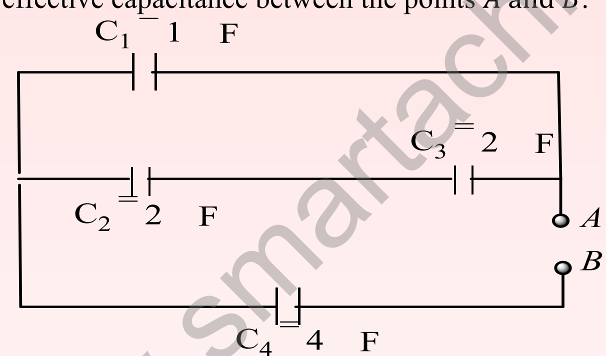
b)



d)



30. Four capacitors are connected in a circuit as shown in the following figure. Calculate the effective capacitance between the points A and B.

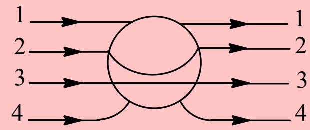


a) $\frac{4}{3}$ μF b) $\frac{24}{5}$ μF c) 9 μF d) 5 μF

31. Two capacitors of capacitance C are connected in series. If one of them is filled with dielectric substance K, what is the effective capacitance?

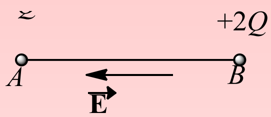
$a)$ $\frac{KC}{(1+K)}$ b) $C(K+1)$ c) $\frac{2KC}{(1+K)}$ d) None of these

32. A metallic solid sphere is placed in a uniform electric field. The lines of force follow the paths shown in figure



a) 1 b) 2 c) 3 d) 4

33. Charges $+2Q$ and $-Q$ are placed as shown is figure. The point at which electric filed intensity is zero will be



a) Somewhere between $-Q$ and $+2Q$

b) Somewhere on the left of $-Q$

c) Somewhere on the right of $+2Q$

d) Somewhere on the right bisector of line joining $-Q$ and $+2Q$.

34. The electric potential inside a conducting sphere

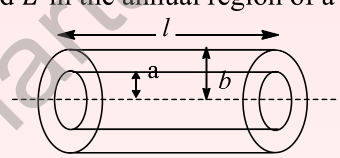
a) Increases from centre to surface

b) Decreases from centre to surface

c) Remains constant from centre to surface

d) Is zero at every point inside

35. The magnitude of electric field $\vec{E}$ in the annual region of a charged cylindrical capacitor



a) Is same throughout

b) Is higher near the outer cylinder than near the inner cylinder

c) Varies as $\frac{1}{r}$, where r is the distance from the axis

d) Varies as $\frac{1}{r^2}$, where r is the distance from the axis

36. A ball of mass 1 carrying a charge 10^{-8} Cmoves from a point A at potential 600 V to a point B at zero potential. The change in its KE is

$a) -6 \times 10^{-6}$ erg b) -6×10^{-6} J c) 6×10^{-6} J d) 6×10^{-6} erg

37. An air parallel plate capacitor has capacity C. The capacity and distance between plates are doubled when immersed in a liquid then dielectric constant of the liquid is

a) 1 b) 2 c) 3 d) 4

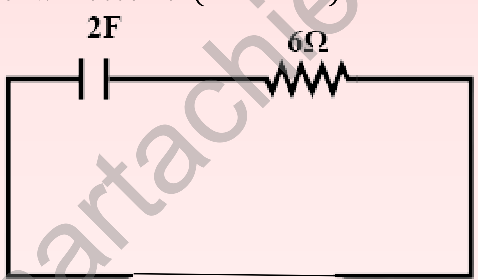
38. If the electric flux entering and leaving an enclosed surface respectively is ϕ_1 and ϕ_1, then, charge enclosed in closed surface is

a) $\frac{\phi_2-\phi_1}{\varepsilon_0}$ b) $\frac{\phi_1+\phi_2}{\varepsilon_0}$ c) $\frac{\phi_1-\phi_2}{\varepsilon_0}$ d) $\varepsilon_0(\phi_2-\phi_1)$

39. A positive point charge q is carried from a point B to a point A in the electric field of a point charge $+Q$ at O. If the permittivity of free space is ε_0, the work done in the process is given by (where a $=OA$ and $b = OR$)

a) $\frac{qQ}{4\pi\varepsilon_0}\left(\frac{1}{a}+\frac{1}{b}\right)$ b) $\frac{qQ}{4\pi\varepsilon_0}\left(\frac{1}{a}-\frac{1}{b}\right)$ c) $\frac{qQ}{4\pi\varepsilon_0}\left(\frac{1}{a^2}-\frac{1}{b^2}\right)$ d) $\frac{qQ}{4\pi\varepsilon_0}\left(\frac{1}{a^2}+\frac{1}{b^2}\right)$

40. In the capacitor shown in the circuit is changed to 5 V and left in the circuit, in 12s the charge on the capacitor will become $(e = 2.718)$



a) $\frac{10}{e}$C b) $\frac{e}{10}$C c) $\frac{10}{e^2}$C d) $\frac{e^2}{10}$C

--------------------------------ANSWER KEY--------------------------------

1)	**a**	**2)**	**b**	**3)**	**c**	**4)**	**c**
5)	**b**	**6)**	**b**	**7)**	**c**	**8)**	**c**
9)	**c**	**10)**	**d**	**11)**	**b**	**12)**	**d**
13)	**d**	**14)**	**d**	**15)**	**b**	**16)**	**c**
17)	**c**	**18)**	**b**	**19)**	**c**	**20)**	**b**
21)	**c**	**22)**	**d**	**23)**	**b**	**24)**	**a**
25)	**c**	**26)**	**d**	**27)**	**d**	**28)**	**d**
29)	**a & c**	**30)**	**a**	**31)**	**a**	**32)**	**d**
33)	**b**	**34)**	**c**	**35)**	**c**	**36)**	**c**
37)	**d**	**38)**	**d**	**39)**	**b**	**40)**	**b**

HINTS AND SOLUTIONS

1. a)
Work done by electrostatic force is
$W = q(V_B - V_A)$
$= q(-40-20) = -60\ q$ J
$= 9.6 \times 10^{-19}$ J

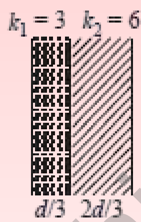
2. b)
Potential at the centre of hollow metallic Sphere is given by $V = \frac{1}{4\pi\varepsilon_0}\frac{Q}{R}$

3. c)
$V_Q - V_P = E(R_Q - R_P)$
$= 10(4-0)$
$= 40V$

4. c)

5. b)

(d) : $C = \frac{\varepsilon_0 A}{d} = 9 \times 10^{-12}$ F



With dielectric, $C = \frac{\varepsilon_0 kA}{d}$

$C_1 = \frac{\varepsilon_0 A \cdot 3}{d/3} = 9C$;

$C_2 = \frac{\varepsilon_0 A \cdot 6}{2d/3} = 9C$

$\therefore\ C_{total} = \frac{C_1 C_2}{C_1 + C_2}$ as they are in series.

$= \frac{9C \times 9C}{18C} = \frac{9}{2} \times C$ or $\frac{9}{2} \times 9 \times 10^{-12}$ F

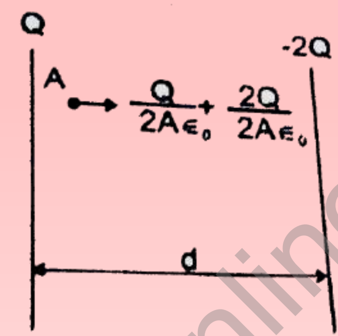
$\Rightarrow\ C_{total} = 40.5$ pF.

6. b)
$C_{eq} = \frac{\epsilon_0 A}{d} + \frac{\epsilon_0 A}{d}$

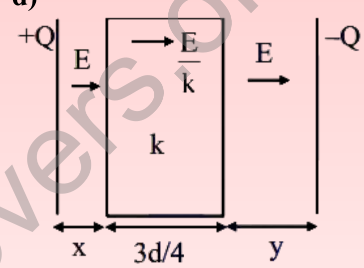
7. c)
Hint-
The radius of soap bubble increases because of outward energy following up at the bubble because of charging

8. c)
The Electric Field inside the conducting sphere is zero.

9. c)
Hint



10. d)



$$x + y + \frac{3d}{4} = d$$

$$x + y = \frac{d}{4}$$

$$\frac{A\epsilon_0}{d} = C_0$$

$$\Delta V = Ex + \frac{E}{k} \times \frac{3d}{4} + Ey$$

$$= \frac{3Ed}{4k} + E(x+y)$$

$$\Delta V = E\left[\frac{3d}{4k} + \frac{d}{4}\right]$$

$$\Delta V = \frac{\sigma}{\epsilon_0}\left[\frac{3d + dk}{4k}\right] = \frac{Qd}{A\epsilon_0}\left[\frac{3+k}{4k}\right]$$

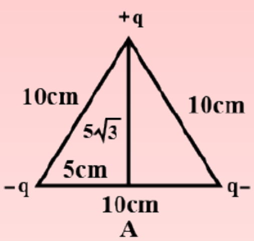
$$\frac{Q}{\Delta V} = C = \frac{A\epsilon_0}{d}\left[\frac{4k}{3+k}\right] = \frac{4kC_0}{k+3}$$

11. b)

When a positive charge is moved from one point to another in an electric of magnetic field, then under the influence of the field force acts on the particle and an external agent will have to do work against this force. But in the given case the charge moves under influence of no field, hence it does not experience any force therefore, no work is done.

$$W_A = W_B = W_C = 0$$

12. d)



13. d)

Use

U= $kq_1 q_2/r$ and put the values.

14. d)

$$W = (\varepsilon 0 \times AV2/2d)$$

15. b)

16. c)

The capacitor is isolated after charging. Capacitors capacitance is inversely proportional to the Potential difference of the capacitor. Moreover, the capacitance of the capacitor is inversely proportional to the distance of plates of the capacitor.

17. c)

Let us consider that the initial charge on the capacitor is Q∘.

The charge on a parallel plate capacitor is capacitance times the potential difference is,

Q0=CV

Now, a charge Q is given to the positive plate and the new potential is V'. We get,

$$V' = Ed = E1 + E2d$$

Where, E1 and E2 are the field in the gap due to charges Q+, Q0 and -Q0 respectively.

So, the electric fields are,

$$E1 = Q + Q\circ/2\varepsilon \circ A,$$

And

$$E2 = Q\circ/2\varepsilon \circ A$$

We get,

$$V' = Q + Q\circ/2\varepsilon \circ A + Q\circ/2\varepsilon \circ Ad$$

So, the potential difference across the capacitor is $Q/2C + V$.

18. b)

Let there are ‘x’ no of capacitors in series i.e in a row

So, x × 50 = 200 => x = 4 capacitors.

Effective capacitance in a row = 10/4

Now, let there are ‘y’ such rows,

So, 10/4 × y = 10 => y = 4 capacitors.

So, the combinations of four rows each of 4 capacitors.

19. c)

A uniform electric field is present between the plates of capacitors in case of absence of dielectric material.

When a dielectric material is inserted in between the plates of capacitor, the dielectric becomes electrically polarized. The polarization charges induced on the two faces of the slab produce their own electric field E0′, which opposes the external field E0. Hence, the resultant field E within the dielectric is smaller than E0 but is in the same direction as E0.

As in the given question the electric field in the region of dielectric will be less as compared to other regions but will not be zero. As K2>K1, the drop in the electric field for K2 dielectric is more than K1.

20. c)

$$C_1 = \frac{K\epsilon_0 A}{d/2} = \frac{2K\epsilon_0 A}{d}$$

$$C_2 = \frac{\epsilon_0 A}{d/2} = \frac{2\epsilon_0 A}{d}$$

$$C^1 = \frac{C_1 C_2}{C_1 + C_2} = \frac{\left(\frac{2K\epsilon_0 A}{d}\right)\left(\frac{2\epsilon_0 A}{d}\right)}{\frac{2K\epsilon_0 A}{d} + \frac{2\epsilon_0 A}{d}}$$

$$\Rightarrow C^1 = \frac{5\epsilon_0 A}{3d}$$

$$= \frac{\frac{5}{3}\frac{\epsilon_0 A}{d} - \frac{\epsilon_0 A}{d}}{\frac{\epsilon_0 A}{d}}$$

$$= \frac{5}{3} - 1 = \frac{2}{3} \times 100$$

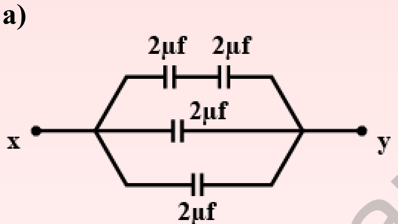
$$= 66.6\%$$

21. (d)
Capacitance C=V/Q
For a dielectric media C=dε/A

∴ Capacitance C of a capacitor is independent of the geometrical configuration of the capacitor

22. (d)
The electric field of a hollow spherical capacitor is localized in between inner and outer surface of the spherical conductor. Therefore, at point $r_1 < r < r_2$, the electric field will not be zero.

23. b)
24. a)



25. c)
Potential energy is given by

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

Or $U \propto \frac{1}{r}$

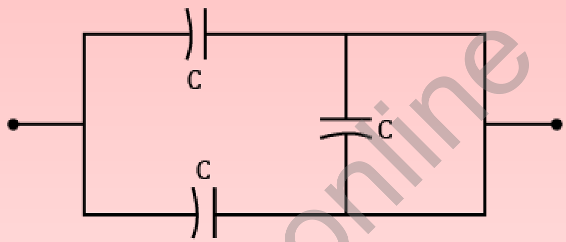
26. d)
When the two charged conductors of capacitances C_1 and C_2 at potential V_1 and V_2 respectively are connected by a conducting wire, the charge flows from higher to lower potential, until the potential of the both conductors are equal.
The initial charges on them are

$$q_1 = C_1 V_1 \qquad q_2 = C_2 V_2$$

The contact makes them to behaves as a parallel combination having charge and capacitance given respectively as

$$\because \quad q = q_1 + q_2$$
$$C = C_1 + C_2$$

27. d)



A connecting wire is connected across the third or the right-most capacitor. It is of no use, as the potential difference across it is zero. Thus, the circuit gets reduced to two capacitors in parallel.

Hence, equivalent capacitance will be

Ceq=C+C=2C

28. d)
A conductor is an equipotential body. The potential of the conductor inside the conductor is same as the potential of the surface of the conductor.

29. a) and c)

30. a)
Effective capacitance of C_2 and C_3

$$\frac{1}{C} = \frac{1}{2} + \frac{1}{2}$$

∴ $C = 1\mu$ F
Now, C_1 and C are in parallel, therefore effective capacitance C'

$$C' = 1 + 1 = 2\mu \text{ F}$$

Now, C' and C_4 are in series, therefore,
effective capacitance between points A and B

$$\frac{1}{C''} = \frac{1}{2} + \frac{1}{4} = \frac{3}{4}$$

$$\Rightarrow \quad C'' = \frac{4}{3} \mu\text{F}$$

31. a)

Effective capacitance of C_2 and C_3

$$\frac{1}{C}=\frac{1}{2}+\frac{1}{2}$$

∴ $C = 1\mu$ F

Now, C_1 and C are in parallel, therefore effective capacitance C'

$C' = 1+1 = 2\mu$ F

Now, C' and C_4 are in series, therefore, effective capacitance between points A and B

$$\frac{1}{C''}=\frac{1}{2}+\frac{1}{4}=\frac{3}{4}$$

$$\Rightarrow \quad C''=\frac{4}{3}\mu\text{F}$$

32. (d)

In a uniform electric field, field line should be straight but line of force cannot pass through the body of metal sphere and must end/start from the sphere normally. All these conditions are fulfilled only in plot (d).

33. (b)

For neutral point $\vec{E}_A+\vec{E}_B=\vec{0}$ *or* $\vec{E}_A=-\vec{E}_B$. It is possible, in present problem, only at a point somewhere on the left of $-Q$

34. (c)

Electric potential inside a conductor is constant and it is equal to that on the surface of conductor

35. (c)

$E \propto \frac{1}{r}$, where r is the distance from the axis.

36. (c)

As work is done by the field, KE of the body increase by

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

$= 10^{-8}(600-0) = 6\times10^{-6}$ J

37. (d)

The capacitance of parallel plate air capacitor

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

where A is the area of each plate and d is the distance between the plates. In a medium of dielectric constant K and with given condition

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

Given, $A'=A, d'=2d, C'=2C$

∴ $2C=\frac{K\varepsilon_0 A}{2d}$ ...(ii)

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

$K=4$

38. (d)

Net electric flux of surface

$$(\phi_2-\phi_1)=\frac{1}{\varepsilon_0}(q)\Rightarrow q=\varepsilon_0(\phi_2-\phi_1)$$

39. (b)

$$W_{BA}=q(V_A-V_B)=q\left[\frac{Q}{4\pi\varepsilon_0 a}-\frac{Q}{4\pi\varepsilon_0 b}\right]$$

$$=\frac{qQ}{4\pi\varepsilon_0}\left[\frac{1}{a}-\frac{1}{b}\right]$$

40. (a)

Final charge on capacitor is

$$q=q_0e^{-t/RC}$$

where q_0= charge on capacitor at $t=0$,

RC=time constant of the circuit.

Putting $q_0=CV_0$

∴ $q=CV_0^{-1/RC}$

Given, $C=2\text{F}, V_0=5$ volt, $R=6\ \Omega, t=12$ s

Hence, $q=(2\times5)\,e^{-(12/6\times2)}$

$$=10e^{-1}=\frac{10}{e}\text{C}$$