CBSE Test Paper-03

Class - 12 Physics (Electrostatic Potential and Capacitance)

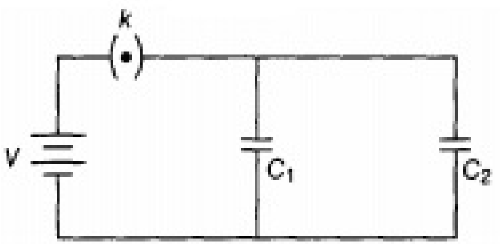
1. Which of the following is true about equipotential lines. Electric field lines are
   a. parallel to equipotential lines
   b. opposite to equipotential lines
   c. tangential to equipotential lines
   d. perpendicular to equipotential lines
2. A semi-circular arc of radius 'a' is charged uniformly and the charge per unit lengths is λ. The electric field at the centre is:
   a. $\frac{\lambda}{2\pi\varepsilon_0 a^2}$
   b. $\frac{\lambda}{4\pi\varepsilon_0 a}$
   c. $\frac{\lambda}{2\pi\varepsilon_0 a}$
   d. $\frac{\lambda^2}{2\pi\varepsilon_0 a}$
3. At the surface of a charged conductor, electrostatic field must be
   a. normal to the surface at every point
   b. never normal to the surface at every point
   c. tangential to the surface at every point
   d. parallel to the surface at every point
4. The dielectric constant K of an insulator can be
   a. 4.0
   b. -4.0
   c. 0.4
   d. 0.0
5. If one penetrates a uniformly charged solid metallic sphere, the electric field strength E
   a. is zero at all points
   b. decreases
   c. remains the same as at the surface
   d. increases
6. What is the shape of the equipotential surfaces for a uniform electric field?

7. What will be the effect on capacity of a parallel plate condenser when area of each plate is doubled and distance between them is also doubled?

8. Is potential difference a scalar or a vector?

9. Two uniformly large parallel thin plates having charge densities $+\sigma$ and $-\sigma$ are kept in the X Z- plane at a distance d apart. Sketch an equipotential surface due to electric field between the plates. If a particle of mass m and charge q remains stationary between the plates. What is the magnitude and direction of this field?

10. Two parallel plate capacitors of capacitances C_1 and C_2 such that $C_1 = 2C_2$ are connected across a battery of V volt as shown in the figure. Initially, the key (k) is kept closed to fully charge the capacitors. The key is now thrown open and a dielectric slab of dielectric constant K is inserted in the two capacitors to completely fill the gap between the plates.
    Find the ratio of
    i. the net capacitance and
    ii. the energies stored in the combination before and after the introduction of the dielectric slab.

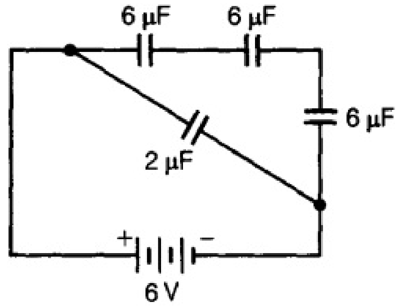


11. What is meant by capacitance? Give its SI unit.

12. Define an equipotential surface. Draw equipotential surfaces
    i. in case of a single point charge
    ii. in a constant electric field in Z-direction. Why the equipotential surfaces about a single charge are not equidistant?
    iii. Can electric field exist tangential to an equipotential surface? Give reason.

13. In a Van de Graaff type generator a spherical metal shell is to be a $15 \times 10^5 V$ electrode. The dielectric strength of the gas surrounding the electrode is $5 \times 10^7 Vm^{-1}$. What is the minimum radius of the spherical shell required?

14. Four capacitors of values 6 μF, 6 μF, 6 μF and 2 μF are connected to a 6 V battery as shown in the figure.



Determine the (i) equivalent capacitance of the network. (ii) charge on each capacitor.

15. A parallel plate capacitor is charged to a potential difference V by a DC source. The capacitor is then disconnected from the source. If the distance between the plates is doubled, state with reason, how the following will change-
    i. Electric field between the plates?
    ii. Capacitance?
    iii. Energy stored in the capacitor?

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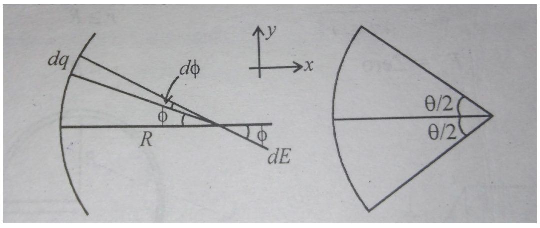
Answers

1. d. perpendicular to equipotential lines

   Explanation: The potential at all points on an equipotential surface is constant and work done in moving a charge on an equipotential surface is zero. Electric field lines show the direction of the electric field at the point. If the electric field lines were tangential, parallel or opposite to the equipotential surface, a tangential field will exist on the surface and work done in moving a charge on the surface is not zero. Therefore electric field lines are always perpendicular to the equipotential surface.

2. c. $\frac{\lambda}{2\pi\varepsilon_0 a}$

   Explanation: I have used the symbol R for radius in the diagram.

   Letλ be the linear charge density .then a small charge element dq=λ a $d\phi$ and electric field due to this element at centre of arc dE=$\frac{dq}{4\pi\in_0 a^2}$

   For every dq there exist a dq' such that y component of dE cancels out thus E_x = $\int_{-\pi/2}^{\pi/2} \; dE \; \cos\varnothing$. Substitute for dE and dq

   E_x =$\int_{-\pi/2}^{\pi/2} \frac{\lambda a \cos\varnothing d\varnothing}{4\pi \in_0 a^2}$ on solving integral.

   E_x =$\frac{\lambda}{2\pi\varepsilon_0 a}$

3. a. normal to the surface at every point

   Explanation: Under static conditions, no current exists on the surface of a conductor. If the electric field at its surface is tangential or parallel to the surface, the tangential electric field would cause the charges to move on the surface of the conductor causing currents to flow on its surface. Therefore electrostatic field is always normal to the surface of a charged conductor at every point.

4. a. 4.0

   Explanation: Dielectric constant of air is 1. All dielectrics generally have a value of the dielectric constant greater than 1.

   $K = \frac{F}{F_m}$

   where F_m is the force between two charged particles in a medium of dielectric constant K and F is the force between the two charges when placed in air.

   The force between two charges is greatest in air or vacuum and it decreases when any medium is placed between the charges.

   K cannot have negative, fractional or zero values.

5. b. decreases

   Explanation: Electric field due to a solid sphere of uniform charge density at points inside the sphere varies as $E = \frac{1}{4\pi\varepsilon_0}\frac{qr}{R^3}$ for $r < R$

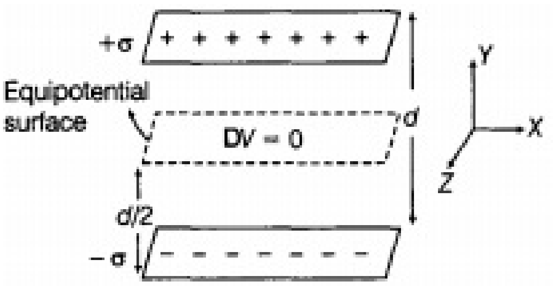
   It decreases at the rate $\frac{r}{R^3}$

   However, if the sphere were a hollow shell, the electric field would be zero at all points where r < R

6. The equipotential surfaces are perpendicular to the direction of electric field.

7. It will remain unaffected.

8. It is a scalar

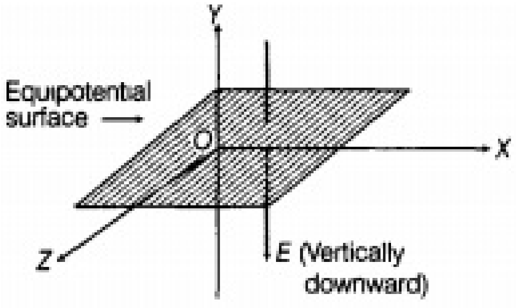
9. 

   The equipotential surface is at a distance d/2 from either plate in XZ-plane. -q charge experiences a force in a direction opposite to the direction of electric field i.e. along the direction of the plate having charge density $+\sigma$.

   $\therefore$ The force on the '-q' charge balances when, the electrostatic force becomes equal to the weight of the charge itself i.e.

   $qE = mg \Rightarrow E = \frac{mg}{q}$

   The direction of electric field along vertically downward direction. The XZ-plane is so chosen that the direction of electric field due to two plates is along vertically downward direction, otherwise weight (mg) of the charged particle could not be balanced. The equipotential surface lies in between the two given plates and on the XZ - plane, as shown below.



10. When a dielectric medium of dielectric constant K is introduced

    a. in an isolated (not connected with battery) capacitor, then total charge on capacitor remains same.
    b. in a capacitor connected with battery, then potential difference across the capacitor remains same as that of potential difference across battery.

    Two identical capacitors C_1 and C_2 get fully charged with 5 V battery initially.

    So, the charge and potential difference on both capacitors becomes
    $q = CV = 2 \times 10^{-6} \times 5\text{V} = 10\mu\text{C}$
    and V= 5V
    On introduction of dielectric medium of K = 5.

    i. **For C_1** (continue to be connected with battery)

       potential difference of C_1, (V') = 5 V

       Capacitance of $C_1' = KC = 5 \times 2\mu F = 10\mu F$
       Charge, $q' = C'V' = (10\mu F)(5\text{V}) = 50\mu\text{C}$
    ii. **For C_2** (disconnected with battery)

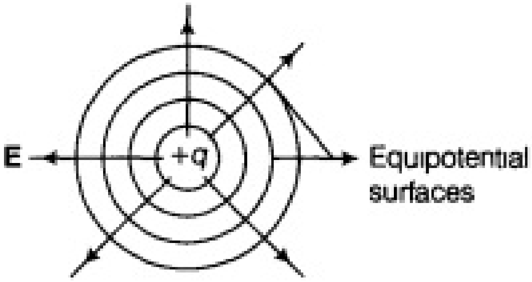
       Charge, q' = q = 10 μC
       Potential difference, $V' = \frac{V}{K} = \frac{5}{5} = 1\text{V}$

11. The ratio of the electric charge on capacitor to its electric potential due to the charge is termed as the capacitance of a conductor. The SI unit of capacitance is Farad.

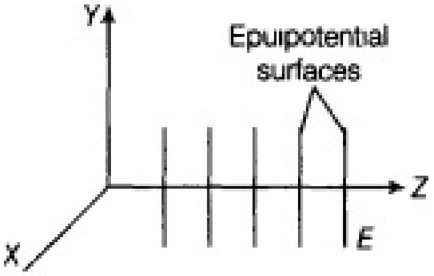
12. Any surface that has same electric potential at every point on it and no work is done

to move a point charge from one point to another on it is called equipotential surface.

i. Equipotential surfaces in case of single point charge are concentric spheres keeping the charge at the centre.



ii. Equipotential surfaces are the parallel planes lying in the YZ-plane along the Z axis, when the electric field is in Z-direction.



The equipotential surfaces due to a single point charge is represented by concentric spherical shells of increasing radius, so they are not equidistant.

iii. No, the electric field does not exist tangentially to an equipotential surface because no work is done in moving a charge from one point to other on an equipotential surface. This indicates that the line integral of electric field along the equipotential surface is zero. i.e. $\int \vec{E}.\overrightarrow{dl} = 0$. Hence, the equipotential surface is always perpendicular to the electric field lines at each and every point on the surface.

13. Dielectric strength of gas surrounding the electrodes $E = 5 \times 10^7 V/m$
Potential of sphere $V = 15 \times 10^5 V$
Suppose radius of the shell = R
For spherical shell $V = \frac{1}{4\pi\varepsilon_0}\left(\frac{q}{r}\right)$
As $V = \frac{kg}{R}$
$E = \frac{kg}{R^2}$ ..... (i)
$E = \frac{V}{R}$ [From (i)]
$R = \frac{V}{E} = 0.3m = 30cm$
$R = \frac{15\times10^5}{10\% \ of \ 5\times10^7}$

$R=\frac{15\times10^5}{\frac{10}{100}\times5\times10^5\times100}$
$=\frac{3}{10}m$
R = 30 cm

14. In series combination, charge on each capacitor always remains same.
    i. All capacitors of capacitances 6 μF are in series combination, then equivalent capacitance of this series combination is given by
    $\frac{1}{C'}=\frac{1}{C_1}+\frac{1}{C_2}+\frac{1}{C_3}$ or $C'=\frac{C}{n}=\frac{6\mu F}{3}=2\mu\mathrm{F}$
    Now this C' and another 2μF capacitors are in parallel combination.
    Hence, the equivalent capacitance of the whole circuit,
    C_{eq} = C' + 2μF= 2μF + 2μF
    C_{eq} = 4 μF
    ii. Since, C' and 2μF are in parallel combination, therefore both of them will get the same potential difference i.e. 6 V.
    Now charge on C'
    q' = C'V = (2μF) $\times$ 6V = 12 μC
    The charge across each capacitor of capacitance 6 μF is same and equal to charge across the series combination of them i.e.12μC
    Charge on 2μF capacitor, q = CV = (2μF)(6 V) = 12μC

15. After disconnection from battery and doubling the separation(d) between the two plates of the given capacitor,
    i. Charge on capacitor remains same.
    i.e, CV= C'V'(C, V, C', V' are the initial capacitance, initial potential difference, final capacitance and final voltage respectively)
    $\Rightarrow \quad CV=\left(\frac{C}{2}\right)V' \Rightarrow V'=2V$ (since C $\propto \frac{1}{d}$, that's why C' = C/2)
    Final electric field between the plates
    $E'=\frac{V'}{d'}=\frac{2V}{2d}$
    $E'=\frac{V}{d}=E$ = initial electric field
    Electric field between the two plates remains same.
    ii. Capacitance reduces to half of original value as

$C \propto \frac{1}{d} \Rightarrow C' = \frac{C}{2}$

iii. Energy stored in the capacitor before disconnection from battery. Initial stored energy,

$U_1 = \frac{q^2}{2C}$

Now, energy stored in the capacitor when distance between the plates doubled is

$U_2 = \frac{q^2}{2(C')} = \frac{q^2}{2 \times \left(\frac{C}{2}\right)} = \frac{q^2}{C}$

$\Rightarrow \quad U_2 = 2\left(\frac{q^2}{2C}\right) = 2U_1 \quad \therefore U_2 = 2U_1$

Hence, final energy stored in capacitor gets doubled to its initial value.