

Electric charge is a fundamental property of matter.

ELECTRIC CHARGES AND FIELD

CLASS XII PHYSICS – FORMULA SHEET

CHAPTER AT A GLANCE

- Electric charge
- Coulomb's law
- Electric field
- Electric flux & Gauss's law
- Conductors
- Applications

1 ELECTRIC CHARGE

Key Points

- Charge is a fundamental property of matter.
- SI unit : Coulomb (C)
- Two types of charge : Positive (+) and Negative (-)
- Like charges repel, unlike charges attract.
- Charge is conserved.
- Charge is quantised.

Quantisation of Charge

$$q = ne$$

where $n = 0, \pm 1, \pm 2, \dots$
 $e = 1.6 \times 10^{-19} \text{ C}$

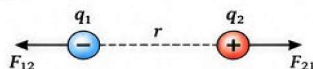
Additivity of Charge

$$q_{\text{net}} = \sum_i q_i$$

Charge is invariant under change of frame of reference.



2 COULOMB'S LAW



The electrostatic force between two point charges is directly proportional to the product of charges and inversely proportional to the square of the distance between them, acting along the line joining them.

$$F_{12} = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r^2}$$

Where,
 $\epsilon_0 = 8.854 \times 10^{-12} \text{ C}^2 \text{ N}^{-1} \text{ m}^{-2}$
 F_{12} = force on q_1 due to q_2

Key Points

- ✓ $F \propto q_1 q_2$
- ✓ $F \propto \frac{1}{r^2}$
- ✓ Force is equal and opposite on both charges.

3 ELECTRIC FIELD

Electric Field Intensity ($\vec{E}$)

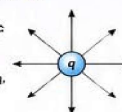
Electric field at a point is the force experienced per unit positive test charge placed at that point.

$$\vec{E} = \frac{\vec{F}}{q_0} \quad \text{SI unit : N/C}$$

Field due to a Point Charge

$$\vec{E} = \frac{1}{4\pi\epsilon_0} \frac{q}{r^2} \hat{r}$$

(radially outward for +q,
inward for -q)



Field due to a System of Charges

$$\vec{E} = \vec{E}_1 + \vec{E}_2 + \vec{E}_3 + \dots$$

(Principle of superposition)

Electric Field Lines

- Originate from + charge and terminate on - charge (or at infinity).
- Tangent at any point gives direction of $\vec{E}$.
- Do not intersect.
- Closer lines $\Rightarrow$ stronger field.

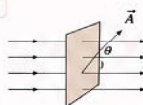
4 ELECTRIC FLUX

Electric flux through a surface is the measure of the number of electric field lines passing through it.

$$\Phi_E = \vec{E} \cdot \vec{A} = EA \cos \theta$$

Where,

- $\vec{A}$ = area vector (perpendicular to surface)
- θ = angle between $\vec{E}$ and $\vec{A}$



Flux depends on

- ✓ Magnitude of $\vec{E}$
- ✓ Area of surface (A)
- ✓ Orientation (θ)

Special Cases

$\theta = 0^\circ$ (Maximum flux)	$\Phi_E = EA$
$\theta = 90^\circ$ (Zero flux)	$\Phi_E = 0$
Arbitrary θ	$\Phi_E = EA \cos \theta$

5 GAUSS'S LAW

The total electric flux through any closed surface is equal to $\frac{1}{\epsilon_0}$ times the total charge enclosed.

$$\oint \vec{E} \cdot d\vec{A} = \frac{q_{\text{enc}}}{\epsilon_0}$$

Applications (for symmetric charge distributions)

(i) Infinite Line Charge (λ)

$$E = \frac{\lambda}{2\pi\epsilon_0 r}$$

(radially outward)

(ii) Infinite Plane Sheet (σ)

$$E = \frac{\sigma}{2\epsilon_0}$$

(perpendicular to sheet)

(iii) Spherical Shell (σ)

$$E = \frac{\sigma}{\epsilon_0} \quad (\text{outside})$$

$$E = 0 \quad (\text{inside})$$

(iv) Solid Sphere (ρ)

$$E = \frac{1}{4\pi\epsilon_0} \frac{Q}{r^2}, \quad r \geq R$$

$$E = \frac{1}{4\pi\epsilon_0} \frac{Qr}{R^2}, \quad r < R$$



Key Idea

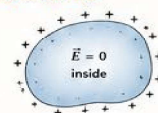
Choose a Gaussian surface that matches the symmetry of the charge distribution to simplify calculations.

6 CONDUCTORS (IN ELECTROSTATIC EQUILIBRIUM)

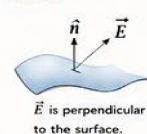
Properties

- ✓ $\vec{E} = 0$ inside the conductor
- ✓ Potential is constant throughout
- ✓ Charge resides on the outer surface
- ✓ Surface is an equipotential surface
- ✓ Electric field just outside the surface is perpendicular to it

Excess Charge Resides on Outer Surface



Electric Field Just Outside the Surface



Charge Density (σ)

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

Where, Q = charge on surface
 A = surface area

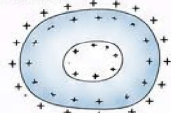
Shape of Conductors

Charge resides on the surface in such a way that there is no electric field inside.

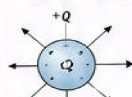


7 CONDUCTORS – IMPORTANT FACTS

- Hollow cavity inside a conductor with no charge $\Rightarrow \vec{E} = 0$ everywhere inside the cavity.
- If a charge is placed inside the cavity, it induces charges on the inner surface; still $\vec{E} = 0$ in the conductor material.



Electric Field due to a Charged Conducting Sphere



$$E = \frac{1}{4\pi\epsilon_0} \frac{Q}{r^2}, \quad r \geq R$$

$$E = 0, \quad r < R$$

8 APPLICATIONS OF ELECTRIC FIELD

Electrostatic Precipitators



Remove smoke and dust particles from industrial gases.

Photocopiers



Uses electric field to attract toner particles to paper.

Lightning



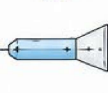
Due to large charge separation between clouds and ground.

Van de Graaff Generator



Builds up very high charge to produce strong electric fields.

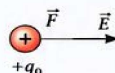
Deflection in CRT



Electric field deflects electron beam in TV/monitor screens.

DIRECTION REMINDER

$\vec{E}$ points in the direction of force on a positive test charge.



FIELD LINES SUMMARY

- ✓ Start from + and end on - (or at ∞)
- ✓ Never intersect each other
- ✓ Crowded lines $\Rightarrow$ stronger field
- ✓ Continuous and closed in conductors

REMEMBER

- ✓ Charge is conserved and quantised.
- ✓ Coulomb's law governs the force.
- ✓ Electric field is a vector quantity.
- ✓ Gauss's law is a powerful tool for symmetric charge distributions.



★ **EXAM TIP :** Draw clear diagrams, choose proper Gaussian surface, apply symmetry, write units, and state direction!

CHAPTER 2

ELECTROSTATIC POTENTIAL AND CAPACITANCE

1 ELECTROSTATIC POTENTIAL (V)

Work done in bringing a unit positive charge from infinity to a point (without acceleration).

$$V = -\frac{W_{\infty \rightarrow P}}{q_0}$$

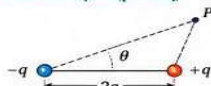
1 Due to point charge (q)

$$V = \frac{1}{4\pi\epsilon_0} \frac{q}{r}$$

2 System of charges $q_1, q_2, \dots, q_n$

$$V = \frac{1}{4\pi\epsilon_0} \sum_{i=1}^n \frac{q_i}{r_i}$$

3 Due to electric dipole ($p = 2aq$)



(i) At any point

$$V = \frac{1}{4\pi\epsilon_0} \frac{p \cos \theta}{r^2} = \frac{1}{4\pi\epsilon_0} \frac{\vec{p} \cdot \vec{r}}{r^2}$$

(ii) On dipole axis ($\theta = 0, \pi$)

$$V = \frac{1}{4\pi\epsilon_0} \frac{2p}{r^2}$$

(iii) In equatorial plane ($\theta = \frac{\pi}{2}$)

$$V = 0$$

2 UNIFORMLY CHARGED SPHERICAL SHELL (Q, R)



(i) Outside ($r > R$)

$$V = \frac{1}{4\pi\epsilon_0} \frac{Q}{r}$$

(ii) On surface ($r = R$)

$$V = \frac{1}{4\pi\epsilon_0} \frac{Q}{R}$$

(iii) Inside ($r < R$)

$$V = \frac{1}{4\pi\epsilon_0} \frac{Q}{R}$$

CONDUCTORS & INSULATORS

Conductors

- Have free charges which can move freely.
- Electric field inside a conductor is zero in electrostatic equilibrium.

Insulators

- Charges are bound to atoms and cannot move freely.
- Act as barriers to the flow of charge.

FREE CHARGES & BOUND CHARGES INSIDE A CONDUCTOR

- Free charges reside on the surface.
- Inside the conductor, $E = 0$ and $V = \text{constant}$.

3 POTENTIAL DIFFERENCE (ΔV)

Work done against electric field in moving a unit positive charge from one point to another.

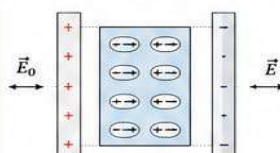
$$V_2 - V_1 = -\frac{W_{12}}{q_0}$$

If W_{12} is work done in moving a charge q from one point to another point then

$$V_2 - V_1 = \frac{W_{12}}{q}$$

$$W_{12} = q(V_2 - V_1)$$

4 DIELECTRICS & ELECTRIC POLARIZATION



When a dielectric is placed in an electric field, its molecules get polarized.

Electric dipole moment of molecules induced in the direction of $\vec{E}$.

$$\vec{p} = \text{Electric dipole moment of molecule}$$

4 CAPACITORS & CAPACITANCE

A capacitor consists of two conductors separated by an insulator (dielectric). Capacitance (C) is the ability of a capacitor to store charge.

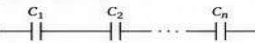


$$C = \frac{Q}{V} \quad (\text{Farad})$$

where Q = charge, V = potential difference

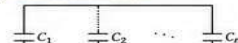
Combination of Capacitors

(i) Series Combination



$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \dots + \frac{1}{C_n}$$

(ii) Parallel Combination



$$C_{eq} = C_1 + C_2 + \dots + C_n$$

Parallel Plate Capacitor



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



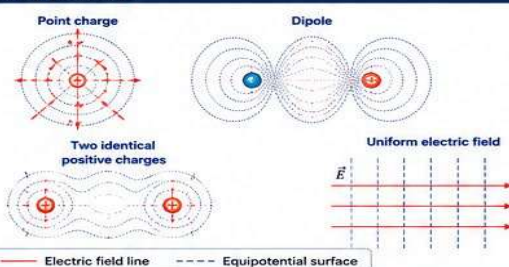
$$C = \frac{K\epsilon_0 A}{d}$$

Energy stored in a capacitor

$$U = \frac{1}{2} CV^2 = \frac{Q^2}{2C} = \frac{1}{2} QV$$

EQUIPOTENTIAL SURFACES

- Electric potential is same at all points on the surface.
- Electric field lines are always perpendicular to equipotential surfaces.
- Two equipotential surfaces cannot intersect.
- No work is required to move a charge along an equipotential surface.
- No work is required to move a charge along an equipotential surface ($\Delta V = 0$).
- Shapes of Equipotential Surfaces

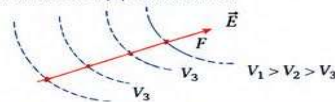


— Electric field line --- Equipotential surface

RELATION BETWEEN FIELD & POTENTIAL

$$\vec{E} = -\nabla V$$

- Electric field is in the direction in which the potential decreases steepest.
- Its magnitude is given by the change in the magnitude of potential per unit displacement normal to the equipotential surface.



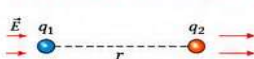
ELECTRIC POTENTIAL ENERGY (U)

(i) For two point charges q_1 and q_2



$$U = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r}$$

(ii) Two charges in an external field



$$U = q_1 V_1 + q_2 V_2 + \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r}$$

(iii) Dipole in an external field



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

Equilibrium of a Dipole

Stable equilibrium $\theta = 0^\circ$ ($\vec{p} \parallel \vec{E}$)

Unstable equilibrium $\theta = 180^\circ$ ($\vec{p}$ anti-parallel to $\vec{E}$)

EFFECT OF DIELECTRIC (CONSTANT K) ON A CAPACITOR

Condition Quantity	Battery Connected ($V = \text{Constant}$)			Battery Disconnected ($Q = \text{Constant}$)		
	Without Dielectric ($K = 1$)	With Dielectric (K)	Change (in terms of K)	Without Dielectric ($K = 1$)	With Dielectric (K)	Change (in terms of K)
Capacitance (C)	C_0	KC_0	$\times K$	C_0	KC_0	$\times K$
Charge (Q)	$C_0 V$	$KC_0 V$	$\times K$	Q_0	Q_0	No change
Potential Difference (V)	V	V	No change	$\frac{Q_0}{C_0} = V_0$	$\frac{Q_0}{KC_0} = \frac{V_0}{K}$	$\div K$
Energy Stored (U)	$\frac{1}{2} C_0 V^2$	$\frac{1}{2} KC_0 V^2$	$\times K$	$\frac{Q_0^2}{2C_0}$	$\frac{Q_0^2}{2KC_0} = \frac{1}{K} \left(\frac{Q_0^2}{2C_0} \right)$	$\div K$

DIELECTRIC IN A CAPACITOR



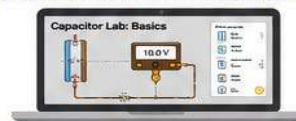
Dielectric polarizes and reduces the effective electric field between plates, thus increasing capacitance.

APPLICATIONS IN DAILY LIFE

- Power Distribution**
Voltage drives current to deliver power to devices.
- Electronic Devices**
Controls the movement of charges in devices like TV screens, electron microscopes.
- Lightning Rods**
Facilitates the transfer of charge and prevents damage.
- High-Voltage Lines**
Smooth surfaces prevent charge leakage.
- Audio Equipment**
Capacitors filter noise and stabilize signals for clear sound.
- Camera Flashes**
Capacitors store energy to provide high-power flashes.
- Automotive Systems**
Used in hybrid and electric vehicles for energy recuperation.
- Medical Devices**
Capacitors in defibrillators deliver a burst of energy.

SIMULATION LINK FOR CAPACITOR

Explore interactive learning for capacitors at:
<https://phet.colorado.edu/en/simulations/capacitor-lab-basics>



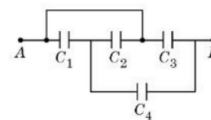
MULTIPLE CHOICE QUESTIONS

Q1 In a region electric field is given by $\vec{E} = 4x\hat{i}$ N/C. The potential difference between points A(x=1m) and B (x=3m), $V_A - V_B$ is given by: **CBSE 2026 55/1/2**

- (a) -16V (b) 16V (c) -8V (d) 8V

Q2 From the figure given below calculate the capacitance of the given combination of capacitors between points A and B ($C_1 = C_2 = C_3 = 1 \mu\text{F}$, $C_4 = 2\mu\text{F}$) **JEE MAINS 2026**

- (a) 2 (b) 7/2 (c) 7/3 (d) 5/2



Q3 A point charge lies at a distance x from the midpoint of an electric dipole on its axis. The electric potential at a point P is proportional to:

- (a) $1/x^3$ (b) $1/x^2$ (c) $1/x^4$ (d) $1/x^{1/2}$

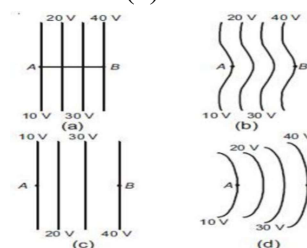
Q4 Ten capacitors, each of capacitance $1 \mu\text{F}$, are connected in parallel to a source of 100 V. The total energy stored in the system is equal to:

- (a) 10^{-2} J (b) 10^{-3} J (c) 0.5×10^{-3} J (d) 5.0×10^{-2} J

Q5 The diagrams below show the regions of equipotential.

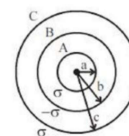
A positive charge is moved from A to B in each diagram then:

- (a) Maximum work is required to move q in figure (c).
 (b) In all the four cases the work done is the same.
 (c) Minimum work is required to move q in figure (a).
 (d) Maximum work is required to move q in figure (b)



Q6 As shown in figure, A, B and C are concentric shells of radius a, b and c respectively ($a < b < c$). Their surface charge densities are σ , $-\sigma$ and σ respectively. What is the electric potential on the surface of shell A?

- (a) $\frac{-\sigma}{\epsilon_0} (a+b+c)$ (b) $\frac{\sigma}{\epsilon_0} (a+b+c)$ (c) $\frac{\sigma}{\epsilon_0} (b-a-c)$ (d) $\frac{\sigma}{\epsilon_0} (a-b+c)$



Q7: Four charges 10^{-8} C, -2×10^{-8} C, $+3 \times 10^{-8}$ C and 2×10^{-8} C are placed at the four corners of a square of side 1m the potential at the center of the square is :

- (a) zero (b) 360 volt (c) $360\sqrt{2}$ volt (d) 180V

Q8: The electrostatic force between the metal plates of an isolated parallel plate capacitor C having a charge Q and area A, is:

- (a) Independent of the distance between the plates (b) Linearly proportional to the distance between the plates
 (c) Proportional to the square root of the distance between the plates
 (d) Inversely proportional to the distance between the plates

Q9: A capacitor is charged by a battery. The battery is removed and another identical uncharged capacitor is connected in parallel. The total electrostatic energy of resulting system

- (a) Increases by a factor of 4 (b) Decreases by a factor of 2
 (c) Remains the same (d) Increases by a factor of 2

Q10: A capacitor works as the charge storing device in

- (a) AC circuits (b) DC circuits (c) Both (1) & (2) (d) Neither (1) nor (2)

Q11. A uniform electric field pointing in positive x-direction exists in a region. Let A be the origin, B be the point on the x-axis at $x = +1$ cm and C be the point on the y-axis at $y = +1$ cm. Then, the potentials at the points A, B and C satisfy

- (a) $V_A < V_B$ (b) $V_A > V_B$ (c) $V_A < V_C$ (d) $V_A > V_C$

Q12. Which statement is not correct for an equipotential surface?

- (a) Electric field intensity is always perpendicular to the equipotential surface.
 (b) Potential difference between any two points on it is zero.
 (c) Equipotential surfaces are spherical in shape.
 (d) No work is required to move a charge on an equipotential surface

Q13. An electron mass m and charge e travels from rest through a potential difference of V . What will be the final velocity of electron?

- (a) eV (b) $\frac{2eV}{m}$ (c) $\sqrt{\frac{2eV}{m}}$ (d) $\sqrt{\frac{2mV}{e}}$

Q14. Four point charges $-Q$, $-q$, $2q$ and $2Q$ are placed, one at each corner of the square. The relation between Q and q for which the potential at the centre of the square zero, is

- (a) $Q = -q$ (b) $Q = \frac{-1}{q}$ (c) $Q = q$ (d) $Q = \frac{1}{q}$

Q15. A hollow metal sphere of radius 10 cm is charged such that the potential on its surface is 80 V. The ratio of potential at a distance 5cm from the centre of the sphere to the potential at the surface of sphere is

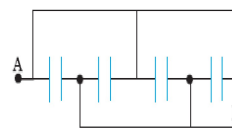
- (a) 1:2 (b) 2:1 (c) 1:1 (d) 1:4

Q16. There is one charged isolated air capacitor and U is the energy stored in it. Separation between the plates of the capacitor is increased to double of the initial value. Energy stored becomes

- (a) $U/2$ (b) $2U$ (c) $U/3$ (d) $3U$

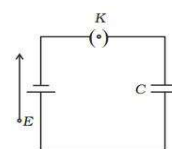
Q17. Four condensers are joined as shown in the figure and the capacity of each condenser is $8 \mu\text{F}$. The equivalent capacity between the points A and B will be:

- (a) $16 \mu\text{F}$ (b) $8 \mu\text{F}$
 (c) $32 \mu\text{F}$ (d) $2 \mu\text{F}$



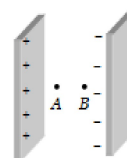
Q18. A parallel plate capacitor is connected to a battery as shown in Fig. Consider two situations: A: Key K is kept closed and plates of capacitors are moved apart using insulating handle. B: Key K is opened and plates of capacitors are moved apart using insulating handle. Choose the correct option(s).

- (a) In A : Q remains same but C changes.
 (b) In B : V remains same but C changes.
 (c) In A : V remains same and hence Q changes.
 (d) In B : C remains same and hence V changes.



Q19. Two protons A and B are placed in space between plates of a parallel plate capacitor charged up to V volts (See fig.) Forces on protons are F_A and F_B , then

- (a) $F_A > F_B$ (b) $F_A < F_B$
 (c) $F_A = F_B$ (d) none of the above



Q20. n small droplets of same size are charged to a same potential V . If all of them combine to form a single drop then potential of the single drop will be

- (a) nV (b) V/n (c) $n^{2/3}V$ (d) $n^{1/3}V$

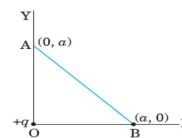
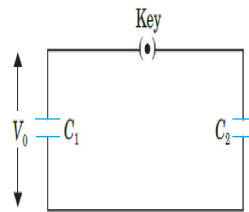
ANSWERS

- Q1 (a) $V_A - V_B = - \int E \cdot dx$ so potential difference $= -2x^2 = -2(3^2 - 1^2) = -16V$
- Q2 (a) C_1 & C_2 are parallel so $2\mu F$.. This $2\mu F$ is in series with C_4 . So $1\mu F$. now this is in parallel with C_3 so final equivalent resistance is $1\mu F + C_3 = 2\mu F$
- Q3 (b) For an electric dipole, the electric potential at a point on its axial line is given by $V = kp/x^2$ where distance between the charges is much smaller than the distance at which potential is to be calculated.
- Q4 (d) Net capacitance $= 10 \times 1\mu F = 10^{-5}F$ connected to $100V$ so total energy is $U = 1/2 C_{eq} V^2$ so we get $5 \times 10^{-2}J$
- Q5 (b) Work done $w = q\Delta V$, ΔV is same in all the cases so work is done will be same in all the cases.
- Q6(d) Electric charge on shell A is $q_A = 4\pi a^2 \sigma$; Electric charge on shell B is $q_B = -4\pi b^2 \sigma$
Electric charge on shell C is $q_C = 4\pi c^2 \sigma$
- Shell A is inside the shell B and C. so $V_A = \frac{1}{4\pi\epsilon_0} (q_A + q_B + q_C)$
- Q7 (c) Potential at the centre is : $V = kq/r : V = \frac{1}{4\pi\epsilon_0} (q_1/r_1 + q_2/r_2 + q_3/r_3 + q_4/r_4) = 360\sqrt{2} V$
- Q8 (a) For isolated capacitor $Q = \text{Constant}$: $F_{avg} = \frac{Q^2}{2A\epsilon_0}$; F is independent of the distance between plates
- Q9 (b) Common potential $= V/2$; Initial energy $U_i = 1/2 CV^2$ final energy $U_f = 1/4 CV^2$ so loss of energy $= 1/2 CV^2 - 1/4 CV^2 = 1/4 CV^2$ decreases by a factor of 2
- Q10 (b) DC circuits
- Q11. (b) $E = - \frac{dV}{dr}$, Direction of electric field must be in the direction of the decreasing order of electric potential.
- Q12. (c) Shape of equipotential surface depends on charge or distribution of charges
- Q13. (c) $eV = \frac{1}{2}mv^2$ so $v = \sqrt{\frac{2eV}{m}}$
- Q14. (a) $\frac{1}{4\pi\epsilon_0} \frac{-Q}{R} + \frac{1}{4\pi\epsilon_0} \frac{-q}{R} + \frac{1}{4\pi\epsilon_0} \frac{2Q}{R} + \frac{1}{4\pi\epsilon_0} \frac{2q}{R} = 0$ $Q = -q$
- Q15. (c) Value of potential inside and on the surface of a charged spherical shell is same
- Q16.(b) As capacitor is isolated so charge on capacitor remains same
New capacitance $C' = \frac{C}{2}$ and $V' = 2V$
Hence, new energy $U' = 2U$
- Q17.(c) All capacitors are connected in parallel so $C_{eq} = C_1 + C_2 + C_3 + C_4$ so $C_{eq} = 32\mu F$
- Q18.(c) As it is connected to battery so V remains same but as capacitance changes so charge changes
- Q19.(c) As $F = qE$ and value of electric field is uniform in the space between the plates
So $F_A = F_B$
- Q20.(c) total charge $Q = nq$ and $R = n^{1/3}r$, So $V = n^{2/3}V$

PRACTICE QUESTIONS

- If a charged spherical conductor of radius 10 cm has potential V at a point 5 cm distant from its center, then the potential at a point 15 cm distant from the center will be:
 - $3V$
 - $\frac{3}{2}V$
 - $\frac{2}{3}V$
 - $\frac{1}{3}V$
- A parallel plate air capacitor has capacitance $18\mu F$. If the distance between the plates is made thrice 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
3. Select the incorrect statement.
- Electric potential decreases inside electric field if one goes in a direction making an angle less than 90° with the direction of electric field intensity.
 - Electric potential increases at the fastest rate if one goes in the direction of electric field intensity.
 - Electric potential decreases at the fastest rate if one goes in the direction of electric field.
 - Electric potential increases at the fastest rate if one goes in the direction opposite to that of electric field.
4. A capacitor C_1 is charged by a potential difference V_0 as shown in the figure. This charging battery is then removed and the capacitor is connected to an uncharged capacitor C_2 . The final potential difference V across the combination is:
- (a) $V_0 \left(\frac{C_1 - C_2}{C_1} \right)$ (b) $V_0 \left(\frac{C_1}{C_1 - C_2} \right)$ (c) $V_0 \left(\frac{C_1}{C_1 + C_2} \right)$ (d) $V_0 \left(\frac{C_1 + C_2}{C_1} \right)$
5. 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 [co-ordinates $(0, a)$] to another point B [co-ordinates $(a, 0)$] along the straight path AB is:
- (a) Zero (b) $\left(\frac{-qQ}{4\pi\epsilon_0 a^2} \right) \sqrt{2}a$ (c) $\left(\frac{qQ}{4\pi\epsilon_0 a^2} \right) \frac{a}{\sqrt{2}}$ (d) $\left(\frac{-qQ}{4\pi\epsilon_0 a^2} \right) \sqrt{2}a$



ANSWERS

- 1.C 2.C 3.B 4.C 5.D

ASSERTION-REASON QUESTIONS

Select the correct answer to these questions from the codes (a), (b), (c) and (d) as given below:

- Both assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of Assertion (A).
 - Both assertion (A) and Reason (R) are true and Reason (R) is NOT the correct explanation of Assertion (A).
 - Assertion (A) is true and Reason (R) is false.
 - Assertion (A) is false and Reason (R) is also false.
- Assertion (A):** Electric field is always normal to equipotential surfaces and along the direction of decreasing order of potential.
Reason (R): electric field is defined as negative gradient of electric potential.
 - Assertion (A):** Electric field inside a hollow conducting sphere is zero.
Reason (R): Charge is present only on the outer surface of conductor.
 - Assertion (A):** Work done in moving a charge between any two points in a uniform electric field is independent of the path followed by the charge between these two points.
Reason (R): Electrostatic forces are non-conservative.
 - Assertion (A):** Electrostatic potential and electric potential energy are two different quantities.
Reason (R): For a test charge Q and a point charge Q , the electric potential energy becomes equal to the potential.
 - Assertion (A):** When the distance between the parallel plates of a parallel plate capacitor is halved and the dielectric constant of the dielectric used is made three times, then the capacitance becomes three times.

Reason (R): Capacitance does not depend upon the external battery connected.

6. **Assertion (A):** Circuit containing capacitors should be handled very carefully even when the power is off.

Reason (R): The capacitors may break down at any time.

7. **Assertion (A):** Capacity of a conductor is independent on the amount of charge on it.

Reason (R): Capacitance depends on the dielectric constant of surrounding medium, shape and size of the conductor.

8. **Assertion (A):** Two parallel metal plates having charge +Q and –Q are facing at a distance between them. The plates are now immersed in kerosene oil and the electric potential between the plates decreases.

Reason (R): Dielectric constant of kerosene oil is less than 1.

9. **Assertion (A):** Two adjacent conductors of unequal dimensions, carrying the same positive charge have a potential difference between them.

Reason (R): The potential of a conductor does not depend upon the charge given to it.

10. **Assertion (A):** Polar molecules do not have permanent dipole moment.

Reason (R): In polar molecules, the centers of positive and negative charges coincide even when there is no external field.

ANSWERS

1. Option (A) is correct : $E = -\frac{dV}{dr}$. So, the electric field is always perpendicular to equipotential surface. Negative gradient of electric potential is electric field. So, direction of electric field must be in the direction of the decreasing order of electric potential.

2. Option (A) is correct: Since no charge resides in the surface of a hollow sphere, the electric field also zero inside. For hollow conducting sphere, the charged reside on the surface only.

3. Option (C) is correct. Work done in moving a charge between any two points in a uniform electric field = charge $\times$ potential difference. So, it is independent of the path followed by the charge. Electrostatic forces are conservative type.

4. Option (C) is correct. Electric potential and electric potential energy are two different quantities. Electric potential is defined as the potential energy per unit charge. Hence $V = \text{P.E.}/q$.

5. Option (B) is correct. Initial capacitance $C_1 = C = \frac{K\epsilon_0 A}{d}$, $C_2 = \frac{3K\epsilon_0 A}{d/2}$ So $C_2 = 6C_1$,

6. Option (C) is correct. Even when power is off capacitor may have stored charge which may discharge through human body and thus one may get a shock. Breakdown of capacitors requires high voltage.

7. Option (A) is correct. $C = \frac{\epsilon_0 A}{d}$. In the expression, there is no involvement of charge. So, capacitance is independent of charge. It depends on permittivity of the surrounding medium and the area of the plate.

8. Option (C) is correct. Electric field for parallel plate capacitor in vacuum $E = \frac{\sigma}{\epsilon_0}$. Electric field in dielectric $E' = \frac{\sigma}{K\epsilon_0}$. Since the value of K for Kerosene oil is greater than 1, then $E' < E$. Dielectric constant of Kerosene oil is greater than 1.

9. Option (C) is correct. Potential of a conductor depends upon charge and size of the body so potential of both will not be same.

10. Option (D) is correct. In polar molecules centre of positive charge does not coincide with centre of negative charge so they have net dipole moment.

PRACTICE QUESTIONS

1. **Assertion (A):** A metal plate is introduced between the plates of a charged parallel plate capacitor, its capacitance increased.

Reason(R): A metal plate is introduced between the plates of a charged parallel plate capacitor, the effective separation between the plates is decreased.

2. **Assertion (A):** Sensitive instruments can protect from outside electrical influence by enclosing them in a hollow conductor.

Reason(R): Potential inside the cavity is zero.

3. **Assertion (A):** The field intensity in between such sheets having equal and opposite uniform surface densities of charge become constant.

Reason(R): The field intensity does not depend upon the distance between the thin sheets.

4. **Assertion (A):** The electrostatic force between the plates of a charged isolated capacitor decreases when dielectric fills whole space between plates.

Reason(R): The electric field between the plates of a charged isolated capacitance increases when dielectric fills whole space between plates.

5. **Assertion (A):** Electric field inside a conductor is zero.

Reason(R): The potential at all the points inside a conductor is same.

Answers

1. A

2.C

3.A

4.D

5.B

VERY SHORT ANSWER TYPE QUESTIONS (2 MARKS)

Q1 Two points R and S are equidistant from two charges $+Q$ and $-2Q$. Calculate the amount of work done in moving a charge $-Q$ from point R to S. **CBSE 2026 (55/5/3)**

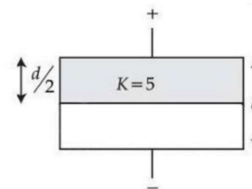
Q2 Two point charges $-2\ \mu\text{C}$ and $5\ \mu\text{C}$ are placed at $(-30\text{cm}, 0)$ and $(30\text{cm}, 0)$ respectively in an external electric field $\vec{E} = \frac{A}{x^2} \hat{i}$ where $A=9 \times 10^5\ \text{Nm}^2\text{C}^{-1}$. Find the electrostatic potential energy of the configuration. **CBSE 2026 (55/3/2)**

Q3 A parallel plate capacitor of plate area A and plate separation d is completely filled with two dielectric slabs of dielectric constant K_1 and K_2 each of area $A/2$. Find the effective capacitance of the capacitor. **55B CBSE 2026**

Q4: (a) Draw electric field lines and equipotential surfaces for a system of two equal positive charges separated by some distance. (b) Using the drawings in (a) above, explain that electric field need not be a constant over each point of an equipotential surface. **CBSE 55/2/3**

Q5 Two air filled capacitors C_1 and C_2 are connected in parallel with a dc battery. After the capacitors are fully charged, a slab of dielectric constant K is inserted between the plates of each capacitor. How will the i) charge on each capacitor and ii) energy stored in the capacitor affected after the slab is introduced. **CBSE 55/2/3**

Q6 A parallel plate capacitor has a capacitance C . When it is half filled with a material of dielectric constant $K=5$ as shown in the figure, then calculate the percentage increase in the capacitance of the capacitor. **IIT JEE MAINS 2026**



Q7 A parallel plate air capacitor is connected to a battery. The plates are pulled apart at a uniform speed v . If x is the separation between the plates at any instant of the capacitor is then the time rate change of the electrostatic energy of the capacitor is proportional to x^α . Calculate the value of α . **IIT JEE 2026**

Q8: Obtain an expression for electrostatic potential energy of a system of three charges q , $2q$ and $3q$ placed at the vertices of an equilateral triangle of side a .

Q9 Two small conducting balls A and B of radius r_1 and r_2 have charges q_1 and q_2 respectively. They are connected by a wire. Obtain the expression for charges on A and B, in equilibrium.

Q10. Draw an equipotential surface for a system consisting of two charges Q , $-Q$ separated by a distance r in air. Locate the points where the potential due to the dipole is zero.

SOLUTIONS

1: work $W=q(V_S-V_R)$; $V_R=\frac{1}{4\pi\epsilon_0}\left(\frac{Q}{r_1}+\frac{(-2Q)}{r_2}\right)$; $V_R=V_S$ so potential difference is zero and hence work done is also zero.

2: $V(r)=-\int E \cdot dx = -\int \frac{A}{x^2} \cdot dx = \frac{A}{x}$; $U=q_1 V(x_1) + q_2 V(x_2) + \frac{q_1 q_2}{4\pi\epsilon_0 x_{12}} = q_1 A/x_1 + q_2 A/x_2 + \frac{q_1 q_2}{4\pi\epsilon_0 x_{12}}$

$x_1=x_2=30\text{cm}$, and $x_{12}=60\text{cm}$

So after substituting all the values we get $U=8.85\text{J}$

3 : Sol $C_1=\frac{K_1\epsilon_0 A/2}{d}$ and $C_2=\frac{K_2\epsilon_0 A/2}{d}$ so $C_{eq}=C_1+C_2=\frac{K_1\epsilon_0 A}{2d}+\frac{K_2\epsilon_0 A}{2d}=\frac{\epsilon_0 A}{2d}(K_1+K_2)$

4 (a)



(b) Different points on an equipotential surface might be at different distances from the source charge, so the electric field will not be constant at all points as shown in the diagram

5: In parallel combination the potential difference is same across the capacitors. On inserting dielectric slab capacitance become K times, so charge becomes K times.

Energy stored by a capacitor $U=1/2 CV^2$. As capacitance becomes K times energy stored by each capacitor also increases by a factor of K (dielectric constant)

6 Initial capacitance: $C=C=\epsilon_0 A/d$ New capacitance $= C/2 (1+K)$; $K=5$ (given) so $C_{\text{new}}=3C$ change in capacitance $= 2C$ so change in $\% = 200\%$

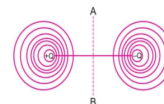
7: $C=\frac{\epsilon_0 A}{x}$ $U=1/2 CV^2$, $U=1/2 \frac{\epsilon_0 A}{x} V^2$ so $U \propto 1/x$, Now $dU/dt = dU/dx \times dx/dt$ $dx/dt = \text{velocity}$

Since $U \propto 1/x$ so $dU/dx \propto x^{-2}$ hence α is proportional to x^{-2}

8: potential energy of the system is $U=\frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r}$ so $U=\frac{1}{4\pi\epsilon_0} \frac{(-7q^2)}{a}$

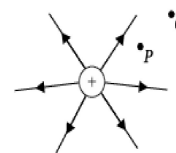
9: According to law of conservation of charge ; $q_i=q_f$: $q_1+q_2=q_1+q_2=Q$, if When two balls are connected with wire : $V_1=V_2$: $q_1=\frac{Qr_1}{r_1+r_2}$ and $q_2=\frac{Qr_2}{r_1+r_2}$ and $Q=q_1+q_2$

10: The equipotential surface for the system is as shown. Electric potential is zero at all points in the plane passing through the dipole equator AB.



PRACTICE QUESTIONS

Q1. Figure shows the field lines on a positive charge. Is the work done by the field in moving a small positive charge from Q to P positive or negative? Give reason.



Q2. What is the amount of work done in moving a point charge Q around a circular arc of radius 'r' at the centre of which another point charge 'q' is located?

Q3. What should be the charge on a sphere of radius 4 cm, so that when it is brought in contact with another sphere of radius 2 cm carrying charge of $10\ \mu\text{C}$, there is no transfer of charge from one sphere to other?

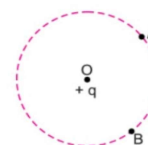
Q4. A parallel plate is charged by a battery. When the battery remains connected, a dielectric slab is inserted in the space between the plates. Explain what changes if any, occur in the values of (i) Potential difference between the plates (ii) Capacitance (iii) Charge on the plates (iv) Energy stored in the capacitor?

Q5. A parallel plate capacitor of capacitance C is charged to a potential V. It is then connected to another uncharged capacitor having the same capacitance. Find out the ratio of the energy stored in the combined system to that stored initially in the single capacitor.

ANSWERS

1. The work done by the field is negative. This is because the charge is moved against the force exerted by the field.

2. The potential of points A and B are same being equal to $V_A = V_B = \frac{1}{4\pi\epsilon_0} \frac{q}{R}$, Where R is the radius of the circle. Work done $W = q(V_B - V_A) = q(V_A - V_A) = 0$



3. $V_A = V_B$, Hence $Q = 20\ \mu\text{C}$

4. (i) When battery remains connected, the potential difference remains the same.

(ii) The capacitance of capacitor increases as $K > 1$. (iii) The charge $Q = CV$, $V = \text{same}$, $C = \text{increases}$; there, charge on plates increases (iv) Energy stored by capacitor increases.

(v) Electric field strength remains same.

5. $U_f : U_i = 1:2$

SHORT ANSWER TYPE QUESTIONS (3 MARKS)

Q1 Two parallel plate capacitors X and Y are connected in series to a 6 V battery. They have the same plate area and same plate separation but capacitor X has air between its plates, whereas capacitor Y contains a material of dielectric constant 4.

(a) Calculate the capacitances of X and Y, if the equivalent capacitance of the combination of X and Y is $4\ \mu\text{F}$.

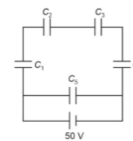
(b) Calculate the potential difference across the plates of X and Y. **(CBSE 2026 55/5/1)**

Q2 A $12\ \mu\text{F}$ capacitor is charged to a potential difference of 150V. The terminals of the charged capacitor are then connected to those of an uncharged $6\ \mu\text{F}$ capacitor. Calculate the potential difference and charge on each capacitor.

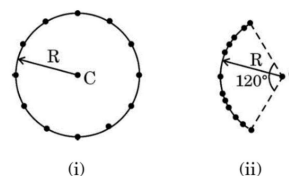
Q3 A three coulomb charge moves from a point (0,-2,-5) to another point (5, 1, 2) in an electric field given by $E = 2x\hat{i} + 3y^2\hat{j} + 4z\hat{k}$ N/C. Calculate the work done in moving the charge in this distance. **JEE Mains 2026**

Q4 A metal sphere of capacitance 100pF is charged to a potential of 100V. Another identical metal uncharged sphere is brought in contact with the charged sphere. Calculate the change in energy stored in the capacitors when they touch each other. ($5/2 \times 10^{-7}J$)

Q5 Five capacitors of capacitances $C_1 = C_2 = C_3 = C_4 = 10 \mu F$ and $C_5 = 2.5 \mu F$ are connected as shown, along with a battery of 50 V. Find the equivalent capacitance and the charges on each capacitor



Q6 a) Twelve negative charges of same magnitude are equally spaced and fixed on the circumference of a circle of radius R as shown in Fig. (i). Relative to potential being zero at infinity, find the electric potential and electric field at the center C of the circle.
b) If the charges are unequally spaced and fixed on an arc of 120° of radius R as shown in Fig. (ii), find electric potential at the center C. **CBSE 55/1/1**



Q7 A parallel plate capacitor (A) of capacitance C is charged by a battery to voltage V. The battery is disconnected and an uncharged capacitor (B) of capacitance 2C is connected across A. Find the ratio of:

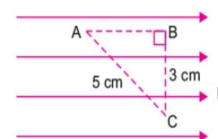
(a) Final charges on A and B

(b) Total electrostatic energy stored in A and B initially and energy stored in A initially

Q8 Two point charges + q and q are located at points (3a, 0) and (0, 4a) respectively in x-y plane. A third charge Q is kept at the origin. Find the value of Q, in terms of q and a, so that the electrostatic potential energy of the system is zero.

Q9 Two isolated metallic spheres S_1 and S_2 of radii 1 cm and 3 cm respectively are charged such that both have the same charge density ($2/\pi \times 10^{-9} C/m^2$). They are placed far away from each other and connected by a thin wire. Calculate the new charge on sphere S_2 .

Q10. Three points A, B and C lie in a uniform electric field (E) of $5 \times 10^3 NC^{-1}$ as shown in the figure. Find the potential difference between (i) A and B, and (ii) A and C.



SOLUTIONS

1: $1/C_{eq} = 1/C_1 + 1/C_2$ given that $C_{eq} = 4$, and $C_x = C$, $C_y = 4C$ so $C = 5 \mu F$ and $C_y = 4C = 20 \mu F$. Total charge $q = C_{eq}V = 24 \times 10^{-6} C$, $V_x = q/C_x = 4.8 V$ & $V_y = q/C_y = 1.2 V$

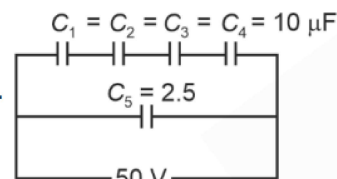
2: Common potential across both the capacitors $= \frac{C_1V_1 + C_2V_2}{C_1 + C_2}$, $V_2 = 0$ so $V_c = 100V$,

Charge on C_1 , $q_1 = C_1V_c = 12 \mu F \times 100V = 1200 \mu C$ and $q_2 = C_2V_c = 600 \mu C$

3: $W = \int E \cdot dr = \int 2x\hat{i} + 3y^2\hat{j} + 4z\hat{k} \cdot (dxi + dyj + dzk)$, $W = x^2 + y^3 + 4z$ evaluate this from (0,-2,-5) to another point (5,1,2) & we get $W = 186J$.

4: Ans: common potential = $V_c = 50V$, $U_i = \frac{1}{2} CV^2 = 5 \times 10^{-7} J$ and $U_f = 2.5 \times 10^{-7} J$. Change in the energy = $2.5 \times 10^{-7} J$

5: $C_{eq} = 2.5 + 2.5 = 5 \mu F$, $q_1 = q_2 = q_3 = q_4 = 2.5 \times 50 = 125 \mu C$, $q_5 = 2.5 \times 50 = 125 \mu C$



6: a) Electric potential due to point charge $V = kq/R$ Value of each charge = $-q$, Total charge = $-12q$ Total potential $V = k(-12q)/R = -12q/4\pi\epsilon_0 R$. By symmetry the resultant of all electric field vectors becomes zero. So electric field is zero. (b) Electric potential is a scalar quantity and does not depend on placement of charges. Therefore $V = 12kq/R$, $V = -12q/4\pi\epsilon_0 R$

7: a) Initially $Q = CV$ Finally $q_A = C_A V_1$ and $q_B = C_B V_1$; $q_A/q_B = C_A/C_B = 1/2$

(b) $q_A + q_B = Q$, $q_A = Q/3$ & $q_B = 2Q/3$ so $U_A + U_B / U_{Ai} = 1/3$

8: Potential energy of the system = $k(\frac{Q(-q)}{4a} + \frac{qQ}{3a} - \frac{q^2}{5a})$; Potential energy of the system = 0.

So $K(\frac{Q(-q)}{4a} + \frac{qQ}{3a} - \frac{q^2}{5a}) = 0$; $Q = 12q/5$

9: Charge on sphere S_1 : $Q_1 = \text{surface charge density} \times \text{surface Area} = 8 \times 10^{-13} C$. Charge on sphere S_2 : $72 \times 10^{-13} C$. When connected by a thin wire they acquire a common potential V and the charge remains conserved. $Q_1 + Q_2 = Q'_1 + Q'_2$ on solving $Q'_1 = 2 \times 10^{-12} C$

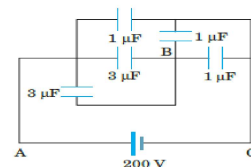
10: (i) Potential difference between A and B = $E \times (AB) = 5 \times 10^3 \times (4 \times 10^{-2}) = 200 \text{ volt}$

(ii) The line joining B to C is perpendicular to electric field, so potential of B = potential of C i.e., $V_B = V_C$ Distance AB = 4 cm

Potential difference between A and C = $E \times (AC) = 5 \times 10^3 \times (4 \times 10^{-2}) = 200 \text{ volt}$

PRACTICE QUESTIONS

Q1. A charged particle of mass m and charge q is kept initially at rest on a frictionless surface. Another charged particle of mass $4m$ and charge $2q$ starts moving with velocity v towards it. Calculate the distance of the closest approach for both the charged particles.



Q2. (a) Four identical metallic balls were placed diametrically opposite on the circumference of an imaginary circle of radius 10m. The first three balls were charged with 30mC, 40mC and -70mC charge. Evaluate the value of charge(q) given to the fourth ball so that the net potential at the centre of the circle becomes zero.

Q3. A capacitor of 200 pF is charged by a 300 V battery. The battery is then disconnected and the charged capacitor is connected to another uncharged capacitor of 100 pF. Calculate the difference between the final energy stored in the combined system and the initial energy stored in the single capacitor.

Q4. A parallel plate capacitor is charged by a battery. After sometime the battery is disconnected and a dielectric slab with its thickness equal to the plate separation is inserted between the plates. How will (i) the capacitance of the capacitor, (ii) potential difference between the plates and (iii) the energy stored in the capacitor be affected? Justify your answer in each case.

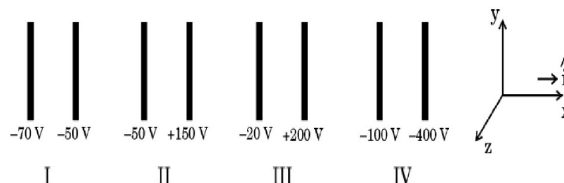
Q5. Find the ratio of the potential difference that must be applied across the parallel and the series combination of two identical capacitors so that the energy stored in the two cases, becomes the same.

ANSWERS

1. $\frac{1}{4\pi\epsilon_0} \frac{5q^2}{mv^2}$ 2. $q=0$ 3. $3 \times 10^{-6} \text{ J}$ 4. $C = KC_0, V = \frac{1}{K}V_0, E = \frac{1}{K}E_0$ 5. $V_P : V_S = 1:2$

CASE STUDY TYPE QUESTIONS

1. The above figure shows four pairs of parallel identical conducting plates, separated by the same distance 2.0 cm and arranged perpendicular to x-axis. The electric potential of each plate is mentioned. The electric field between a pair of plates is uniform and normal to the plates. (i) For which pair of the plates is the electric field E along $\hat{i}$?



- (A) I (B) II (C) III (D) IV

(ii) An electron is released midway between the plates of pair IV. It will:

- (A) Move along $\hat{i}$ at constant speed (B) move along $-\hat{i}$ at constant speed
 (C) Accelerate along $\hat{i}$ (D) accelerate along $-\hat{i}$

(iii) Let E_1, E_2, E_3 and E_4 be the magnitudes of the electric field between the pairs of plates, I, II, III and IV respectively, then:

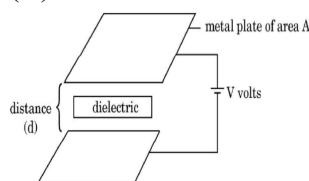
- (A) $E_1 > E_2 > E_3 > E_4$ (B) $E_3 > E_4 > E_1 > E_2$
 (C) $E_4 > E_3 > E_2 > E_1$ (D) $E_2 > E_3 > E_4 > E_1$

(iv) An electron is projected from the right plate of set I directly towards its left plate. It just comes to rest at the plate. The speed with which it was projected is about:

(Take $e/m = 1.76 \times 10^{11} \text{ C/kg}$)

- (A) $1.3 \times 10^5 \text{ m/s}$ (B) $2.6 \times 10^6 \text{ m/s}$ (C) $6.5 \times 10^5 \text{ m/s}$ (D) $5.2 \times 10^7 \text{ m/s}$

2. A parallel plate capacitor is an arrangement of two identical metal plates kept parallel, a small distance apart. The capacitance of a capacitor depends on the size and separation of the two plates and also on the dielectric constant of the medium between the plates. Like resistors, capacitors can also be arranged in series or parallel or a combination of both. By virtue of electric field between the plates, charged capacitors store energy.



(a) The capacitance of a parallel plate capacitor increases from $10\mu\text{F}$ to $80\mu\text{F}$ on introducing a dielectric medium between the plates. Find the dielectric constant of the medium.

(b) n capacitors, each of capacitance C , are connected in series. Find the equivalent capacitance of the combination.

(c) A capacitor is charged to a potential (V) by connecting it to a battery. After some time, the battery is disconnected and a dielectric is introduced between the plates. How will the potential difference between the plates, and the energy stored in it be affected? Justify your answer.

ANSWERS

Ans.1. (i) (D) IV (ii) (D) accelerate along $-\hat{i}$ (iii) (C) $E_4 > E_3 > E_2 > E_1$ (iv) (B) $2.6 \times 10^6 \text{ m/s}$

Ans.2 (a) $K=8$ (b) $C_s = \frac{C}{n}$ (c) Potential difference decreases by a factor $1/K$, Energy reduces by a factor $1/K$

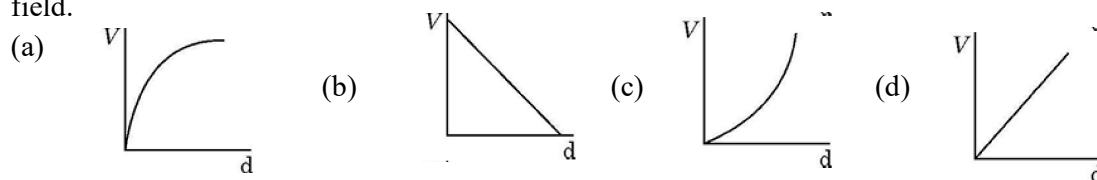
PRACTICE QUESTIONS

Q1 .A parallel plate capacitor has two parallel plates which are separated by an insulating medium like air, mica etc. When the plate are connected to the terminals of a battery they get equal and opposite charges and an electric field is set up in between them. The electric field between the two plates depends upon the potential difference applied, the separation of the plates and nature of the medium between the plates.

(i) The electric field between the plates of a parallel plate capacitor is E . Now the separation between the plates is doubled and simultaneously the applied potential difference between the plates is reduced to half of its initial value The new value value of the electric field between the plates will be :

- (a) E (b) $2E$ (c) $E/4$ (d) $E/2$

(ii) A constant electric field is to be maintained between the two plates of a capacitor whose separation d changes with time. Which of the graphs correctly depict the potential difference (V) between the plates as a function of separation between the plates to maintain the constant electric field.



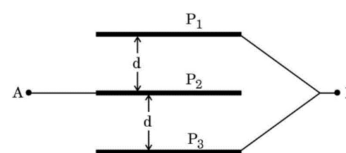
(iii) In the above figure P,Q are the two parallel plates of a capacitor. Plate Q is at positive potential with respect to plate P. MN is an imaginary line drawn perpendicular to the plates. Which of the graphs shown correctly the variation of the magnitude of electric field strength E along the line MN?



(iv) Three parallel plates are placed above each other with equal displacement d between the neighboring plates. The electric field between the first pair of the plates is E_1 and electric field between the second pair of the plate is E_2 . The potential difference between the third and first plate is?

- (a) $(\vec{E}_1 + \vec{E}_2) \cdot \vec{d}$ (b) $(\vec{E}_1 - \vec{E}_2) \cdot \vec{d}$ (c) $(\vec{E}_2 - \vec{E}_1) \cdot \vec{d}$ (d) $d(E_1 + E_2)/2$

2. A parallel plate capacitor consists of two conducting plates kept generally parallel to each other at a distance. When the capacitor is charged, the charge resides on the inner surfaces of the plates and an electric field is set up between them. Thus, electrostatic energy is stored in the capacitor. The figure shows three large square metallic plates, each of edge length 'L' held parallel and equidistant from each other. The space



between P_1 and P_2 and P_2 and P_3 is completely filled with mica sheets of dielectric constant K . The plate P_2 is connected to point A and other plates P_1 and P_3 are connected to point B. Point A is maintained at a positive potential with respect to point B and the potential difference between A and B is V . **2025 CBSE**

(i) The capacitance of the system between A and B will be:

(a) $\frac{\epsilon_0 K L^2}{d}$ (b) $\frac{\epsilon_0 K L^2}{2d}$ (c) $\frac{2\epsilon_0 K L^2}{d}$ (d) $\frac{2\epsilon_0 K d}{L^2}$

(ii) The charge on plate P_1 is:

(a) $\frac{\epsilon_0 V K L^2}{2d}$ (b) $\frac{\epsilon_0 V K L^2}{d}$ (c) $\frac{2\epsilon_0 V K L^2}{d}$ (d) $\frac{\epsilon_0 V K L^2}{4d}$

(iii) The electric field in the region between P_1 and P_2 is:

(a) V/d (b) $2V/d$ (c) $V/2d$ (d) d/V

(iv) The separation between the plates of same area L^2 of a parallel plate air capacitor having capacitance equal to that of this system, will be :

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

ANSWERS PRACTICE QUESTIONS

Ans.1 (i) (c) $E/4$. (ii) (d) (iii) (c) (iv) (a) $(\vec{E}_1 + \vec{E}_2) \cdot \vec{d}$

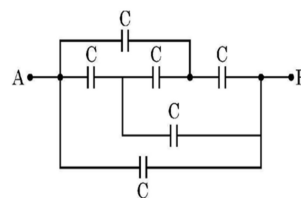
Ans 2: (i) (c) $\frac{2\epsilon_0 K L^2}{d}$ (ii) (b) $\frac{\epsilon_0 V K L^2}{d}$ (iii) (a) V/d (iv) (c) $d/2K$

LONG ANSWER TYPE QUESTIONS

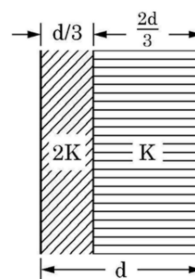
Q1 (i) Find the equivalent capacitance between A and B in the given figure.

(ii) A dielectric slab is inserted between the plates of a capacitor. The electric between the plates decreases. Explain.

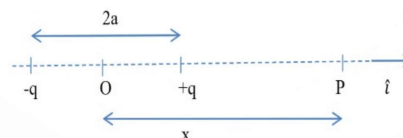
(iii) A capacitor A of capacitance C , having a charge Q is connected across another uncharged capacitor B of capacitance $2C$ find an expression for (a) potential difference across the combination and (b) Charge lost by capacitor A



(iv) Two slabs of dielectric constant $2K$ and K fill the space between plates of a parallel plate capacitor of plate area A and plate separation d as shown in the figure. Find the equivalent capacitance of the system



Q2. (i) An electric dipole (dipole moment $\vec{p} = p\hat{i}$), consisting of charges $-q$ and q , separated by distance $2a$, is placed along the x -axis, with its centre at the origin. Show that the potential V , due to this dipole, at a point x , ($x \gg a$) is equal to $\frac{1}{4\pi\epsilon_0} \frac{\vec{p} \cdot \hat{i}}{x^2}$



(ii) Two isolated metallic spheres S_1 and S_2 of radii 1 cm and 3 cm respectively are charged such that both have the same charge density $\left(\frac{2}{\pi} \times 10^{-9}\right) \text{C/m}^2$. They are placed far away from each other and connected by a thin wire. Calculate the new charge on sphere S_1 .

Q3 (i) Derive an expression for potential energy of an electric dipole p in an external uniform electric field E . When is the potential energy of the dipole (1) maximum, and (2) minimum?

(ii) Three point charges q , $2q$ and nq are placed at the vertices of an equilateral triangle. If the potential energy of the system is zero, find the value of n .

ANSWERS

1: (i) $C_{\text{net}} = C + C = 2C$, (ii) Within the dielectric slab, induced electric field due to polarization, Decreases the electric field. $E = E_0/K$ (iii) (a) $V' = Q_{\text{total}} / C_{\text{eq}} = Q/3C = V/3$ (b) charge lost by capacitor $= Q - Q/3 = 2Q/3$ (iv) $C_1 = 6K\epsilon_0 A/d$, $C_2 = 3K\epsilon_0 A/2d$, $1/C_{\text{eq}} = 1/C_1 + 1/C_2$; $C_{\text{eq}} = 6K\epsilon_0 A/5d$

2 : (i) Derive expression of potential at P, $V = \frac{1}{4\pi\epsilon_0} \frac{p}{x^2 - a^2}$ As p is along x -axis so, $V = \frac{1}{4\pi\epsilon_0} \frac{\vec{p} \cdot \vec{i}}{x^2 - a^2}$

If $x \gg a$, $V = \frac{1}{4\pi\epsilon_0} \frac{\vec{p} \cdot \vec{i}}{x^2}$ (ii) Charge on $S_1 = \sigma \times 4\pi r^2 = \left(\frac{2}{\pi} \times 10^{-9}\right) \times 4\pi (1 \times 10^{-2})^2 = 8 \times 10^{-13} \text{ C}$,

Charge on $S_2 = \sigma \times 4\pi r^2 = \left(\frac{2}{\pi} \times 10^{-9}\right) \times 4\pi (3 \times 10^{-2})^2 = 72 \times 10^{-13} \text{ C}$ When connected by thin

wire they acquire common potential V and charge remains conserved $Q_1 + Q_2 = Q'_1 + Q'_2$ and $\frac{Q'_1}{Q'_2} = \frac{r_2}{r_1}$, On solving $Q'_1 = 2 \times 10^{-12} \text{ C}$

3: (i) Derivation of expression of potential Energy, $U(\theta) = -p E \cos \theta = \vec{p} \cdot \vec{E}$

(1) Potential energy is maximum $\theta = 180^\circ$, (2) Potential energy is minimum $\theta = 0^\circ$

(ii) Consider an equilateral triangle of side a , Potential energy $U = \frac{kq_1q_2}{a} + \frac{kq_2q_3}{a} + \frac{kq_1q_3}{a}$

$U = \frac{kq \cdot 2q}{a} + \frac{k2q \cdot nq}{a} + \frac{kq \cdot nq}{a}$, According to question $U=0$, So $\frac{kq \cdot 2q}{a} + \frac{k2q \cdot nq}{a} + \frac{kq \cdot nq}{a} = 0$, After

solving $n = -\frac{2}{3}$

PRACTICE QUESTIONS

1. (i) Draw equipotential surfaces of an electric dipole.

(ii) Two point charges q_1 and q_2 are located at $\vec{r}_1$ and $\vec{r}_2$ respectively in an external field $\vec{E}$. Obtain an expression for potential energy of the system

(iii) The dipole moment of a molecule is 10^{-30} Cm . It is placed in an electric field $\vec{E}$ of 10^5 V/m such that its axis is along the electric field. The direction of $\vec{E}$ is suddenly changed by 60° at an instant. Find the change in the potential energy of the dipole, at that instant.

2. (i) A dielectric slab of dielectric constant 'K' and thickness 't' is inserted between plates of a parallel plate capacitor of plate separation d and plate area A . Obtain an expression for its capacitance. (ii) Two capacitors of different capacitances are connected first (1) in series and then (2) in parallel across a dc source of 100 V . If the total energy stored in the combination in the two cases are 40 mJ and 250 mJ respectively, find the capacitance of the capacitors.

3.(a) Derive an expression for potential energy of a dipole in an external field.

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

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

ANSWERS

1. (i) Suitable Diagram, (ii) potential energy of the system $= q_1 V(\vec{r}_1) + q_2 V(\vec{r}_2) + \frac{1}{4\pi\epsilon_0} \frac{q_1q_2}{r_{12}}$,

(iii) $5 \times 10^{-26} \text{ J}$

2. (i) Derivation of correct expression. $C = \frac{K\epsilon_0 A}{d-t+\frac{t}{K}}$. (ii) $C_1 = 40 \mu\text{f}$ and $C_2 = 10 \mu\text{f}$