Ready For Boards
10th & 12th Exam Prep

CHAPTER 2

Electrostatic Potential and Capacitance

CBSE Class 12 · Physics · Chapter 2

CBSE · Physics · Class 12

WHAT THIS CHAPTER DOES

Boards prep that builds confidence, not anxiety.

TODAY'S MISSION

Today's mission

WHY THIS MATTERS

Why this chapter matters

TOPIC

A

Electric Potential — energy per unit charge

THEOREM · LOAD-BEARING RESULT

Electric Potential V at a point

> *Electric potential V at a point in an electric field is defined as the WORK DONE PER UNIT POSITIVE CHARGE in bringing a small test charge from INFINITY to that point against the field, without acceleration.*

STATEMENT

Mathematically: V = W/q (work per unit charge). SI unit: VOLT (V) = JOULE per COULOMB. Scalar quantity (no direction). Relationship with field: $E = -\nabla V$ (gradient form) or in 1D: $E = -dV/dr$. The minus sign means E points

WHY THIS MATTERS

- Potential simplifies energy calculations enormously — it is a scalar field, so contributions from multiple charges ADD algebraically (no vector resolution needed)
- Force/field calculations require vector addition
- potential calculations require only scalar addition

WATCH OUT FOR

NOTE V (potential, J/C) and U (potential energy, J) are RELATED but DIFFERENT — U = qV. V is independent of test charge; U depends on it. Confusing them is the most common 1-mark loss.

TOPIC

Computing V — four key cases

POINT CHARGE

V = kq/r where k = 9×10^9 Nm^2/C^2, q is the source charge in coulombs, r is the distance from charge to point. SIGN MATTERS: positive q gives positive V; negative q gives negative V. V decreases as 1/r — slower than field's $1/r^2$. CBSE 1-mark MCQ: V at 1m from a +1μC charge = $9\times10^9 \times 10^{-6}$ / 1 = 9000 V.

MULTIPLE CHARGES (SUPERPOSITION)

V_total = $V_1 + V_2 + \ldots + V_n$ = Σ kq_i/r_i. ALGEBRAIC SUM — signed scalars add directly (unlike electric field which requires vector addition). This is the key computational advantage of working with potential. Example: +q at (a,0) and −q at (−a,0); V at origin = kq/a + k(−q)/a = 0. CBSE 3-mark numericals exploit this

DIPOLE ON AXIAL LINE

Dipole p = q × 2a. Potential on axial line at distance r (r >> a): V_axial = kp/r^2 (note: falls as $1/r^2$, not 1/r). Reason: positive and negative ends partially cancel. SIGN: positive on the +q side, negative on the −q side. CBSE 3-mark derivation expected.

DIPOLE ON EQUATORIAL LINE

On the equatorial line (perpendicular bisector of dipole axis): V_eq = 0 at all points. Reason: equal distances from +q and −q give equal-magnitude opposite-sign contributions that cancel exactly. This is a useful sanity-check property in dipole problems. CBSE 2-mark MCQ frequently tests this.

TOPIC

B

Equipotential Surfaces

TOPIC

Properties + types of equipotential surfaces

PROPERTY 1 — PERPENDICULAR TO FIELD

Equipotential surfaces are ALWAYS PERPENDICULAR to the electric field lines. Reason: if E had a component along the surface, moving a charge along that direction would change its potential — contradicting 'equipotential'. So E must be entirely perpendicular to the surface at every point.

PROPERTY 2 — WORK DONE ON SURFACE = 0

Work done in moving a charge ON an equipotential surface = 0 because $W = q \times \Delta V$ and $\Delta V = 0$ by definition of equipotential. This explains why equipotential surfaces are 'free' to move along — no energy cost. Useful for designing charge-transport experiments where minimum energy is

PROPERTY 3 — SURFACES NEVER INTERSECT

Two equipotential surfaces NEVER intersect. If they did, the intersection point would have two different potential values — physically impossible (potential is a single-valued function of position). Also, closer-spaced equipotential surfaces indicate STRONGER field (since dV/dr is larger). This is the

TYPES — THREE COMMON CASES

(1) POINT CHARGE: concentric SPHERES centred on the charge ($V = kq/r$ constant on each sphere). (2) UNIFORM FIELD: parallel PLANES perpendicular to the field direction. (3) DIPOLE: complex curved surfaces around each charge that flatten at the equatorial plane ($V = 0$ there). CBSE

TOPIC

C

Capacitors and Capacitance

THEOREM · LOAD-BEARING RESULT

Capacitance — the central definition

> *A capacitor is a device that stores electrical energy by accumulating equal-magnitude opposite-sign charges on two conductors separated by an insulator. Capacitance C is defined as the ratio of charge stored Q to potential difference V across the conductors: $C = Q/V$.*

STATEMENT

SI unit: FARAD (F) = COULOMB per VOLT. Practical capacitors are in μF (10^{-6}) and nF (10^{-9}) and pF (10^{-12}) range. Capacitance depends on: (1) GEOMETRY (area A and separation d for parallel plates), (2) DIELECTRIC between

WHY THIS MATTERS

- Capacitors store energy in the electric field between their plates ($\frac{1}{2}CV^2$) and store charge proportional to applied voltage ($Q = CV$)
- Applications: defibrillators (rapid energy release), camera flashes, computer DRAM memory, power-factor correction, oscillators, filters.

WATCH OUT FOR

NOTE C is determined by geometry + dielectric, NOT by Q or V. Doubling V doubles Q but C stays the same. The relationship $Q = CV$ is causal: applied V creates charge Q, with C as the proportionality constant. CBSE 1-mark questions test this 'C depends on what?' framing.

TOPIC

Parallel-plate capacitor — derivation outline

STEP 1 — SETUP

Two parallel conducting plates of area A separated by small distance d ($d << \sqrt{A}$ so edge effects negligible). Top plate has +Q charge, bottom has −Q. Vacuum between plates initially. Surface charge density $\sigma = Q/A$ on each plate.

STEP 2 — FIELD BETWEEN PLATES

Using Gauss's law (Ch 1) for one plate: E from one plate $= \sigma/(2\varepsilon_0)$. Both plates contribute (one pulls + charge, one pushes), giving NET FIELD INSIDE $= \sigma/\varepsilon_0 = Q/(\varepsilon_0 A)$. This field is UNIFORM (independent of position between plates). Field outside the capacitor ~0 in the ideal case.

STEP 3 — VOLTAGE

$V = E \times d$ (uniform field × separation) $= Qd/(\varepsilon_0 A)$. Direction of V: positive plate is at higher V; negative plate at lower V (by definition since E points from + to −).

STEP 4 — CAPACITANCE

$C_0 = Q/V = \varepsilon_0 A/d$. Vacuum case. With dielectric of constant K filling the gap: $C = K \times C_0 = K\varepsilon_0 A/d$. The increase by factor K is the polarisation-of-dielectric effect (reduces internal field, lowers V for same Q, raises C). CBSE 5-mark derivation expected.

TOPIC

D

Combinations — Series and Parallel

TOPIC

Series combination of capacitors

CONSTRAINT

In SERIES, all capacitors carry the SAME CHARGE Q (charge cannot accumulate at intermediate junctions). Total voltage divides among them. Useful when applied voltage exceeds individual capacitor rating — splitting across series reduces voltage per capacitor.

DERIVATION

Total V = $V_1 + V_2 + \ldots + V_n = Q/C_1 + Q/C_2 + \ldots + Q/C_n$. Define C_eq = Q/V_total → 1/C_eq = $1/C_1 + 1/C_2 + \ldots + 1/C_n$. Reciprocals add. C_eq is SMALLER than the smallest individual capacitance. Special case: two equal capacitors C in series give C/2.

VOLTAGE DIVISION

In series, V_i = Q/C_i. Capacitor with SMALLEST C has LARGEST voltage across it (paradoxically — small capacitance means small charge held per volt, so for the same Q, it needs more voltage). CBSE numericals test this voltage-division behavior.

APPLICATION

Series used when high voltage rating is needed: combine 3 capacitors each rated 600V in series to safely handle 1800V (each capacitor sees only 600V). Series is the dual of parallel — opposite to resistor behavior.

TOPIC

Parallel combination of capacitors

CONSTRAINT

In PARALLEL, all capacitors have the SAME VOLTAGE V across them (both terminals are connected to the same nodes). Total charge is the SUM of individual charges. Useful when more capacitance is needed than a single capacitor can provide.

DERIVATION

Total $Q = Q_1 + Q_2 + \ldots + Q_n = C_1V + C_2V + \ldots + C_nV = (C_1+C_2+\ldots+C_n)V$. Define $C_{eq} = Q/V \rightarrow C_{eq} = C_1 + C_2 + \ldots + C_n$. Capacitances ADD DIRECTLY. C_{eq} is LARGER than the largest individual capacitance.

CHARGE DIVISION

In parallel, $Q_i = C_i \times V$ (with V common). Capacitor with LARGEST C carries LARGEST charge. The fraction of charge on each capacitor equals its fraction of total capacitance. CBSE 3-mark numericals test this division.

APPLICATION

Parallel used when more total charge storage is needed: connect 5 × 100µF capacitors in parallel to get 500µF total. Power supplies use parallel banks for high-current short bursts (camera flash). Memorise: parallel ADDS for capacitors — OPPOSITE of resistors where series adds.

TOPIC

E

Energy Stored in a Capacitor

THEOREM · LOAD-BEARING RESULT

Energy stored in a capacitor + redistribution

> *Energy stored in a charged capacitor equals the work done to assemble the charge Q on it: $U = \frac{1}{2} Q^2/C = \frac{1}{2} CV^2 = \frac{1}{2} QV$ (three equivalent forms).*

STATEMENT

Derivation: at instantaneous charge q, voltage = q/C. Work to add infinitesimal dq is $dW = (q/C)dq$. Total $W = \int_0^Q (q/C)\, dq = Q^2/(2C) = U$. Three equivalent forms by substituting $Q = CV$. Energy DENSITY (energy per unit

WHY THIS MATTERS

- Energy storage is the practical purpose of capacitors
- The ½ factor (NOT just QV) comes from integrating the work as charge accumulates — the voltage builds from 0 to V during charging, so average voltage is V/2 and total work is QV/2.

WATCH OUT FOR

NOTE When two charged capacitors are connected, CHARGE IS CONSERVED but ENERGY IS NOT. The 'lost' energy = $\frac{1}{2} \times C_1C_2(V_1-V_2)^2/(C_1+C_2)$ is dissipated as heat in connecting wires + EM radiation. Claiming energy conservation is the canonical 4-mark loss.

PYQ PATTERNS

Top 5 PYQ patterns to drill

MARKS DISTRIBUTION

Where to spend revision time

TOPIC

Potential vs Potential Energy

TRAP → TRUTH

✕ **MISTAKE** Electric potential V and electric potential energy U are the same quantity.

✓ **CORRECT** Potential V is potential energy PER UNIT charge — $V = U/q$. V is a property of the field (independent of the test charge); U is the energy of a SPECIFIC charge in that field. SI units: V in volts (J/C); U in joules (J). The relationship is $U = qV$. CBSE 1-mark MCQs frequently trap students who conflate them.

TOPIC

Direction of decrease of V vs E

TRAP → TRUTH

× **MISTAKE** Electric field E points from low potential to high potential, like a slope going uphill.

✓ **CORRECT** Electric field E points from HIGH potential to LOW potential — in the direction of DECREASING V. Mathematically: $E = -dV/dr$ (the minus sign captures this). Intuition: positive charges experience force in the direction of E (they 'roll downhill' from high V to low V) and lose potential energy in doing so.

TOPIC

Capacitance depends on charge/voltage?

TRAP → TRUTH

× **MISTAKE** Capacitance C depends on the charge stored Q or the voltage V applied.

✓ **CORRECT** Capacitance C is a GEOMETRIC + DIELECTRIC property — depends ONLY on the PHYSICAL DESIGN (area, separation, dielectric) of the capacitor, NOT on Q or V. The ratio $Q/V = C$ is fixed by geometry; doubling V doubles Q but C stays the same. CBSE 1-mark question: 'C depends on which?' Answer: geometry + dielectric, not Q or V.

TOPIC

Dielectric in a capacitor — effect on C, V, Q

TRAP → TRUTH

× **MISTAKE** Inserting a dielectric ALWAYS increases voltage and energy.

✓ **CORRECT** Effect depends on the BOUNDARY CONDITION. CASE 1 — battery connected (V constant): C↑ (×K), Q↑ (×K), U↑ (×K). CASE 2 — capacitor isolated (Q constant): C↑ (×K), V↓ (÷K), U↓ (÷K). The two cases give opposite voltage and energy responses. CBSE 4-mark long-answers test the boundary-condition distinction explicitly.

TOPIC

Series vs parallel — formula direction

TRAP → TRUTH

× **MISTAKE** For series capacitors, add capacitances; for parallel, add reciprocals.

✓ **CORRECT** Reverse: SERIES adds RECIPROCALS ($1/C_{eq} = \Sigma\, 1/C_i$), PARALLEL adds DIRECTLY ($C_{eq} = \Sigma\, C_i$). Memorise: capacitors are OPPOSITE to resistors (resistors: series adds directly, parallel reciprocals). Reversing these is a common 2-mark loss. Voltage divides in series (Q same); charge divides in parallel (V same).

TOPIC

Energy stored when capacitors are connected in parallel

TRAP → TRUTH

× **MISTAKE** When a charged capacitor is connected to an uncharged identical one, total stored energy is conserved.

✓ **CORRECT** Total CHARGE is conserved ($\sum Q_i$ = constant), but stored ENERGY is NOT. Energy is LOST as heat in the connecting wires + electromagnetic radiation. Lost energy = $E_{initial} - E_{final} = \frac{1}{2} Q^2 \times (1/C_i - 1/C_f)$. This 'redistribution loss' is a favourite 5-mark numerical CBSE problem. Always state energy is lost; never claim conservation.

TOPIC

Equipotential surface and field

TRAP → TRUTH

× **MISTAKE** Electric field lines lie ALONG equipotential surfaces.

✓ **CORRECT** Electric field lines are ALWAYS PERPENDICULAR to equipotential surfaces — never along them. Reason: if E had a component along the surface, it would mean potential changes along the surface (contradiction with 'equipotential'). Work done to move a charge ON an equipotential surface = 0 (because $\Delta V = 0$ along the surface). Two equipotential surfaces never intersect (would imply two potentials at one point).

TOPPER TEMPLATE · MARK-BY-MARK

5-mark derivation: Capacitance of parallel-plate capacitor with dielectric slab of constant K

1 — SET UP: PARALLEL PLATES WITH VACUUM FIRST (1 m)

Two parallel plates of area A separated by distance d. Charge +Q on top, −Q on bottom. Vacuum between. Field E_o between plates (uniform, ignoring edges) = $\sigma/\varepsilon_o = Q/(\varepsilon_o A)$.

2 — COMPUTE V_o AND C_o FOR VACUUM CASE (1 m)

Potential difference $V_o = E_o \times d = Qd/(\varepsilon_o A)$. Capacitance $C_o = Q/V_o = \varepsilon_o A/d$. This is the vacuum case.

3 — INSERT DIELECTRIC SLAB OF CONSTANT K (2 m)

With dielectric K filling the gap fully, the field inside REDUCES to $E = E_o/K = \sigma/(K\varepsilon_o)$ (polarisation of dielectric reduces effective field). New voltage $V = E \times d = Qd/(K\varepsilon_o A) = V_o/K$. New capacitance $C = Q/V = K\varepsilon_o A/d = K \cdot C_o$.

4 — RESULT + INTERPRETATION (1 m)

$C = K\varepsilon_o A/d$. Capacitance INCREASES by factor K with dielectric. Physical reason: polarisation of dielectric reduces internal field → lower V for same Q → higher $C = Q/V$.

TOPPER TEMPLATE · MARK-BY-MARK

5-mark question: Equivalent capacitance for series and parallel combinations + derivation

1 SERIES COMBINATION DERIVATION (2 m)

n capacitors $C_1, C_2, \ldots, C_n$ in series. Same charge Q on each. Total $V = V_1 + V_2 + \ldots + V_n = Q/C_1 + Q/C_2 + \ldots + Q/C_n$. C_eq = Q/V → $1/C_{eq} = 1/C_1 + 1/C_2 + \ldots + 1/C_n$. Equivalent capacitance is LESS than the smallest individual capacitance.

2 PARALLEL COMBINATION DERIVATION (2 m)

n capacitors in parallel. Same V across each. Total $Q = Q_1 + Q_2 + \ldots + Q_n = C_1V + C_2V + \ldots + C_nV = (C_1+C_2+\ldots+C_n)V$. $C_{eq} = Q/V = C_1 + C_2 + \ldots + C_n$. Equivalent capacitance is GREATER than the largest individual capacitance.

3 MNEMONIC + KEY CONTRAST WITH RESISTORS (1 m)

Memory: capacitors OPPOSITE to resistors. Resistors: series adds, parallel reciprocals. Capacitors: series reciprocals, parallel adds. Confusing these is the most common error in CBSE 5-mark questions on combination networks.

TOPPER TEMPLATE · MARK-BY-MARK

4-mark question: Energy stored in capacitor + redistribution on connection

1 **DERIVE ENERGY STORED FORMULA** 1 m

Building charge q on capacitor (instantaneous voltage = q/C). Work to add dq = (q/C)dq. Total W = $\int_0$^Q (q/C)dq = $Q^2/(2C)$. So U = ½ Q^2/C = ½ CV^2 = ½ QV (three equivalent forms).

2 **REDISTRIBUTION ON PARALLEL CONNECTION** 2 m

Capacitor C_1 charged to V_1 (charge $Q_1 = C_1V_1$) connected in parallel to uncharged C_2. New shared voltage V = $Q_1/(C_1+C_2)$. Final charges: $Q_1' = C_1V$, $Q_2' = C_2V$. Charge IS conserved. Energy initial = ½ $C_1V_1^2$; final = ½$(C_1+C_2)V^2$. Energy LOST = E_initial – E_final = ½ × $C_1C_2V_1^2/(C_1+C_2)$. Released as heat in wires + EM radiation.

3 **KEY INSIGHT: CHARGE CONSERVED, ENERGY NOT CONSERVED** 1 m

Total CHARGE is always conserved (Kirchhoff). Energy is NOT — it dissipates as heat + radiation in the connecting process. This is a counter-intuitive but exam-tested fact. State both conservations explicitly.

PYQ PATTERNS

Top PYQ patterns to drill

#1	Equivalent capacitance	series, parallel, mixed networks (5 marks) — 95%
#2	Parallel-plate capacitor with dielectric	derive C (5 marks) — 80%
#3	Energy stored = ½ CV^2 = ½ Q^2/C = ½ QV (4 marks)	75%
#4	Potential due to point/multiple charges (numerical) (3 marks)	80%
#5	Equipotential surfaces	properties + types (3 marks) — 60%

MARKS DISTRIBUTION

10-year marks distribution

10-YEAR PYQ MARKS DISTRIBUTION

Capacitor combinations (series, parallel, mixed)	25%
Potential and PE of charges + dipole	20%
Equipotential surfaces + E-V relationship	15%
Capacitor with dielectric + parallel plate	20%
Energy stored in capacitor + sharing on connection	15%
Numerical: V due to point/multiple charges	5%

RECAP · MEMORISE THESE

5-line revision

1 Potential V — Energy per unit charge. V = kq/r for point charge. V_total = Σ V_i (algebraic sum — SCALARS). E = −dV/dr (E points from high V to low V).

2 Equipotentials — Always perpendicular to E. Work on surface = 0. Never intersect. Closer surfaces = stronger field. Types: spheres (point charge), planes (uniform), curved (dipole).

3 Capacitance — C = Q/V (farad). Depends on GEOMETRY + DIELECTRIC, NOT on Q or V. Parallel plate: C = $K\varepsilon_0 A/d$.

4 Combinations — Series: 1/C_eq = Σ 1/C_i

5 Energy — U = ½CV^2 = ½Q^2/C = ½QV (three

WHAT'S NEXT

Coming up next

→

- → Chapter 3 — Current Electricity (current = moving charge through potential difference). The energy framework of Ch 2 maps directly to circuits.
- → Quick check: can you derive $C = K\varepsilon_0 A/d$ in under 5 minutes? If yes, ready for Ch 3.

Practise — drill, board paper, CBT

15-MCQ Drill → Board Paper → 20-MCQ Chapter CBT.

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