

Chapter 2 · Electrostatic Potential and Capacitance

CBSE Class 12 Physics (042) · Unit I Electrostatics · Unit I + II = 16 marks · Ultimate Revision Sheet

SCOPE ALERT — CHECKED AGAINST THE OFFICIAL 2026-27 SYLLABUS Energy stored in a capacitor is "formulae only, no derivation". Learn the three forms; do not spend time deriving them. The syllabus names capacitance of a parallel plate capacitor with and without a dielectric — that one is derivable and is asked.

60-SECOND RECALL

Potential	$V = kq/r$ (scalar, signed) · $V = W/q_0$
Relation with field	$E = -dV/dr \rightarrow$ field points from high V to low V
Dipole potential	Axial kp/r^2 · Equatorial ZERO
PE of two charges	$U = kq_1q_2/r$
Dipole PE	$U = -pE \cos\theta$ · minimum at $\theta = 0$
Parallel plate C	$C = \epsilon_0 A/d$ · with dielectric $C = K\epsilon_0 A/d$
Combination	Series $1/C = \Sigma 1/C_i$ · Parallel $C = \Sigma C_i$ (opposite of resistors)
Energy	$U = \frac{1}{2}CV^2 = \frac{1}{2}QV = Q^2/2C$

1. Electric Potential

WRITE THIS VERBATIM Electric potential at a point is the work done per unit positive test charge in bringing it from infinity to that point, without acceleration. $V = W/q_0$, unit volt ($J C^{-1}$), a scalar.

FORMULAS

$V = kq/r$ (point charge — carries the **sign** of q)

$V_{\text{total}} = \Sigma kq_i/r_i$ (**algebraic** sum, not vector)

$E = -dV/dr$ the negative of the potential gradient

Dipole potential: axial $V = kp/r^2$ · equatorial $V = 0$ · general $V = kp \cos\theta/r^2$

THE CONTRAST EXAMINERS TEST Potential is a **SCALAR** and adds algebraically; field is a **VECTOR** and adds by components.

On the equatorial line of a dipole, $V = 0$ but $E \neq 0$. At the midpoint between two equal like charges, $E = 0$ but $V \neq 0$. Zero of one never implies zero of the other.

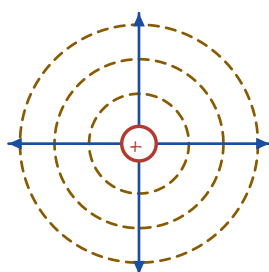
2. Equipotential Surfaces

THE FOUR PROPERTIES 1. Potential is the same at every point, so no work is done moving a charge along one.

2. They are always **perpendicular to the field lines**.
 3. They **never intersect** — a point cannot have two potentials.
 4. They are **closer together where the field is stronger** (since $E = -dV/dr$).
- Shapes: point charge → concentric **spheres** · uniform field → parallel **planes**.

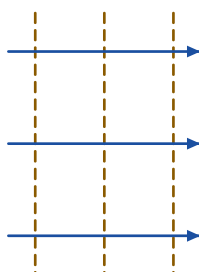
Equipotentials (dashed) are ALWAYS perpendicular to field lines (solid)

(a) point charge



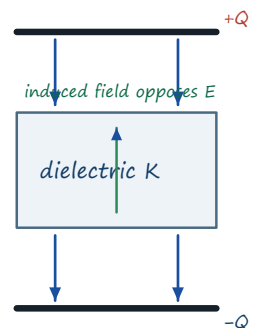
spheres · $V \propto 1/r$

(b) uniform field



equally spaced planes

(c) dielectric slab



E falls to E/K , so C rises to KC

No work is done moving a charge along an equipotential, because V does not change — that is the one-line reason they sit at 90° to $\mathbf{E}$.

3. Potential Energy

FORMULAS

Two charges: $U = kq_1q_2/r$

Three charges: $U = k[q_1q_2/r_{12} + q_2q_3/r_{23} + q_1q_3/r_{13}]$

Dipole in a field: $U = -pE \cos\theta = -\mathbf{p} \cdot \mathbf{E}$

Work done in rotating a dipole from θ_1 to θ_2 : $W = pE(\cos\theta_1 - \cos\theta_2)$

TRAP $\theta = 0^\circ \rightarrow U = -pE$, minimum energy, **STABLE**. $\theta = 180^\circ \rightarrow U = +pE$, maximum, **UNSTABLE**. $\theta = 90^\circ \rightarrow U = 0$.

The sign matters: U is **negative** for unlike charges (attractive, bound) and **positive** for like charges.

4. Conductors and Dielectrics

INSIDE A CONDUCTOR — the five facts

1. $E = 0$ everywhere inside.
2. The whole conductor is at **one potential** (equipotential).
3. Any excess charge resides entirely on the **outer surface**.
4. The field just outside is σ/ϵ_0 and **perpendicular** to the surface.
5. There is **no net charge** inside the body.

DIELECTRICS

A dielectric has **no free charges**. In a field its molecules develop **induced dipole moments** — this is **polarisation**. The induced field **opposes** the applied field, so the net field reduces to E_0/K .

Polar molecules (HCl , H_2O) have a permanent dipole moment; **non-polar** (H_2 , O_2 , CO_2) acquire one only in a field.

5. Capacitance

FORMULAS

$$C = Q/V \quad \text{unit farad (F)} = \text{C V}^{-1}$$

$$\text{Parallel plate: } C = \epsilon_0 A / d$$

$$\text{With a dielectric filling the gap: } C = K\epsilon_0 A / d = KC_0$$

$$\text{With a slab of thickness } t \text{ (} t < d \text{): } C = \epsilon_0 A / [d - t(1 - 1/K)]$$

Capacitance depends only on geometry and the medium — never on the charge or the voltage applied.

COMBINATIONS — the opposite of resistors

	SERIES	PARALLEL
Formula	$1/C_s = 1/C_1 + 1/C_2 + \dots$	$C_p = C_1 + C_2 + \dots$
Same for all	Charge Q	Voltage V
Divides	Voltage, as $V \propto 1/C$	Charge, as $Q \propto C$
Result	Less than the smallest	More than the largest

6. Energy Stored

FORMULAE ONLY — the syllabus says no derivation

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

$$\text{Energy density } u = \frac{1}{2}\epsilon_0 E^2 \text{ (energy per unit volume)}$$

THE TWO CASES YOU MUST SEPARATE When a dielectric is inserted, *what stays constant decides everything.*

Battery still connected (V constant): $C \rightarrow KC$, so Q increases K times and U increases K times.

Battery disconnected (Q constant): $C \rightarrow KC$, so V falls to V/K and U falls to U/K .

Read the question for the words "battery remains connected" or "after disconnecting" — they are there on purpose.

WORKED EXAMPLE Two capacitors $3\ \mu\text{F}$ and $6\ \mu\text{F}$ are joined in *series* across $90\ \text{V}$.

$$1/C_s = 1/3 + 1/6 = 3/6 \Rightarrow C_s = 2\ \mu\text{F}$$

$$Q = C_s V = 2 \times 90 = 180\ \mu\text{C} \text{ (same through both)}$$

$$V_3 = 180/3 = 60\ \text{V} \cdot V_6 = 180/6 = 30\ \text{V} \text{ check: } 60 + 30 = 90\ \checkmark$$

$$\text{Energy} = \frac{1}{2} C_s V^2 = \frac{1}{2} \times 2 \times 10^{-6} \times 8100 = 8.1 \times 10^{-3}\ \text{J}$$

7. Question Triggers what the wording is really asking

If the question says...	Use
"work done in moving a charge between two points"	$W = q(V_B - V_A)$
"work done along an equipotential surface"	ZERO
"potential due to several charges"	Algebraic sum of kq/r
"dielectric inserted, battery connected"	V fixed $\rightarrow$ Q and U rise K times
"dielectric inserted after disconnecting"	Q fixed $\rightarrow$ V and U fall K times
"energy lost when two charged capacitors are joined"	Common potential first, then compare total U before and after
"field just outside a charged conductor"	σ/ϵ_0

MOST-ASKED BOARD QUESTIONS

- [3M]** Derive the *capacitance of a parallel plate capacitor* with a dielectric slab between the plates.
- [3M]** Derive an expression for the *potential due to a point charge / an electric dipole*.
- [3M]** Two capacitors in series/parallel — find equivalent C , charge, voltage and energy.
- [2M]** Define an *equipotential surface* and give two properties.
- [2M]** Derive the *potential energy of a dipole* in a uniform electric field.
- [1M]** Why is the electrostatic potential *constant inside* a charged conductor?
- [1M]** Where on a dipole is the potential zero but the field non-zero? $\rightarrow$ **Equatorial line**

THE HABIT THAT SCORES — In every capacitor problem, write down first whether Q or V is the quantity being held constant. Almost every mark lost in this chapter comes from carrying the wrong one through an otherwise perfect calculation.