Collegedunia NCERT Formula Sheet

The Ultimate Formula Reference for Class 12 Physics

Chapter 2: Electrostatic Potential and Capacitance

Constant / Unit	Value
Permittivity of free space, ϵ_0	8.854×10^{-12} C^2/(N·m^2)
Coulomb constant, $k = \frac{1}{4\pi\epsilon_0}$	9×10^9 N·m^2/C^2
Volt (V)	1 V $= 1$ J/C
Farad (F)	1 F $= 1$ C/V
Common multiples	$1\ \mu$F $= 10^{-6}$ F; 1 pF $= 10^{-12}$ F
Dielectric constant K (typical)	air ≈ 1; paper ≈ 3.5; glass ≈ 5; water ≈ 80

1 Electric Potential

This section covers the definition of electrostatic potential and its values for a point charge, a dipole, and a system of charges (NCERT 2.2–2.5). Potential is a **scalar** field; addition is algebraic, not vectorial.

What is electric potential?

The electric potential V at a point is the **work done by an external force** to bring a unit positive test charge from infinity (taken as zero) to that point, against the electrostatic field. Potential is a scalar; only **differences** have physical meaning.

Definition of potential

$$V(P) = \frac{W_{\infty \to P}}{q_0}$$

$$V_B - V_A = -\int_A^B \vec{E} \cdot d\vec{l}$$

where W = work done by external force; q_0 = test charge (C). Units: volt (V) $=$ J/C.

Potential is path-independent — the line integral depends only on endpoints. Work done by the field is $-q\,(V_B - V_A)$.

Potential due to a point charge

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

where q = source charge (C); r = distance from charge (m).

Positive for $+q$, negative for $-q$. Falls as $1/r$ — **slower decay** than the field's $1/r^2$.

Potential due to an electric dipole

General point ($r \gg a$): $V = \frac{1}{4\pi\epsilon_0}\frac{p\cos\theta}{r^2}$

Axial ($\theta = 0$): $V = \frac{1}{4\pi\epsilon_0}\frac{p}{r^2}$

Equatorial ($\theta = 90°$): $V = 0$

where $p = q(2a)$ = dipole moment; θ = angle from dipole axis.

Dipole potential falls as $1/r^2$ (faster than a point charge's $1/r$). **Zero everywhere on the equatorial plane** — but $\vec{E}$ there is non-zero.

Potential due to a system of charges

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

where r_i = distance from charge q_i to the field point.

Algebraic (scalar) sum — no vectors. This is what makes potential easier to compute than $\vec{E}$ for many charges.

V is scalar, not vector

Potential adds **algebraically** (with signs). Don't apply vector addition. Two charges $+q$ and $-q$ at equal distance from a point give $V = 0$ (cancellation), even though the $\vec{E}$ vectors there add up to a non-zero magnitude.

2 Equipotentials & E–V Relation

Equipotential surfaces are surfaces of constant V (NCERT 2.6). The electric field is the spatial **rate of fall** of potential — this is the practical link between V (easy to compute) and $\vec{E}$ (what acts on charges).

Equipotential surfaces

Surfaces on which the potential is the **same at every point**. Properties: (i) no work is done in moving a charge along the surface; (ii) the electric field is **always perpendicular** to the surface; (iii) two equipotentials never intersect; (iv) closer spacing means stronger field.

Relation between $\vec{E}$ and V

1D: $E = -\frac{dV}{dr}$

3D: $\vec{E} = -\nabla V = -\left(\frac{\partial V}{\partial x}\hat{i} + \frac{\partial V}{\partial y}\hat{j} + \frac{\partial V}{\partial z}\hat{k}\right)$

$\vec{E}$ points from high to low potential (down the gradient). **Magnitude** of $\vec{E}$ equals the steepness of the V landscape.

3 Electrostatic Potential Energy

The potential energy of a charge configuration is the work required to assemble it from infinity (NCERT 2.7–2.8). For a system of n charges, sum over all distinct pairs.

Two-charge system

$$U = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{r_{12}}$$

where r_{12} = separation (m).

Positive for like charges (work done against repulsion is stored), **negative** for unlike (system releases energy on assembly).

System of n charges

$$U = \frac{1}{4\pi\epsilon_0}\sum_{i<j}\frac{q_i q_j}{r_{ij}}$$

Sum over all **distinct pairs** (each pair counted once). For 3 charges, three terms; for 4, six terms; in general $\binom{n}{2}$ terms.

Charge in an external field

Single charge: $U = qV(\vec{r})$

Two charges in external V: $U = q_1 V(\vec{r}_1) + q_2 V(\vec{r}_2) + \frac{q_1 q_2}{4\pi\epsilon_0 r_{12}}$

First terms: each charge's PE in the external field. Last term: **mutual** PE between the two charges.

Dipole in an external field

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

Stable equilibrium at $\theta = 0$ (aligned, $U = -pE$); unstable at $\theta = 180°$ ($U = +pE$). Same as in Chapter 1.

4 Conductors & Dielectrics

In electrostatic equilibrium, conductors have a strict set of properties (NCERT 2.9). Dielectrics, in contrast, have bound charges that polarise but don't flow (NCERT 2.10).

Conductor in electrostatic equilibrium

Five properties: (i) $\vec{E} = 0$ everywhere **inside** the bulk; (ii) $\vec{E}$ just outside is **perpendicular** to the surface; (iii) any net charge resides **only on the surface**; (iv) V is **constant** throughout the bulk and on the surface; (v) field at the surface: $E = \sigma/\epsilon_0$.

Field at a conductor surface

$E = \dfrac{\sigma}{\epsilon_0}$

where σ = local surface charge density (C/m^2).

Note the factor of ϵ_0 (not $2\epsilon_0$ as for an isolated sheet) — the conductor's interior already has $E = 0$, so the entire field appears on the outside.

Electrostatic shielding

A hollow conductor placed in an external field has **zero field in its interior cavity**, regardless of the external field's strength. This is the basis of the **Faraday cage** — protecting sensitive electronics from external EM disturbance.

Polar vs non-polar dielectrics

Non-polar (e.g., H_2, O_2): no permanent dipole; develop induced moments only when an external field is applied. **Polar** (e.g., H_2O, HCl): have permanent dipoles that align with the external field. Both reduce the net field inside the dielectric.

Polarisation & dielectric constant

$\vec{P} = \chi_e \epsilon_0 \vec{E}$

$E_{\text{inside}} = \dfrac{E_0}{K}$

$K = 1 + \chi_e$

where $\vec{P}$ = polarisation (dipole moment per unit volume); χ_e = electric susceptibility; K = dielectric constant; E_0 = applied field.

Inserting a dielectric **reduces the field** by factor K. For vacuum $K = 1$, for water $K \approx 80$.

5 Capacitance & Combinations

A capacitor stores charge at a given potential difference; its capacitance is the proportionality constant (NCERT 2.11–2.14). The parallel-plate is the canonical case; series and parallel combinations follow rules opposite to those for resistors.

What is capacitance?

Capacitance C is the **charge-storing capacity** of a conductor or pair of conductors per unit potential difference. It depends only on **geometry** (size, shape, separation) and the medium between the plates — never on Q or V themselves.

Definition of capacitance

$C = \dfrac{Q}{V}$

where Q = charge on either plate; V = potential difference. Unit: **farad** (F) $=$ C/V.

1 F is enormous — typical capacitors are in μF or pF. The ratio Q/V stays constant for a given geometry.

Parallel-plate capacitor

Vacuum: $C = \dfrac{\epsilon_0 A}{d}$

With dielectric (slab fills gap): $C = \dfrac{K\epsilon_0 A}{d}$

where A = plate area; d = plate separation; K = dielectric constant.

Insert a dielectric and capacitance **increases** by factor K. Larger area or smaller gap also increases C.

Series combination

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

Same charge Q on each capacitor; total V is the sum of individual V_i. C_{eq} is **smaller than the smallest** C_i.

Parallel combination

$$C_{\text{eq}} = C_1 + C_2 + \cdots + C_n$$

Same V across each; total charge is the sum. C_{eq} is **larger than the largest** C_i. Pattern is the **opposite of resistors**.

Capacitors vs Resistors

For **capacitors**: series → reciprocal-add, parallel → direct-add. For **resistors**: series → direct-add, parallel → reciprocal-add. Capacitance is "inverse-resistance" in this sense — the rules **flip**.

JEE/NEET Extension: Other geometries

Isolated sphere of radius R: $C = 4\pi\epsilon_0 R$.
Spherical capacitor (inner R_1, outer R_2): $C = 4\pi\epsilon_0 \dfrac{R_1 R_2}{R_2 - R_1}$.
Cylindrical capacitor (length L, radii $a < b$): $C = \dfrac{2\pi\epsilon_0 L}{\ln(b/a)}$.

6 Energy Stored in a Capacitor

Charging a capacitor requires work; that work is stored as electrostatic energy in the field between the plates (NCERT 2.15). This energy can be expressed in three equivalent forms, and is distributed throughout the field volume.

Energy stored

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

All three forms are equivalent (use $Q = CV$ to interchange). Energy is stored **in the electric field** between the plates, not in the plates themselves.

Energy density of $\vec{E}$ field

Vacuum: $u = \frac{1}{2}\epsilon_0 E^2$

With dielectric: $u = \frac{1}{2}K\epsilon_0 E^2$

where u = energy per unit volume (J/m³).

Energy is stored **wherever a field exists**, not just in capacitors. Integrating u over the volume gives total energy.

JEE/NEET Extension: Force & energy loss

Force between parallel plates: $F = \dfrac{Q^2}{2\epsilon_0 A} = \dfrac{1}{2}\epsilon_0 E^2 A$.
On connecting a charged capacitor C_1 (V_1) to an uncharged C_2, common potential $V = \dfrac{C_1 V_1}{C_1 + C_2}$. **Energy lost** (as heat / radiation): $\Delta U = \dfrac{C_1 C_2}{2(C_1 + C_2)} V_1^2$.

$1/2$ factor

Don't write $U = QV$ for a capacitor — that is the work to move charge Q through a fixed V. In a capacitor, V **builds up linearly** from 0 to its final value as charge accumulates, so the average is $V/2$ and $U = (1/2)QV$.

Quick Reference — Potential, Capacitance & Energy

Quantity / Configuration	Expression	Notes
V due to point charge	$\frac{1}{4\pi\epsilon_0}\frac{q}{r}$	Falls as $1/r$; signed
V due to dipole (general)	$\frac{1}{4\pi\epsilon_0}\frac{p\cos\theta}{r^2}$	Falls as $1/r^2$; zero on equator
$\vec{E}$ from V	$-\nabla V$	Points from high to low V
U of two charges	$\frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{r}$	$+$ for like; $-$ for unlike
E at conductor surface	$\frac{\sigma}{\epsilon_0}$	Perpendicular to surface
Capacitance (def.)	$\frac{Q}{V}$	Unit: farad (F)
Parallel-plate (vacuum)	$\frac{\epsilon_0 A}{d}$	Geometry only
Parallel-plate (dielectric)	$\frac{K\epsilon_0 A}{d}$	C rises by factor K
Series combination	$\frac{1}{C_{\text{eq}}} = \sum \frac{1}{C_i}$	$C_{\text{eq}} <$ smallest C_i
Parallel combination	$C_{\text{eq}} = \sum C_i$	$C_{\text{eq}} >$ largest C_i
Energy stored	$\frac{1}{2}CV^2 = \frac{Q^2}{2C} = \frac{1}{2}QV$	Three equivalent forms
Energy density (vacuum)	$\frac{1}{2}\epsilon_0 E^2$	Per unit volume of field
Spherical capacitor (ext.)	$4\pi\epsilon_0\frac{R_1 R_2}{R_2 - R_1}$	Concentric shells
Cylindrical capacitor (ext.)	$\frac{2\pi\epsilon_0 L}{\ln(b/a)}$	Coaxial