Collegedunia NCERT Formula Sheet

The Ultimate Formula Reference for Class 12 Physics

Chapter 1: Electric Charges and Fields

Constant	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
Elementary charge, e	1.6×10^{-19} C
Electron mass, m_e	9.11×10^{-31} kg
Proton mass, m_p	1.67×10^{-27} kg

1 Charge & Conductors

This section covers the basic properties of electric charge (NCERT 1.2, 1.5), the distinction between conductors and insulators (1.3), and the process of charging by induction (1.4).

What is electric charge?

Electric charge is an **intrinsic property** of matter that produces and responds to electromagnetic forces. It comes in two signs (positive, negative), is **conserved** in any isolated system, and exists only in **integer multiples** of the elementary charge e. Like charges repel; unlike attract.

Charge quantization

$q = ne$

where $n \in \{0, \pm1, \pm2, \ldots\}$; $e = 1.6 \times 10^{-19}$ C.

Charge always appears in **integer multiples** of e. The total charge of an isolated system never changes, even during chemical or nuclear reactions.

Charge densities

Linear: $\lambda = \dfrac{dq}{dl}$ (C/m)

Surface: $\sigma = \dfrac{dq}{dA}$ (C/m^2)

Volume: $\rho = \dfrac{dq}{dV}$ (C/m^3)

Used to handle **continuous charge distributions** where individual point charges cannot be identified.

Conductors vs Insulators

Conductors (metals, salt solutions, human body) have **free electrons** that can move through the material — charge spreads quickly across the surface. **Insulators** (glass, plastic, wood, dry air) have no free electrons — added charge stays where it is placed.

Charging by induction

A charged body brought near a neutral conductor causes **redistribution** of the conductor's free electrons: opposite charge accumulates on the near side, like charge on the far side. Grounding the far side and removing the inducing body leaves the conductor with a net charge **opposite** to the inducer's — without any contact.

2 Coulomb's Law & Superposition

This section gives the inverse-square Coulomb force between two point charges (NCERT 1.6), how a medium modifies it, and how multi-charge problems are handled by linear superposition (1.7).

Coulomb's law

$$\vec{F}_{12} = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{r^2}\hat{r}_{12}$$

Magnitude: $F = \frac{1}{4\pi\epsilon_0}\frac{|q_1 q_2|}{r^2}$

where q_1, q_2 = charges (C); r = separation (m); $\hat{r}_{12}$ points from q_1 to q_2.

Force is **attractive for unlike** charges, **repulsive for like**. Inverse-square dependence: doubling r **quarters** the force.

Coulomb's law in a medium

$$F_{\text{med}} = \frac{F_{\text{vac}}}{K}$$

where $K = \epsilon_r$ = relative permittivity (dielectric constant) of the medium.

A medium reduces the force between charges by factor K because the medium's molecules **polarise** and partially screen the source charges.

Superposition principle

$$\vec{F}_{1,\text{net}} = \sum_{i=2}^{n} \vec{F}_{1i}$$

Net force on a charge equals the **vector sum** of pairwise Coulomb forces from every other charge. Each pair acts **independently** — no charge "shields" another.

3 Electric Field

The electric field $\vec{E}$ describes the force-per-unit-charge that any test charge would feel at a given point. This section covers fields from a point charge, multiple charges, and continuous distributions (NCERT 1.8, 1.13), plus the qualitative idea of field lines (1.9).

What is electric field?

$\vec{E}$ at a point is the force a small **positive test charge** q_0 would feel there, divided by q_0. The field exists in space **whether or not** a test charge is present; it is a property of the source distribution alone.

Field due to a point charge

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

Force on test charge q_0 at the field point: $\vec{F} = q_0\vec{E}$.

Direction is radially **outward** for $+q$ and **inward** for $-q$. Magnitude falls as $1/r^2$.

Field of a system of discrete charges

$$\vec{E}_{\text{net}} = \sum_i \frac{1}{4\pi\epsilon_0}\frac{q_i}{r_i^2}\hat{r}_i$$

Vector sum of individual point-charge fields. Each $\hat{r}_i$ points from source charge q_i to the field point.

Continuous distribution

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

where $dq = \lambda\, dl$ (line), $\sigma\, dA$ (surface), or $\rho\, dV$ (volume).

Generalises superposition for charge distributed continuously over a curve, surface, or solid.

Electric field lines

Imaginary lines drawn so that the **tangent at every point** gives the direction of $\vec{E}$, and the **density of lines** represents the field magnitude. Lines start on $+$ charges, end on $-$ charges, never cross, never form closed loops in electrostatics, and do not pass through conductors.

Field vs Force

$\vec{E}$ exists at a point in space **whether or not** a test charge is present. $\vec{F} = q\vec{E}$ requires a charge to feel the field. The field of the source charge does **NOT** include any contribution from the test charge itself.

4 Electric Dipole

A dipole is a pair of equal and opposite charges separated by a small distance (NCERT 1.11). This section gives the dipole moment, the field on its axial and equatorial lines, and the torque and potential energy in an external field (1.12).

Dipole moment

$\vec{p} = q \cdot 2\vec{a}$ (C·m)

Magnitude: $p = q(2a)$. Direction: from $-q$ to $+q$.

$\vec{p}$ captures both the charge magnitude and the separation; **bigger q or wider gap** means a stronger dipole.

Field on axial line ($r \gg a$)

$$\vec{E}_{\text{axial}} = \frac{1}{4\pi\epsilon_0}\frac{2\vec{p}}{r^3}$$

Direction: **parallel** to $\vec{p}$.

Dipole field falls as $1/r^3$ (faster than a point charge's $1/r^2$) because the $+q$ and $-q$ contributions partly cancel.

Field on equatorial line ($r \gg a$)

$$\vec{E}_{\text{eq}} = -\frac{1}{4\pi\epsilon_0}\frac{\vec{p}}{r^3}$$

Direction: **anti-parallel** to $\vec{p}$.

At equal distance, $E_{\text{axial}} = 2\,E_{\text{eq}}$ — the axial field is exactly **twice as strong**, in the opposite direction.

Torque on dipole in uniform $\vec{E}$

$\vec{\tau} = \vec{p} \times \vec{E}$

Magnitude: $\tau = pE\sin\theta$.

Net force on the dipole in a uniform field is **zero**, but the torque tries to align $\vec{p}$ with $\vec{E}$. Maximum at $\theta = 90°$, zero at $\theta = 0°$ or $180°$.

Potential energy of dipole

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

Minimum (**stable**): $\theta = 0°$, $U = -pE$.

Maximum (**unstable**): $\theta = 180°$, $U = +pE$.

Aligned with the field is the lowest-energy state; antiparallel is the highest. The dipole "wants" to rotate toward $\theta = 0$.

JEE/NEET Extension: General point of dipole

At distance r and polar angle θ from the dipole axis:

$$E = \frac{p}{4\pi\epsilon_0 r^3}\sqrt{1 + 3\cos^2\theta}$$

Direction: $\tan\alpha = \frac{1}{2}\tan\theta$.

Reduces to the axial form at $\theta = 0$ and the equatorial form at $\theta = 90°$.

Axial vs Equatorial

Axial = 2 $\times$ Equatorial (and parallel to $\vec{p}$). Equatorial is anti-parallel. The factor of 2 is the only thing students confuse — remember "axial doubles".

5 Electric Flux & Gauss's Law

Flux measures how much of the electric field passes through a surface (NCERT 1.10). Gauss's law (1.14) links the total flux through a closed surface to the charge it encloses, and is the fastest tool for high-symmetry field problems.

What is electric flux?

Electric flux Φ_E counts the **net number of field lines** piercing a surface. It is positive when lines exit the surface, negative when they enter, and zero when $\vec{E}$ lies in the surface plane.

Electric flux

Uniform field, flat surface: $\Phi_E = \vec{E} \cdot \vec{A} = EA\cos\theta$

General: $\Phi_E = \int \vec{E} \cdot d\vec{A}$ (N·m²/C)

where θ = angle between $\vec{E}$ and outward normal $\vec{A}$.

Maximum when $\vec{E} \parallel \vec{A}$, **zero** when $\vec{E} \perp \vec{A}$.

Gauss's law

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

Total flux through any closed surface equals $1/\epsilon_0$ times the **net charge enclosed**. The result is **independent of the surface's shape or size** — only the enclosed charge matters.

q_{enc} only

Charges OUTSIDE the Gaussian surface contribute zero net flux but DO contribute to $\vec{E}$ at every point on the surface. Don't drop them when asked for $\vec{E}$ — only when asked for total flux.

6 Applications of Gauss's Law

For symmetric distributions, picking the right Gaussian surface (cylinder, pillbox, or concentric sphere) collapses the flux integral to $E \times A$ and gives $\vec{E}$ in one line. The four canonical applications below all follow that pattern (NCERT 1.15).

Infinite line of charge

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

where λ = linear charge density (C/m); r = perpendicular distance.

Direction: **radial**, away from the line for $+\lambda$. Use a coaxial cylindrical Gaussian surface. $E \propto 1/r$ — **slower decay** than a point charge.

Infinite plane sheet of charge

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

where σ = surface charge density (C/m²).

Direction: **perpendicular** to the sheet, away from it for $\sigma > 0$. Field is **uniform and independent of distance**.

Two parallel sheets, opposite charges

Between sheets: $E = \dfrac{\sigma}{\epsilon_0}$

Outside (both sides): $E = 0$.

This is the **parallel-plate capacitor** configuration — the fields of the two sheets add inside and cancel outside.

Spherical shell of charge q, radius R

Outside ($r > R$): $E = \dfrac{1}{4\pi\epsilon_0}\dfrac{q}{r^2}$

At surface: $E = \dfrac{\sigma}{\epsilon_0} = \dfrac{1}{4\pi\epsilon_0}\dfrac{q}{R^2}$

Inside ($r < R$): $E = 0$

Outside, the shell behaves **exactly like a point charge** at its centre. Inside, **no field at all**.

JEE/NEET Extension: Solid sphere with uniform ρ

Outside ($r \geq R$): $E = \dfrac{1}{4\pi\epsilon_0}\dfrac{q}{r^2}$

Inside ($r < R$): $E = \dfrac{1}{4\pi\epsilon_0}\dfrac{qr}{R^3} = \dfrac{\rho r}{3\epsilon_0}$

Field grows **linearly inside**, then falls as $1/r^2$ outside. Maximum at the surface.

Quick Reference — All $\vec{E}$ Expressions

Source	Field magnitude	Notes / Direction
Point charge	$\frac{1}{4\pi\epsilon_0}\frac{q}{r^2}$	Radial; outward for $+q$, inward for $-q$
Dipole on axial line ($r \gg a$)	$\frac{1}{4\pi\epsilon_0}\frac{2p}{r^3}$	Parallel to $\vec{p}$
Dipole on equatorial line ($r \gg a$)	$\frac{1}{4\pi\epsilon_0}\frac{p}{r^3}$	Anti-parallel to $\vec{p}$
Infinite line of charge	$\frac{\lambda}{2\pi\epsilon_0 r}$	Radial; $\propto 1/r$
Infinite plane sheet	$\frac{\sigma}{2\epsilon_0}$	Perpendicular; uniform
Between two opposite sheets	$\frac{\sigma}{\epsilon_0}$	Uniform; outside $E = 0$
Spherical shell, $r > R$	$\frac{1}{4\pi\epsilon_0}\frac{q}{r^2}$	Like point charge at centre
Spherical shell, $r < R$	0	No field inside
Solid sphere, $r > R$	$\frac{1}{4\pi\epsilon_0}\frac{q}{r^2}$	Like point charge at centre
Solid sphere, $r < R$	$\frac{1}{4\pi\epsilon_0}\frac{qr}{R^3}$	Linear in r