Collegedunia NCERT Formula Sheet

The Ultimate Formula Reference for Class 12 Physics

Chapter 3: Current Electricity

Constant / Unit	Value
Elementary charge, e	1.6×10^{-19} C
Electron mass, m_e	9.11×10^{-31} kg
Ampere (A)	1 A = 1 C/s
Ohm (Ω)	1 Ω = 1 V/A
Resistivity (Cu, 20°C)	1.7×10^{-8} Ω·m
Temperature coefficient α (Cu)	3.9×10^{-3} /K

1 Current & Drift

This section gives the definition of current and its microscopic origin in conductors — the slow drift of free electrons under an applied field (NCERT 3.2–3.5).

What is electric current?

Electric current is the **rate of flow of charge** across a cross-section. By convention, current direction is the direction **positive** charges would move (opposite to actual electron motion in metals). Current is a **scalar** despite having direction in space.

Electric current

$$I = \frac{dq}{dt} \quad \text{(A)}$$

Average: $I_{\text{avg}} = \dfrac{q}{t}$.

One ampere equals one coulomb of charge crossing a section per second. Current is the same at every cross-section of a steady-state circuit.

Drift velocity & current

$$v_d = \frac{eE\tau}{m_e} = \frac{eV\tau}{m_e L}$$

$$I = neAv_d$$

where n = number density of free electrons (m^{-3}); A = cross-section (m^2); τ = mean free time between collisions (s).

Drift velocity is **tiny** ($\sim 10^{-4}$ m/s) but current is large because n is enormous ($\sim 10^{28}$ m^{-3}).

Mobility & current density

Mobility: $\mu = \dfrac{v_d}{E} = \dfrac{e\tau}{m_e}$ (m^2/V/s)

Current density: $\vec{J} = \dfrac{I}{A}\hat{n} = ne\vec{v}_d$ (A/m^2)

Mobility measures how quickly carriers respond to an applied field. $\vec{J}$ is a vector — it carries direction information that scalar I does not.

2 Ohm's Law & Resistivity

Ohm's law links voltage, current, and the material property that resists charge flow (NCERT 3.4–3.8). The microscopic version gives resistivity in terms of electron parameters.

Ohm's law (macroscopic)

$$V = IR$$

$$R = \frac{V}{I} \quad \text{(\textbf{ohm}, } \Omega\text{)}$$

Valid for **ohmic conductors** only — materials where V vs I is a straight line through the origin. Diodes, electrolytes are non-ohmic.

Ohm's law (microscopic)

$$\vec{J} = \sigma\vec{E}$$

$$\vec{E} = \rho\vec{J}$$

where σ = conductivity (S/m); $\rho = 1/\sigma$ = resistivity (Ω·m).

Microscopic form is more general — it applies pointwise inside the material, not just averaged over the conductor.

Resistance from geometry

$$R = \rho\frac{L}{A}$$

where L = length (m); A = cross-section (m^2); ρ = resistivity.

Doubling length **doubles** R; doubling area **halves** R. Resistivity is intrinsic to the material; resistance depends on shape.

Resistivity from electron parameters

$$\rho = \frac{m_e}{ne^2\tau}$$

Resistivity rises when τ falls (more frequent collisions). Scattering with lattice ions is what makes metals resist current flow.

Temperature dependence

$$\rho_T = \rho_0\,[\,1 + \alpha(T - T_0)\,]$$

$$R_T = R_0\,[\,1 + \alpha(T - T_0)\,]$$

where α = temperature coefficient of resistivity (K^{-1}).

Metals: $\alpha > 0$ (resistivity rises with T). **Semiconductors / insulators**: $\alpha < 0$ (resistivity falls). **Alloys** (manganin, constantan): very small α — used for standard resistors.

Limitations of Ohm's law

Ohm's law fails when: (i) V–I relation is **non-linear** (e.g., diodes); (ii) V depends on direction of I (e.g., GaAs at high field); (iii) the relation is not single-valued (e.g., when I has multiple solutions for a given V).

3 Power & Cells

Energy delivered per unit time, plus the role of EMF and internal resistance in real cells (NCERT 3.9–3.11).

Electrical power

$$P = VI = I^2R = \frac{V^2}{R} \quad \text{(W)}$$

Energy: $W = Pt = VIt$.

Three equivalent forms; pick the one that uses the variables you know. Power dissipated as heat in a pure resistor (Joule heating).

EMF vs terminal voltage

EMF (ε) is the work done by the cell per unit charge to drive it from $-$ to $+$ terminal — a property of the cell alone. **Terminal voltage** V is what a voltmeter reads across the cell when current flows; $V = \varepsilon - Ir$ during discharge, $V = \varepsilon + Ir$ during charging.

Cell with internal resistance

$$\varepsilon = I(R + r)$$

$$I = \frac{\varepsilon}{R + r}$$

$$V = \varepsilon - Ir \quad \text{(terminal voltage)}$$

where ε = EMF; r = internal resistance (Ω); R = external resistance.

At open circuit ($I = 0$), $V = \varepsilon$. As I rises, terminal voltage **drops**. Short-circuit current: $I_{\text{sc}} = \varepsilon / r$.

Cells in series

$$\varepsilon_{\text{eq}} = \varepsilon_1 + \varepsilon_2 + \cdots$$

$$r_{\text{eq}} = r_1 + r_2 + \cdots$$

EMFs add; internal resistances add. If a cell is reversed, subtract its EMF. Use when more voltage is needed.

Cells in parallel (identical)

$$\varepsilon_{\text{eq}} = \varepsilon, \quad r_{\text{eq}} = \frac{r}{n}$$

General (two cells): $\varepsilon_{\text{eq}} = \dfrac{\varepsilon_1 r_2 + \varepsilon_2 r_1}{r_1 + r_2}$,

$$r_{\text{eq}} = \frac{r_1 r_2}{r_1 + r_2}$$

Use when more current is needed at the same EMF. Equivalent EMF is a weighted average; equivalent resistance falls.

4 Resistors in Combination

Series and parallel networks reduce to a single equivalent resistor; rules are the standard ones (NCERT 3.11).

Series resistors

$$R_{\text{eq}} = R_1 + R_2 + \cdots + R_n$$

Same current through each; voltages add. R_{eq} is **larger than the largest R_i**.

Parallel resistors

$$\frac{1}{R_{\text{eq}}} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots + \frac{1}{R_n}$$

Two resistors: $R_{\text{eq}} = \dfrac{R_1 R_2}{R_1 + R_2}$

Same voltage across each; currents add. R_{eq} is **smaller than the smallest R_i**.

Resistors vs Capacitors

Resistors: series → direct-add, parallel → reciprocal-add. **Capacitors**: the rules **flip**. Resistance opposes current flow; capacitance stores charge — they are reciprocal in nature, hence reciprocal in combining.

5 Kirchhoff's Rules

Two rules let you solve any network by writing one equation per node and one per loop (NCERT 3.12).

Kirchhoff's Current Law (KCL)

$$\sum_{\text{junction}} I = 0$$

At any junction, the sum of incoming currents equals the sum of outgoing. Statement of **charge conservation** — charge does not accumulate at a node.

Kirchhoff's Voltage Law (KVL)

$$\sum_{\text{loop}} \varepsilon - \sum_{\text{loop}} IR = 0$$

Around any closed loop, the sum of EMF rises equals the sum of IR drops. Statement of **energy conservation** — a charge returning to its start has the same energy.

Sign convention for KVL

Traverse the loop in a chosen direction. EMF: $+\varepsilon$ if traversed $-$ to $+$ inside the cell; $-\varepsilon$ otherwise. Resistor: $-IR$ if traversal direction matches assumed current; $+IR$ if opposite.

6 Wheatstone Bridge

A bridge circuit that detects resistance ratios with high precision (NCERT 3.13). The balance condition zeros the galvanometer current and lets you find an unknown resistance from three known ones.

Balance condition

$$\frac{P}{Q} = \frac{R}{S}$$

where P, Q, R, S are the four arm resistances.

At balance, no current flows through the galvanometer. The condition is **independent** of the cell's EMF and the galvanometer's resistance.

Why Wheatstone is precise

Balance is detected by zero galvanometer deflection — a **null measurement**. Null methods are insensitive to cell EMF drift and instrument calibration; you only need a **ratio** of three known resistors to find the unknown.

JEE/NEET Extension: Power transfer

Maximum power dissipation in external R when $R = r$: $P_{\text{max}} = \frac{\varepsilon^2}{4r}$.

This is the **maximum power transfer theorem** — efficiency at this match is only 50%. For higher efficiency, $R \gg r$.

Internal resistance hiding

Always include r when writing the loop equation. A "12 V battery" delivers 12 V **only at open circuit**. Under load, terminal voltage drops by Ir — forgetting this is a top exam-paper trap.

Quick Reference — Current Electricity

Quantity / Configuration	**Expression**	**Notes**
Current (general)	$\frac{dq}{dt}$	Rate of charge flow
Current (drift)	$neAv_d$	Microscopic origin
Drift velocity	$\frac{eE\tau}{m_e}$	Tiny but n huge
Mobility	$\frac{e\tau}{m_e}$	Response per unit field
Current density $\vec{J}$	$ne\vec{v}_d = \sigma\vec{E}$	Vector form
Ohm's law	$V = IR$	Ohmic conductors
Resistance from geometry	$\rho\frac{L}{A}$	Length / area
Resistivity (electron)	$\frac{m_e}{ne^2\tau}$	Microscopic
Temperature dependence	$\rho_0[1 + \alpha\Delta T]$	$\alpha > 0$ for metals
Power	$VI = I^2R = V^2/R$	Three forms
Cell with r	$I = \frac{\varepsilon}{R + r}$	$V = \varepsilon - Ir$
Series resistors	$\sum R_i$	Currents same
Parallel resistors	$\frac{1}{R_{\text{eq}}} = \sum \frac{1}{R_i}$	Voltages same
Wheatstone balance	$\frac{P}{Q} = \frac{R}{S}$	Null method
Max power transfer	$R = r$	$P_{\text{max}} = \varepsilon^2/4r$