FREE NOTES · NCERT + JEE/NEET LEVEL

Current Electricity

Current, drift velocity, Ohm's law, resistivity, effect of temperature, power, EMF and internal resistance of a cell, Kirchhoff's laws, the Wheatstone bridge, meter bridge and potentiometer.

01 Electric current
02 Drift velocity & mobility
03 Ohm's law
04 Resistivity
05 Effect of temperature
06 Resistors: series & parallel
07 Electrical power
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01 Electric current

$$I = Q / t,\ I = dq/dt$$

Unit ampere (A) = C/s. Direction: that of positive charge flow (opposite to electrons). Current is a **scalar** (it has a direction but doesn't follow vector addition).

Current density $j = I/A$ (A/m²) is a vector.

02 Drift velocity & mobility

Free electrons in a wire move randomly at high speed (≈10^5 m/s) with zero net movement. Applying a field gives them a small average velocity opposite to the field: the **drift velocity**.

$$v_d = e\,E\,\tau / m$$

$$I = n\,e\,A\,v_d$$

τ = relaxation time (average time between collisions), n = free electrons per m³. $v_d \approx 10^{-4}$ m/s (very slow!).

THEN WHY DOES A BULB LIGHT INSTANTLY?

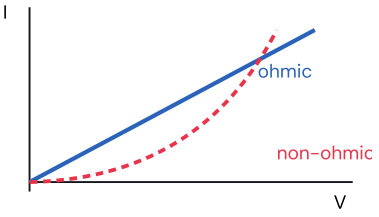
The electric field spreads through the whole wire at nearly the speed of light, and electrons everywhere start drifting at once. The electron itself doesn't travel from the switch to the bulb.

Mobility $\mu = v_d/E = e\tau/m$ (m²/V·s).

03 Ohm's law

STATEMENT

If temperature and other physical conditions stay the same, the current through a conductor is proportional to the potential difference: $V = IR$.



I–V graph: slope = 1/R

R = resistance, unit ohm (Ω). A straight-line graph ⇒ **ohmic**. Vector form: $j = \sigma E$.

WHERE OHM'S LAW FAILS

- Diode: reversing V gives very different current (non-linear).
- Thyristor / GaAs: several V for one I.
- Filament bulb: R rises as it heats, so the graph curves.

04 Resistivity

$$R = \rho L / A$$

$\rho = m/(n e^2 \tau)$, conductivity $\sigma = 1/\rho$

ρ (Ω·m) depends only on **material and temperature**, not size. Metals ≈ 10^{-8}, semiconductors in between, insulators ≈ 10^{14} Ω·m.

STRETCHING A WIRE (SAME VOLUME)

Length × n ⇒ area ÷ n ⇒ $R' = n^2 R$. Radius halved (same volume) ⇒ length × 4 ⇒ R × 16.

05 Effect of temperature

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

α = temperature coefficient of resistivity.

Material	ρ on heating	α	Why
Metals	Increases	Positive	Atoms vibrate more, more collisions, τ falls
Semiconductors	Decreases	Negative	Number of charge carriers (n) increases
Alloys (nichrome, manganin, constantan)	Very little change	Very small	Standard resistors, heater elements

06 Resistors: series & parallel

SERIES

$$R = R_1 + R_2 + \ldots$$

Same current. V divides: more V across the larger R.

PARALLEL

$$1/R = 1/R_1 + 1/R_2 + \ldots$$

Same V. Current divides: more I through the smaller R. Two resistors: $R_1R_2/(R_1 + R_2)$.

House wiring is in **parallel**: each appliance gets the full 220 V, and one switching off doesn't affect the others.

07 Electrical power

$$P = VI = I^2 R = V^2 / R$$

Unit watt. Energy = Pt. Commercial unit: 1 kWh = 3.6×10^6 J (one "unit" of electricity).

BULB QUESTIONS

- A bulb rated (P, V) ⇒ $R = V^2/P$. Higher wattage means lower R.
- In **series**: the lower-wattage bulb glows **brighter** (I same, P = I^2R, larger R).
- In **parallel**: the higher-wattage bulb glows brighter (V same, P = V^2/R).

Power is transmitted at high voltage: same power, less current ⇒ less I^2R loss in the wires.

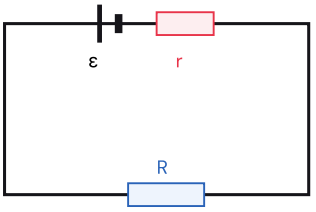
08 Cell: EMF & internal resistance

EMF (ε): the potential difference across a cell's terminals when no current flows. **Internal resistance (r):** the resistance of the cell's electrolyte.

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

Terminal voltage $V = \varepsilon - Ir$ (discharging)

Charging: $V = \varepsilon + Ir$



Cell (ε, r) and external load R

Situation	Result
Open circuit (R = ∞)	V = ε
Short circuit (R = 0)	$I_{max} = \varepsilon/r$
Maximum power to the load	R = r, $P_{max} = \varepsilon^2/(4r)$

09 Combining cells

Combination	Equivalent EMF	Equivalent r
n cells in series (same ε, r)	$n\varepsilon$	nr
m cells in parallel	ε	r/m
Two different cells in parallel	$(\varepsilon_1 r_2 + \varepsilon_2 r_1)/(r_1 + r_2)$	$r_1 r_2/(r_1 + r_2)$
One cell reversed (series)	$\varepsilon_1 - \varepsilon_2$	$r_1 + r_2$

Series: when more voltage is needed. Parallel: for more current, or when r is large.

10 Kirchhoff's laws

JUNCTION RULE (KCL)

Current into a junction = current out: $\Sigma I = 0$. **Conservation of charge**.

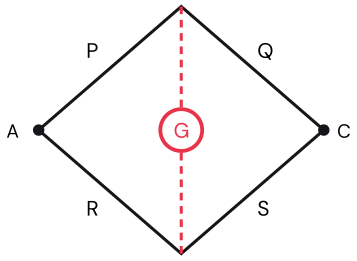
LOOP RULE (KVL)

In any closed loop the sum of all potential changes is 0: $\Sigma\varepsilon - \Sigma IR = 0$. **Conservation of energy**.

SIGN CONVENTION

- Crossing a resistor along the current: -IR. Against it: +IR.
- Crossing a cell from − to +: +ε. From + to −: −ε.
- If you assumed the wrong current direction, the answer simply comes out negative.

11 Wheatstone bridge & meter bridge



Balanced: no current through the galvanometer

BALANCE CONDITION

$$P / Q = R / S$$

In a balanced bridge the galvanometer branch can be removed (no current flows).

METER BRIDGE

$$R/S = l / (100 - l)$$

A uniform 1 m wire; l = balancing length (cm). Used to find an unknown resistance. Error is least when the balance point is near the middle.

12 Potentiometer (JEE)

A steady current through a long uniform wire gives a potential gradient $k = V/L$. At the balance point **no current flows from the cell** ⇒ it measures the true EMF (better than a voltmeter).

Comparing two cells: $\varepsilon_1/\varepsilon_2 = l_1/l_2$

Internal resistance: $r = R\,(l_1 - l_2)/l_2$

l_1 = balance without R, l_2 = with shunt R. A longer wire ⇒ smaller k ⇒ more sensitive.

13 JEE Extra + Tricks

JEE LEVEL

- Balanced Wheatstone bridge (P/Q = R/S): remove the middle resistor. Symmetry tricks for cubes: across body diagonal $R_{eq} = 5R/6$.
- Drift velocity $I = neAv_d$ (very small, ~mm/s); resistance $R \propto L^2$ when wire is stretched (volume constant): $R' = n^2R$ for n times length.
- Maximum power from a cell when external R = internal r; $P_{max} = E^2/4r$.
- Cells: n in series $E_{eq} = nE$; m in parallel: E same, $r_{eq} = r/m$.
- Colour code trick: "**B B R O Y of Great Britain had a Very Good Wife**" = 0–9 (Black, Brown, Red, Orange, Yellow, Green, Blue, Violet, Grey, White).
- Potentiometer (JEE): $E_1/E_2 = l_1/l_2$; internal resistance $r = R(l_1 - l_2)/l_2$.

14 Solved numericals

Q1. 2 A flows for 5 min. Charge and number of electrons?
$Q = 2 \times 300 = 600$ C. $n = 600/1.6 \times 10^{-19} = 3.75 \times 10^{21}$. **Ans: 600 C, 3.75×10^{21}**

Q2. Copper wire: $A = 10^{-6}$ m², I = 1.5 A, $n = 8.5 \times 10^{28}$. Drift velocity?
$v_d = I/(neA) = 1.5/(8.5 \times 10^{28} \times 1.6 \times 10^{-19} \times 10^{-6}) \approx 1.1 \times 10^{-4}$ m/s. **Ans: ≈ 0.11 mm/s**

Q3. A 10 Ω wire is stretched to 3 times its length. New R?
$R' = n^2R = 9 \times 10 = 90$ Ω. **Ans: 90 Ω**

Q4. Cell ε = 2 V, r = 0.5 Ω, external R = 3.5 Ω. Current and terminal voltage?
$I = 2/4 = 0.5$ A. $V = 2 - 0.25 = 1.75$ V. **Ans: 0.5 A, 1.75 V**

Q5. 100 W and 60 W (220 V) bulbs in series on 220 V. Which glows brighter?
$R_{100} = 484$ Ω, $R_{60} \approx 807$ Ω. In series I is the same ⇒ larger R = more power ⇒ the 60 W one. **Ans: 60 W bulb**

Q6. Meter bridge: 10 Ω in the left gap, balance at 40 cm. Right resistance?
$10/S = 40/60$ ⇒ S = 15 Ω. **Ans: 15 Ω**

Q7. A platinum wire is 5 Ω at 0 °C and 5.4 Ω at 100 °C. α?
$\alpha = (5.4 - 5)/(5 \times 100) = 8 \times 10^{-4}$ /°C. **Ans: 8×10^{-4} /°C**

15 Common mistakes

- Confusing drift velocity with the electrons' random speed.
- Thinking resistivity depends on length or area.
- Taking R × n (instead of n^2) for a stretched wire.
- Thinking the higher-wattage bulb glows brighter in series (it's the opposite).
- Always taking terminal voltage as ε.
- Wrong sign conventions in Kirchhoff's laws.

16 Formula sheet

Current	$I = dq/dt = neAv_d$
Drift velocity, mobility	$v_d = eE\tau/m,\ \mu = v_d/E$
Ohm's law	$V = IR,\ j = \sigma E$
Resistance	$R = \rho L/A,\ \rho = m/(ne^2\tau)$
Temperature	$\rho = \rho_0[1 + \alpha\Delta T]$
Series / parallel	$\Sigma R\ /\ 1/R = \Sigma 1/R$
Power	$P = VI = I^2R = V^2/R$
Cell	$I = \varepsilon/(R + r),\ V = \varepsilon - Ir$
Max power	$R = r,\ P = \varepsilon^2/4r$
Wheatstone	$P/Q = R/S$
Meter bridge	$R/S = l/(100 - l)$
Potentiometer	$\varepsilon_1/\varepsilon_2 = l_1/l_2$

17 Practice questions

1. Three 6 Ω resistors: in series and in parallel?
2. Two wires of the same material: lengths 1 : 2, radii 2 : 1. Ratio of resistances?
3. 4 cells (1.5 V, 0.5 Ω) in series with an external 4 Ω. Current?
4. A 1000 W heater runs 2 hours a day for 30 days. How many units?
5. A battery's short-circuit current is 10 A and its EMF 5 V. r?

ANSWERS

1) 18 Ω, 2 Ω · 2) $R \propto L/r^2 \Rightarrow 1/4 : 2 = 1 : 8$ · 3) $6/(2 + 4) = 1$ A · 4) $1 \times 2 \times 30 = 60$ kWh · 5) 0.5 Ω

18 Quick revision: 5 minutes before the exam

BASICS

- $I = neAv_d$; $v_d \approx 10^{-4}$ m/s.
- $R = \rho L/A$; ρ depends on material + T.
- Metal α +, semiconductor α −.
- Stretch × n ⇒ R × n^2.

CIRCUITS

- Series ΣR (I same); parallel (V same).
- $P = I^2R = V^2/R$; 1 kWh = 3.6 MJ.
- In series the lower-watt bulb is brighter.

CELLS

- $V = \varepsilon - Ir$.
- Maximum power: R = r.
- Series nε, nr; parallel ε, r/m.

LAWS & BRIDGES

- KCL: charge; KVL: energy.
- P/Q = R/S.
- Meter bridge R/S = l/(100 − l).

Have a doubt? Ask the AI Doubt Solver at padhaiadda.netlify.app, or take the mock test on this chapter.