CURRENT ELECTRICITY

LET'S PLAY WITH PHYSICS— NEET FORMULA SHEET

1. ELECTRIC CURRENT

Fundamental Formula

$$I = \frac{Q}{t} = \frac{dq}{dt}$$

- I **[Ampere (A)]** dim $[A]$
- Q **[Coulomb (C)]** dim $[A \cdot s]$
- Conventional current: direction of $+ve$ charge flow
- n electrons/s $\Rightarrow I = ne \approx 1.6 \times 10^{-19} n$

- 1 A $= 6.25 \times 10^{18}$ electrons per second
- Current is a **scalar** quantity
- AC: I_{rms} used; DC: constant

2. DRIFT VELOCITY

Key Formulae

$$v_d = \frac{eE\tau}{m} \qquad v_d = \frac{I}{neA}$$

$$I = neAv_d$$

- v_d [m/s] (very slow: $\sim 10^{-3}$ m/s)
- τ = relaxation time [s]
- n = free electron density $[\text{m}^{-3}]$
- $e = 1.6 \times 10^{-19}$ C; A = cross-section area

MEMORY TRICK

"I Need A Visa Daily"
$I = n \cdot e \cdot A \cdot v_d$

NEET TRAP

$v_d \sim 10^{-3}$ m/s (very slow!) but electric signal $\sim c$. Do NOT confuse the two.

3. CURRENT DENSITY

Definition

$$J = \frac{I}{A} = nev_d = \sigma E$$

- J $[\text{A m}^{-2}]$ — **vector** quantity
- Direction = direction of conventional current
- σ = conductivity $[\text{S m}^{-1}] = (\Omega\, m)^{-1}$

4. OHM'S LAW

Ohm's Law (Macro & Micro)

$$V = IR \iff J = \sigma E$$

- Valid for metallic conductors at constant temperature
- V-I graph: straight line through origin (slope = R)
- **Non-ohmic**: diode, thermistor, electrolyte, transistor
- Ohmic: carbon resistor, metal wire at const. T

5. 5. RESISTANCE

Resistance Formulae

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

Microscopic: $R = \dfrac{mL}{ne^2\tau A}$

- R **[Ohm (Ω)]** dim $[kg\, m^2\, A^{-2}\, s^{-3}]$
- ρ = resistivity [Ω·m]
- $R \propto L$; $R \propto 1/A$; $R \propto \rho$

NEET TRAP — WIRE STRETCHING

Wire stretched to n times length (V = const.):

$$A' = \frac{A}{n} \Rightarrow R' = n^2 R$$

Wire compressed to $1/n$ length: $R' = R/n^2$

6. RESISTIVITY & CONDUCTIVITY

Microscopic Relations

$$\rho = \frac{m}{ne^2\tau} \qquad \sigma = \frac{1}{\rho} = \frac{ne^2\tau}{m}$$

Material	ρ (Ω·m)
Metals (Cu, Ag)	$10^{-8} - 10^{-6}$
Alloys (Nichrome)	$10^{-6} - 10^{-4}$
Semiconductor (Si)	$10^{-2} - 0.5$
Insulator (glass)	$10^{10} - 10^{16}$

- Metals: ρ increases with T ($\alpha > 0$)
- Semiconductors: ρ *decreases* with T ($\alpha < 0$)
- Nichrome, Manganin: $\alpha \approx 0$ (used in standard resistors)

7. SERIES COMBINATION

7. Series Combination

$$R_s = R_1 + R_2 + \cdots + R_n$$

- Same current I through all resistors
- Voltages add: $V = V_1 + V_2 + \cdots$
- $R_s > R_{\max}$
- Voltage divider: $V_i = V \cdot \frac{R_i}{\sum R}$

8. PARALLEL COMBINATION

8. Parallel Combination

$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots + \frac{1}{R_n}$$

- Same voltage V across all resistors
- Currents add: $I = I_1 + I_2 + \cdots$
- $R_p < R_{\min}$
- Current divider: $I_i = I \cdot \frac{R_{\text{other}}}{R_1 + R_2}$

Property	Series	Parallel	Two Resistors (R_1, R_2)
Equiv. Resistance	$R_1 + R_2$	$\frac{R_1 R_2}{R_1 + R_2}$	R_p **always less than** $R_{\min}$
Current	**Same everywhere**	**Divides as** $1/R$	$I_1/I_2 = R_2/R_1$
Voltage	**Divides as** R	**Same everywhere**	$V_1/V_2 = R_1/R_2$
Power dissipation	$P \propto R$	$P \propto 1/R$	**Higher** $R \Rightarrow$ **more** P **(series)**
Bulb brightness	**Higher** R **= brighter**	**Lower** R **= brighter**	**Critical NEET concept!**

9. TEMPERATURE DEPENDENCE OF RESISTANCE

Temperature Coefficient Formula

$$R_T = R_0(1 + \alpha\,\Delta T)$$

$$\alpha = \frac{R_T - R_0}{R_0\,\Delta T}$$

- α [K^{-1} or $°C^{-1}$] = temperature coefficient
- Copper: $\alpha \approx 4 \times 10^{-3}\ K^{-1}$
- Metals: $\alpha > 0$ Semiconductors: $\alpha < 0$
- Nichrome, Manganin, Constantan: $\alpha \approx 0$

MEMORY TRICK

Superconductors: $R \to 0$ below critical temp T_c
Zero resistance $\Rightarrow$ zero energy loss!

10. KIRCHHOFF'S LAWS

KCL — Junction Rule

$$\sum I_{\text{in}} = \sum I_{\text{out}}$$

Based on conservation of ***charge***

KVL — Loop Rule

$$\sum \varepsilon = \sum IR$$

Based on conservation of ***energy***

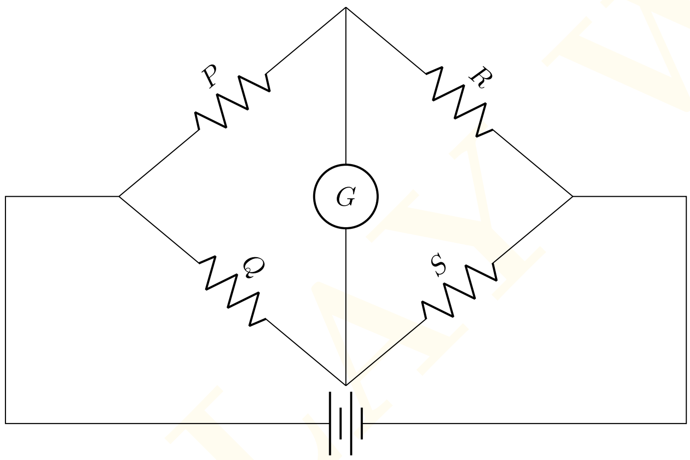
- Traverse in direction of I: $-IR$; opposite: $+IR$
- EMF: enter + terminal: $+\varepsilon$; enter −: $-\varepsilon$
- J junctions $\Rightarrow$ $(J-1)$ KCL equations
- B branches, J junctions $\Rightarrow$ $(B-J+1)$ KVL eqns

11. WHEATSTONE BRIDGE

Balance Condition

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

At balance: $I_G = 0$ (no current through galvanometer)



- Most sensitive when $P = Q = R = S$
- Post Office Box: practical application
- Unbalanced bridge: use Kirchhoff's laws

12. METER BRIDGE

Meter Bridge Formula

$$\frac{R}{X} = \frac{\ell}{100-\ell} \implies X = R \cdot \frac{100-\ell}{\ell}$$

- ℓ = balancing length from left end (in cm)
- R = known resistance (left gap)
- X = unknown resistance (right gap)
- Max sensitivity: $\ell = 50$ cm (when $R = X$)

NEET TRAP

End corrections: actual balance length may differ from observed ℓ due to end resistance. Measure from the wire end, not terminal.

13. ELECTRICAL POWER

Power Formulae

$$P = VI = I^2R = \frac{V^2}{R}$$

Quantity	Series	Parallel
Power	$P \propto R$	$P \propto 1/R$
Brighter bulb	Higher R	Lower R
Rated voltage	Not same	Same (V_{supply})
Total power	$< P_{\text{min,rated}}$	Sum of rated P

- P [Watt (W)] = J/s dim $[kg\, m^2\, s^{-3}]$
- $1\,\text{kWh} = 3.6 \times 10^6\,\text{J}$ (1 unit of electricity)
- $P_{\text{rated}} = V_{\text{rated}}^2/R$ (used to find R of appliance)

NEET TRAP

60 W and 100 W in **series**: 60 W glows brighter ($P \propto R$, $R_{60} > R_{100}$).
In **parallel**: 100 W glows brighter ($P \propto 1/R$).

14. HEATING EFFECT (JOULE'S LAW)

Joule's Law of Heating

$$H = I^2Rt = VIt = \frac{V^2}{R}t$$

$$H_{\text{calories}} = \frac{I^2Rt}{4.18}$$

- $H \propto I^2$ (most important relation!)
- Applications: electric iron, heater, fuse, bulb
- **Fuse wire**: high ρ, low melting point, thin
- Fuse breaks when $P_{\text{fuse}} > P_{\max}$
- Electric energy: $E = Pt = VIt$ [Joules or kWh]

MEMORY TRICK

"Heat Is Produced Real Time"
$H = I^2Rt$

15. CELLS & EMF

EMF and Terminal Voltage

$$\boxed{\varepsilon = V + Ir} \qquad \boxed{V = \varepsilon - Ir}$$

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

- ε = EMF [V] = open circuit terminal voltage
- r = internal resistance [Ω]
- R = external load resistance [Ω]
- Discharge: $V = \varepsilon - Ir < \varepsilon$
- Charging: $V = \varepsilon + Ir > \varepsilon$

- **Open circuit** ($R \to \infty$): $I = 0$, $V = \varepsilon$
- **Short circuit** ($R = 0$): $I_{max} = \varepsilon / r$, $V = 0$
- Power to external: $P_R = I^2 R$
- Power lost internally: $P_r = I^2 r$
- Efficiency: $\eta = R/(R + r)$

16. INTERNAL RESISTANCE

Formulae

$$r = \left(\frac{\varepsilon}{V} - 1\right) R = \frac{\varepsilon - V}{I}$$

Maximum Power Transfer Theorem

$$\boxed{P_{max} = \frac{\varepsilon^2}{4r}} \quad \text{when } R = r$$

At $R = r$: efficiency = 50% only

NEET TRAP

P_{max} delivered to load is NOT when total power is maximum. Efficiency at P_{max} condition is only 50%.

17. COMBINATION OF CELLS

Series (n cells)

$$\varepsilon_{eq} = n\varepsilon$$

$$r_{eq} = nr$$

$$\boxed{I = \frac{n\varepsilon}{R + nr}}$$

Use when: $R \gg nr$

Parallel (m cells)

$$\varepsilon_{eq} = \varepsilon$$

$$r_{eq} = r/m$$

$$\boxed{I = \frac{m\varepsilon}{mR + r}}$$

Use when: $R \ll r/m$

Mixed (n series, m parallel)

$$\boxed{I = \frac{mn\varepsilon}{mR + nr}}$$

I_{max} when $R = \frac{nr}{m}$

Total cells = mn

Combination	ε_{eq}	r_{eq}	Current I	Best For
Series	$n\varepsilon$	nr	$n\varepsilon/(R + nr)$	$R \gg r$
Parallel	ε	r/m	$m\varepsilon/(mR + r)$	$R \ll r$
Mixed ($n \times m$)	$n\varepsilon$	nr/m	$mn\varepsilon/(mR + nr)$	**General use**

18. IMPORTANT GRAPHS

Graph	Shape / Key Inference
V vs I (Ohmic)	**Straight line through origin; slope = R**
V vs I (Non-ohmic)	**Curve (diode, thermistor, bulb)**
R vs T (metal)	**Linear; +ve slope (straight line)**
R vs T (semiconductor)	**Exponential decay curve**
V vs I (cell)	**Straight line; y-int = ε; slope = $-r$**
P vs R (fixed ε)	**Max at $R = r$; bell-shaped curve**
I vs t (RC circuit)	**Exponential decay; $I_0 = V_0/R$**

GRAPH TRAPS

- V-I for cell: slope = $-\mathbf{r}$ (negative!)
- At $R = r$: P to R is max, NOT total P
- Semiconductor R vs T: curve goes DOWN

19. POTENTIOMETER (Bonus Section)

Potentiometer Formulae

$$\phi = \frac{V}{L} \quad \text{(potential gradient)}$$

$$\boxed{\frac{\varepsilon_1}{\varepsilon_2} = \frac{\ell_1}{\ell_2}} \qquad \boxed{r = \left(\frac{\ell_1}{\ell_2} - 1\right) R}$$

- ϕ = potential gradient [V/m]
- **Key advantage**: draws zero current at balance
- Measures true EMF (voltmeter cannot)
- More sensitive: longer wire, lower ϕ
- ℓ_1 = length without shunt; ℓ_2 = with shunt R

20. MOST IMPORTANT NEET FORMULA SUMMARY

Topic	Formula	NEET Key Point
Electric Current	$I = Q/t = neAv_d$	Scalar; direction of + charge
Drift Velocity	$v_d = eE\tau/m = I/(neA)$	$\sim 10^{-3}$ m/s; very slow
Current Density	$J = I/A = nev_d = \sigma E$	Vector; dim $[A\,m^{-2}]$
Ohm's Law	$V = IR$; $J = \sigma E$	Linear; valid for metals only
Resistance	$R = \rho L/A$	$R \propto L$; $R \propto 1/A$
Wire stretched $n\times$	$R' = n^2 R$	Volume conserved!
Temp. dependence	$R_T = R_0(1 + \alpha\Delta T)$	Metal: $\alpha > 0$; SC: $\alpha < 0$
Series	$R_s = R_1 + R_2 + \cdots$	Same I; $P \propto R$
Parallel	$1/R_p = 1/R_1 + 1/R_2 + \cdots$	Same V; $P \propto 1/R$
EMF (discharge)	$V = \varepsilon - Ir$	$V < \varepsilon$ always
EMF (charging)	$V = \varepsilon + Ir$	$V > \varepsilon$ during charging
Short circuit	$I_{\max} = \varepsilon/r$; $V = 0$	When $R = 0$
Max Power	$P_{\max} = \varepsilon^2/(4r)$ at $R = r$	Efficiency $= 50\%$ only
Cells Series	$I = n\varepsilon/(R + nr)$	Use when $R \gg r$
Cells Parallel	$I = m\varepsilon/(mR + r)$	Use when $R \ll r$
Joule Heating	$H = I^2Rt = VIt$	$H \propto I^2$ always
Power	$P = VI = I^2R = V^2/R$	1 kWh $= 3.6 \times 10^6$ J
Wheatstone Bridge	$P/Q = R/S$ (at balance)	$I_G = 0$ at balance
Meter Bridge	$X = R(100 - \ell)/\ell$	Max sensitive: $\ell = 50$ cm
Potentiometer	$\varepsilon_1/\varepsilon_2 = \ell_1/\ell_2$	True EMF; $I = 0$ at balance

TOP 8 NEET TRAPS

1. Stretched wire: $R' = n^2R$ (NOT nR!)
2. Series: higher R bulb is brighter
3. Parallel: lower R bulb is brighter
4. Charging cell: $V = \varepsilon + Ir > \varepsilon$
5. Short circuit: $V = 0$, $I = \varepsilon/r$
6. Max power $\neq$ max efficiency (50% at $R = r$)
7. Potentiometer $\Rightarrow$ true EMF; voltmeter $\Rightarrow$ terminal V
8. KVL sign: enter + of EMF $\Rightarrow +\varepsilon$; else $-\varepsilon$

QUICK MEMORY AIDS

- **I = nEA**V_d: current formula mnemonic
- **OHM**: valid for Homogeneous Metals only
- **Series P**: $P \propto R$ (higher R more heat)
- **Parallel P**: $P \propto 1/R$ (lower R more heat)
- **"Max power when R equals r"**
- **KCL**: charge conserved at junction
- **KVL**: energy conserved in loop

ONE PAGE ULTRA-FAST REVISION

CURRENT ELECTRICITY — NEET

Revise in 5 minutes before your exam!

Current & Drift

$$I = Q/t = neAv_d$$
$$v_d = eE\tau/m$$
$$J = I/A = \sigma E$$

Resistance

$$R = \rho L/A$$
$$R_T = R_0(1+\alpha\Delta T)$$
$$R_{\text{stretch}} = n^2 R$$

Combinations

$$R_s = R_1 + R_2$$
$$R_p = \frac{R_1 R_2}{R_1 + R_2}$$
$$V_1 : V_2 = R_1 : R_2 \text{ (ser.)}$$

Power & Heating

$$P = VI = I^2 R = V^2/R$$
$$H = I^2 Rt$$
$$P_{\max} = \varepsilon^2/(4r) \ (R = r)$$

Cell & EMF

$$V = \varepsilon - Ir \text{ (disch.)}$$
$$V = \varepsilon + Ir \text{ (charg.)}$$
$$I_{\text{SC}} = \varepsilon/r$$

Cell Combinations

$$I_s = \frac{n\varepsilon}{R + nr}$$
$$I_p = \frac{m\varepsilon}{mR + r}$$
$$I_m = \frac{mn\varepsilon}{mR + nr}$$

Kirchhoff's Laws

KCL:
$\sum I_{\text{in}} = \sum I_{\text{out}}$
KVL:
$\sum \varepsilon = \sum IR$

Bridge & Meter

$$\frac{P}{Q} = \frac{R}{S} \text{ (bridge)}$$
$$X = R \cdot \frac{100 - \ell}{\ell}$$

Sensitive at $\ell = 50$ cm

Potentiometer

$$\phi = V/L$$
$$\frac{\varepsilon_1}{\varepsilon_2} = \frac{\ell_1}{\ell_2}$$
$$r = \left(\frac{\ell_1}{\ell_2} - 1\right) R$$

8 MOST TESTED NEET POINTS — NEVER FORGET!

1. $R_{\text{stretch}} = n^2 R$ (volume conserved; area $= A/n$)
2. Series: higher $R \Rightarrow$ brighter bulb (more P)
3. Parallel: lower $R \Rightarrow$ brighter bulb (more P)
4. Max power to load at $R = r$; efficiency only 50%
5. Short circuit: $V = 0$, $I_{\max} = \varepsilon/r$, $R = 0$
6. Open circuit: $I = 0$, $V = \varepsilon$, $R = \infty$
7. Cell charging: $V = \varepsilon + Ir > \varepsilon$
8. Potentiometer measures true EMF; voltmeter gives V

"Physics becomes easy when concepts become visual."

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