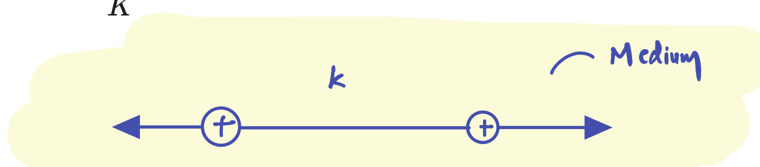
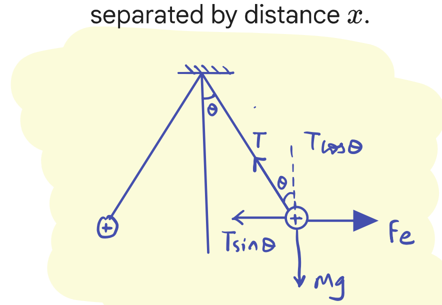
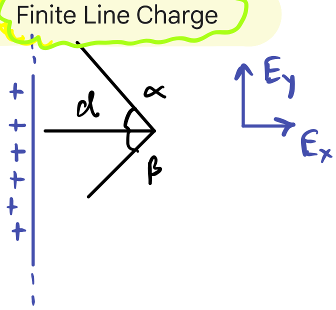
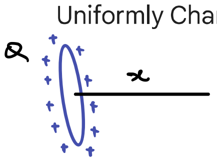
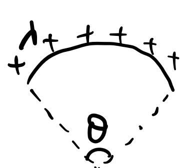
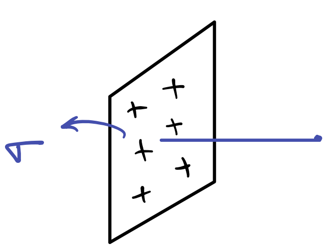
Very Important

Electrostatics

BY AP Sir, Sakaar Classes

Formula Name / Topic	Formula	Conditions / Remarks
1. Coulomb's Law		
Force between two point charges	$F = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{r^2}$	Valid for **point charges** at rest in vacuum/air.
Force in a medium	$F_m = \frac{F_{air}}{K}$	K (or ϵ_r) is the dielectric constant of the medium.
	or 	
	$F_m = \frac{1}{4\pi\epsilon_0 K}\frac{q_1 q_2}{r^2}$	
Vector Form	$\vec{F}_{12} = \frac{k q_1 q_2}{r^3}\vec{r}_{21}$	Force on q_1 due to q_2. Direction is along the line joining them.
Specific Question Case: Equilibrium of suspended charges	$T\sin\theta = F_e$ $T\cos\theta = mg$ $\tan\theta = \frac{F_e}{mg} = \frac{kq^2}{x^2 mg}$	Two identical pith balls suspended by strings of length l, separated by distance x. 
Specific Question Case: Immersion in liquid	$K = \frac{\rho_{ball}}{\rho_{ball} - \rho_{liquid}}$	Condition: Angle of divergence θ remains unchanged when immersed in liquid.

2. Electric Field (E)

Point Charge 	$E = \frac{1}{4\pi\epsilon_0}\frac{Q}{r^2}$	Field at distance r from source charge Q.
Null Point (Two like charges) 	$x = \frac{r}{\sqrt{q_2/q_1}+1}$	Distance x from smaller charge q_1 (where $q_2 > q_1$).
Null Point (Two unlike charges) 	$x = \frac{r}{\sqrt{q_2/q_1}-1}$	Distance x from smaller charge q_1 (outside the line segment).
Finite Line Charge 	$E_x = \frac{k\lambda}{d}(\sin\alpha + \sin\beta)$ $E_y = \frac{k\lambda}{d}(\cos\beta - \cos\alpha)$	d = perpendicular distance. α, β = angles subtended by ends at the point.
Infinite Line Charge	$E = \frac{2k\lambda}{r} = \frac{\lambda}{2\pi\epsilon_0 r}$	Long wire ($\alpha = \beta = 90^\circ$).
Semi-Infinite Line Charge	$E_{net} = \frac{\sqrt{2}k\lambda}{d}$	At one end of the wire ($\alpha = 90^\circ, \beta = 0^\circ$). Angle with normal is 45°.
Uniformly Charged Ring 	$E_{axis} = \frac{kQx}{(R^2+x^2)^{3/2}}$	At distance x on the axis.
Max Field on Ring Axis	$E_{max} = \frac{2kQ}{3\sqrt{3}R^2}$	Condition: At $x = \pm\frac{R}{\sqrt{2}}$.
Charged Arc 	$E = \frac{2k\lambda}{R}\sin(\frac{\theta}{2})$	At the center of curvature. θ is the angle subtended by the arc.
Infinite Plane Sheet 	$E = \frac{\sigma}{2\epsilon_0}$	Independent of distance (for non-conducting sheet).

Conducting Plate Surface

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

Near the surface of a charged conductor.

3. Electric Potential (V)

Point Charge

Main

$$V = \frac{kQ}{r}$$

Scalar quantity.

Relation between E and V

$$E = -\frac{dV}{dr}$$

E flows from Higher Potential to Lower Potential.

Take partial derivative to find E_x E_y E_z

or

Pot. Diff (ΔV)

$$\Delta V = -\int_{r_1}^{r_2} \vec{E} \cdot d\vec{r}$$

Potential Difference

$$V_B - V_A = \frac{W_{ext}(A \to B)}{q_0}$$

Work done by external agent against electrostatic force.

Charged Ring

$$V_{axis} = \frac{kQ}{\sqrt{R^2 + x^2}}$$

At distance x on the axis.

Not Zero at Centre याद रखो.

Concentric Shells (Inner r_1, Outer r_2)

$$V_{center} = \frac{Q_1}{4\pi\epsilon_0 r_1} + \frac{Q_2}{4\pi\epsilon_0 r_2}$$

Potential at the common center.

4. Spheres (Conducting vs Non-Conducting)

Conducting Sphere / Shell

Outside ($r > R$):

$$E = \frac{kQ}{r^2}$$

,

$$V = \frac{kQ}{r}$$

Charge resides only on the surface.

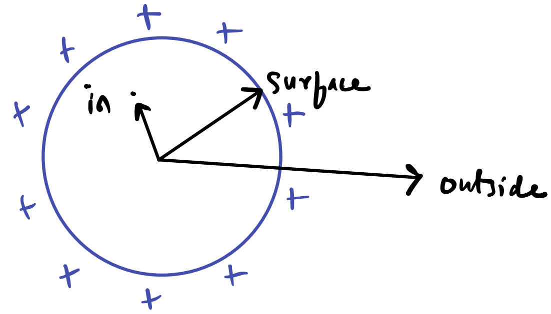
Same as point charge

Surface ($r = R$):

$$E = \frac{kQ}{R^2}$$

,

$$V = \frac{kQ}{R}$$



Inside ($r < R$):

$$E = 0$$

,

$$V = \frac{kQ}{R}$$

(Constant)

Non-Conducting Solid Sphere

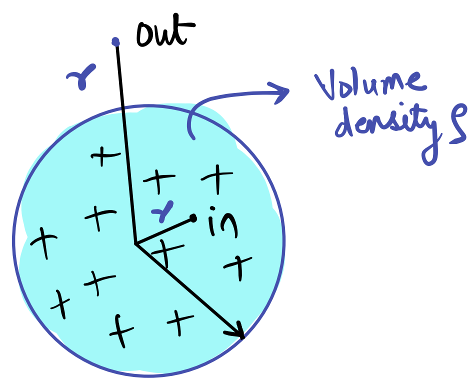
Outside ($r > R$): Same as conducting.

Charge is distributed uniformly throughout the volume.

Inside ($r < R$):

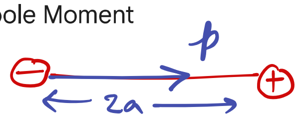
$$E = \frac{kQr}{R^3} = \frac{\rho r}{3\epsilon_0}$$

$$V = \frac{kQ}{2R^3}(3R^2 - r^2)$$



5. Electric Dipole

Dipole Moment



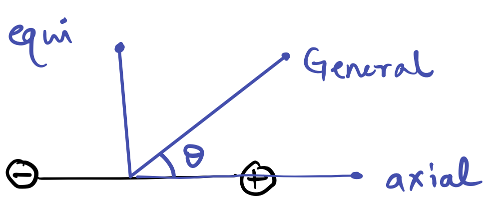
$$\vec{p} = q(2\vec{a})$$

Direction: Negative ($-q$) to Positive ($+q$).

Field on Axial Line

$$E_{axial} \approx \frac{2kp}{r^3}$$

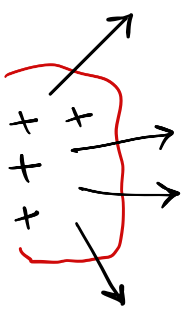
For $r \gg 2a$. Direction along $\vec{p}$.



Field on Equatorial Line	$E_{eq} \approx \frac{kp}{r^3}$	For $r \gg 2a$. Direction opposite to $\vec{p}$.
Field at General Point	$E = \frac{kp}{r^3}\sqrt{1 + 3\cos^2\theta}$	θ is angle between $\vec{r}$ and $\vec{p}$. Angle with radius vector $\tan\alpha = \frac{1}{2}\tan\theta$.
Torque on Dipole	$\vec{\tau} = \vec{p} \times \vec{E} = pE\sin\theta$	Rotational effect in uniform field.
Potential Energy	$U = -\vec{p} \cdot \vec{E} = -pE\cos\theta$	Stable equilibrium at $\theta = 0^\circ$ ($U_{min} = -pE$). Unstable at $\theta = 180^\circ$.
Work Done in Rotation	$W = pE(\cos\theta_1 - \cos\theta_2)$	Work to rotate from θ_1 to θ_2.
Dipole Oscillation (SHM)	$T = 2\pi\sqrt{\frac{I}{pE}}$	For small angular displacement ($\sin\theta \approx \theta$). I = Moment of Inertia.

Imp!

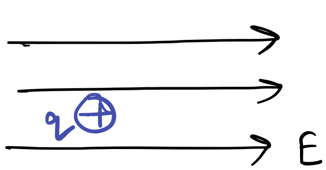
6. Flux and Gauss's Law



Electric Flux	$\phi = \oint \vec{E} \cdot d\vec{A} = \frac{q_{in}}{\epsilon_0}$	q_{in} is the net charge enclosed.
Cube Cases (Charge q)	**Center:** $\phi_{total} = q/\epsilon_0$, $\phi_{face} = q/6\epsilon_0$	Based on symmetry and contribution to the closed Gaussian surface.
	Face Center: $\phi_{total} = q/2\epsilon_0$	
	Corner: $\phi_{total} = q/8\epsilon_0$	

7. Motion of Charged Particle

Acceleration	$a = \frac{qE}{m}$	In uniform Electric field.



Kinetic Energy gained

$$K = qV$$

Particle accelerated through potential difference V.

Trajectory in E-field

$$y = \frac{qE}{2mu^2}x^2$$

Parabolic path (similar to projectile).

Specific Question Case:
Soap Bubble

$$P_{excess} = P_{in} - P_{out} = \frac{4T}{r} - \frac{\sigma^2}{2\epsilon_0}$$

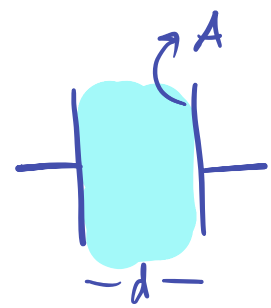
When charged, the bubble expands because electrostatic pressure acts outwards.

Closest Distance of Approach

$$r_0 = \frac{1}{4\pi\epsilon_0}\frac{2Ze^2}{K_{initial}}$$

Alpha particle scattering ($K_{initial} = \frac{1}{2}mv^2$).

8. Capacitance



Parallel Plate Capacitor

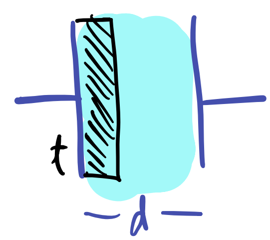
$$C = \frac{\epsilon_0 A}{d}$$

Air filled.

With Dielectric Slab

$$C = \frac{\epsilon_0 A}{d - t + t/K}$$

Slab thickness $t < d$.



With Conducting Slab

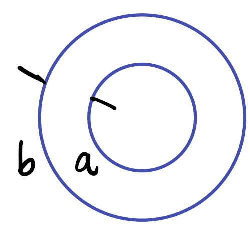
$$C = \frac{\epsilon_0 A}{d - t}$$

Metal slab thickness t.

Spherical Capacitor

$$C = 4\pi\epsilon_0 \left(\frac{ab}{b-a}\right)$$

Inner radius a, Outer radius b (Outer earthed).



Isolated Sphere

$$C = 4\pi\epsilon_0 R$$

Earth can be considered a sphere of $C \approx 711\mu F$.

Energy Stored

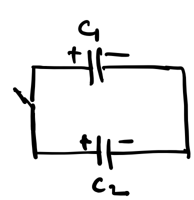
$$U = \frac{1}{2}CV^2 = \frac{Q^2}{2C} = \frac{1}{2}QV$$

Energy density $u = \frac{1}{2}\epsilon_0 E^2$.

Common Potential

$$V_{common} = \frac{C_1 V_1 + C_2 V_2}{C_1 + C_2}$$

When two charged capacitors are connected in parallel.



Heat Loss (Redistribution)

$$\Delta H = \frac{C_1 C_2}{2(C_1 + C_2)}(V_1 - V_2)^2$$

Always positive (Energy is lost).

Specific Question Case:
Dielectric Insertion
(Battery Connected)

$$C' = KC$$

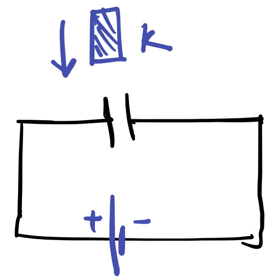
$$Q' = KQ$$

$$V' = V$$

(Constant)

$$U' = KU$$

Battery maintains Potential V.



Specific Question Case:
Dielectric Insertion
(Battery Disconnected)

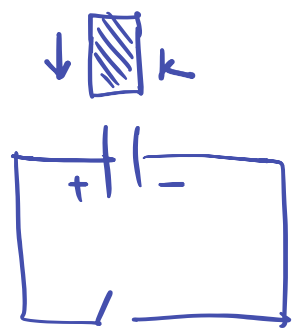
$$C' = KC$$

$$Q' = Q$$

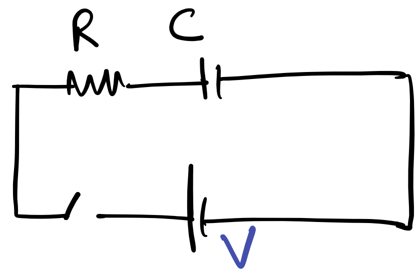
(Constant)

$$V' = V/K$$

Conservation of Charge applies.



RC Circuits



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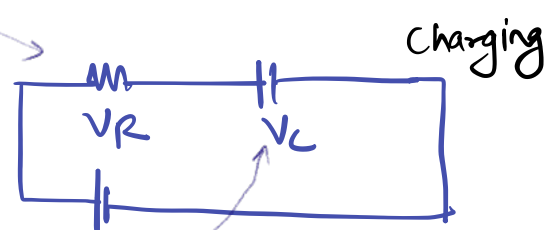
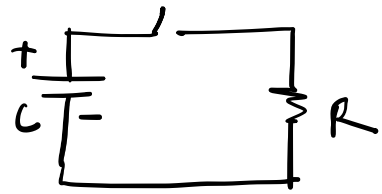
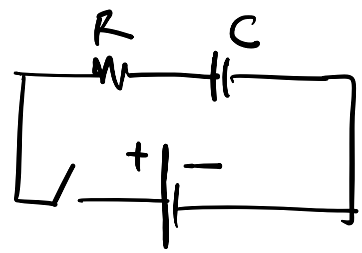
This sheet covers the transient analysis (charging/discharging), steady-state analysis, and energy concepts required for NEET and JEE.

Topic / Formula Name	Formula(e)	Conditions & Usage
1. Time Constant (τ)	$\tau = R_{eq}C_{eq}$	The time required for the charge to grow to 63.2% of its max value (charging) or decay to 36.8% (discharging). Units: Seconds.
2. Charging: Charge vs Time	$q(t) = q_0\left(1 - e^{-t/\tau}\right)$ $q_0 = C\varepsilon$	Used when a completely uncharged capacitor is connected to a battery of EMF ε through a resistor R at $t = 0$.
3. Charging: Current vs Time	$i(t) = i_0 e^{-t/\tau}$ $i_0 = \dfrac{\varepsilon}{R}$	The current decreases exponentially with time. i_0 is the maximum current at the instant the switch is closed ($t = 0$).
4. Potential Drop (Charging)	Across Resistor: $V_R = \varepsilon e^{-t/\tau}$ Across Capacitor: $V_C = \varepsilon(1 - e^{-t/\tau})$	Note that $V_R + V_C = \varepsilon$ at any instant t.
5. Discharging: Charge vs Time	$q(t) = q_i e^{-t/\tau}$	Used when a capacitor with initial charge q_i is discharged through a resistor (Battery removed).



6. Discharging: Current vs Time	$$i(t) = i_0 e^{-t/\tau}$$ $$i_0 = \frac{q_i}{RC}$$	Current flows in the **opposite direction** compared to charging. 
7. Behavior at $t = 0$ (Initial State)	**Replace Capacitor with a plain wire** (Short Circuit).	Valid for uncharged capacitors. At $t = 0$, the capacitor offers zero resistance to current flow.
8. Behavior at $t = \infty$ (Steady State)	**Replace Capacitor with an open switch** (Broken wire).	After a long time, the capacitor is fully charged, and no current flows through the branch containing the capacitor.
9. Work & Energy (Charging)	Work by Battery: $$W_b = q_0\varepsilon = C\varepsilon^2$$ Energy Stored in C: $$U = \frac{1}{2}C\varepsilon^2$$ Heat Dissipated: $$H = \frac{1}{2}C\varepsilon^2$$	Valid for a full charging cycle (0 to ∞). Note: Only 50% of battery work is stored; the rest is lost as heat in the resistor. 
10. General Heat Loss Formula	$$H = \text{Work}_{\text{battery}} - \Delta U_{\text{stored}}$$	**The Golden Rule for JEE/NEET:** Use this for ANY circuit change. $\Delta U = U_f - U_i$.
11. τ in Complex Circuits	$$\tau = R_{th} \times C$$	To find time constant in complex grids: 1. Short-circuit all batteries (replace with wire). 2. Find equivalent Resistance (R_{th}) across the two terminals where C is connected.

12. Specific Time Intervals (Shortcuts)	$$t_{50\%} \approx 0.693\tau$$ (Half Life)	1. Time to reach 50% charge (or drop to 50%).
	$$t_{90\%} \approx 2.3\tau$$	2. Time to reach 90% charge.
	$$t_{99\%} \approx 4.6\tau$$	3. Time usually considered "fully charged" in engineering.
13. Redistribution of Charge	Common Potential: $$V = \frac{C_1V_1 + C_2V_2}{C_1 + C_2}$$ Heat Loss: $$\Delta H = \frac{C_1C_2}{2(C_1 + C_2)}(V_1 - V_2)^2$$	Used when two charged capacitors are connected parallel to each other (Positive plate to Positive plate).
14. Opposite Polarity Connection	Common Potential: $$V = \frac{C_1V_1 - C_2V_2}{C_1 + C_2}$$ Heat Loss: $$\Delta H = \frac{C_1C_2}{2(C_1 + C_2)}(V_1 + V_2)^2$$	Used when two charged capacitors are connected with **reverse** polarity (Positive to Negative).
15. Leakage Current	$$i = \frac{Q}{RC} = \frac{Q}{\rho\epsilon_0 K/C \cdot C} = \frac{Q\sigma}{K\epsilon_0}$$	Condition where a capacitor discharges through its own dielectric material (imperfect insulator). Resistance of dielectric $R = \frac{\rho d}{A}$.
16. LC Oscillations (Ideal)	Frequency: $$\omega = \frac{1}{\sqrt{LC}}$$	When a charged capacitor discharges through a pure inductor (Zero Resistance). Energy oscillates between Electric and Magnetic fields.

Max Current:

$$I_{max} = \omega Q_{max}$$

Note to Students:

- For **Steady State** questions (very common in exams), ignore the exponential formulae. Just redraw the circuit with the capacitor branch cut open.
- For **Transient** questions (asking for current *at* $t = 2s$), use the exponential formulae.

Current Electricity

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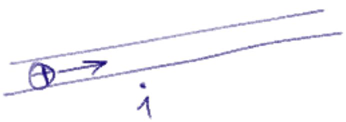
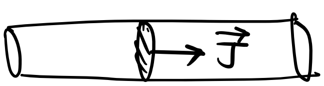
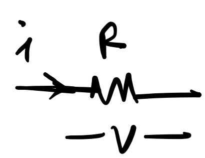
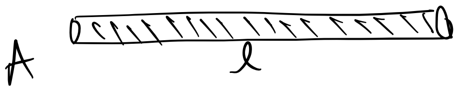
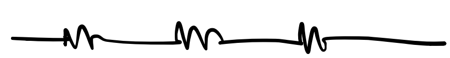
Topic / Formula Name	Formula(e)	Conditions / Context / Usage
1. Basic Current Definitions	$I_{avg} = \frac{\Delta q}{\Delta t}$	General definition of current.
	$I_{inst} = \frac{dq}{dt}$	If current is a function of time.
	$I = \frac{ne}{t}$	Quantization of charge ($q = ne$).
Frequency/Rotational Current	$I = q \cdot f = \frac{q}{T} = \frac{q\omega}{2\pi}$	Current due to a charge q moving in a circle with frequency f.
Current Density	$J = \frac{I}{A}$	Current per unit area (Vector quantity).
	$\vec{J} = nq\vec{v}_d$	Direction is along Electric Field.
2. Drift Velocity	$\vec{v}_d = -\frac{e\vec{E}}{m}\tau$	τ = Relaxation time.
	$v_d = \frac{I}{nAe}$	Relation between Current (I) and Drift Velocity (v_d).
Mobility (μ)	$\mu = \frac{v_d}{E} = \frac{e\tau}{m}$	Ability of charge carriers to move.
3. Ohm's Law	$V = IR$	Scalar form. 

	$$\vec{J} = \sigma \vec{E}$$	**Vector form** (Microscopic view). σ = Conductivity.
Resistance	$$R = \rho \frac{L}{A}$$	ρ = Resistivity (Specific Resistance). Depends only on material and temp.



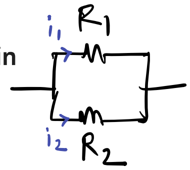
Resistance (Stretching Wire)	$$R' = n^2 R$$	If a wire is stretched to n times its original length. (Volume constant).
Resistance (Compressing)	$$R' = \frac{R}{n^2}$$	If wire radius increases n times (or area increases n^2 times).
Percentage Change (Small)	$$\frac{\Delta R}{R}\% = 2\frac{\Delta L}{L}\%$$	Valid only for very small changes in length ($< 5\%$).
Temperature Dependence	$$R_T = R_0(1 + \alpha \Delta T)$$	R_0 at reference temp, R_T at temp T.
		α = Temp coefficient of resistance.
	$$\rho_T = \rho_0(1 + \alpha \Delta T)$$	
4. Colour Code	$$R = AB \times 10^C \pm D\%$$	**BBROYGBVGW** (Black 0, Brown 1... White 9).
		Tolerance (D): Gold $\pm 5\%$, Silver $\pm 10\%$.
5. Combination of Resistors	$$R_{eq} = R_1 + R_2 + ...$$	**Series Combination**. Current is same, Voltage divides.



	$$V \propto R$$	
	$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + ...$$	**Parallel Combination**. Voltage is same, Current divides.

$$I \propto \frac{1}{R}$$

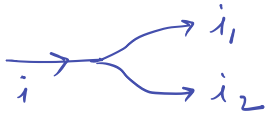
Two Resistors in Parallel



$$R_{eq} = \frac{R_1 R_2}{R_1 + R_2}$$

Specific shortcut for two resistors.

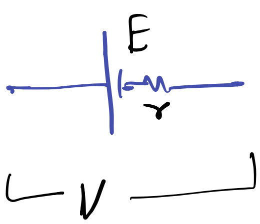
Current Divider Rule



$$I_1 = I\left(\frac{R_2}{R_1 + R_2}\right)$$

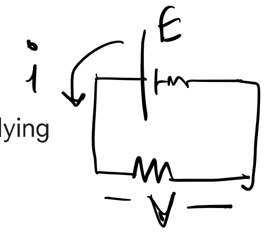
For two resistors in parallel, finding current in branch 1.

6. EMF and Terminal Voltage



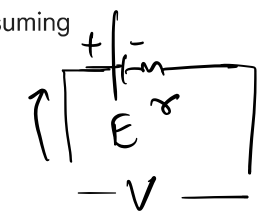
$$V = E - Ir$$

Discharging (Battery supplying energy). $V < E$.



$$V = E + Ir$$

Charging (Battery consuming energy). $V > E$.



$$V = E$$

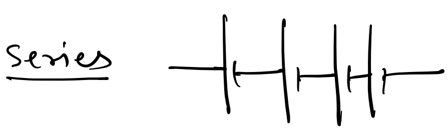
Open Circuit ($I = 0$).

Internal Resistance (r)

$$r = \left(\frac{E - V}{V}\right) R$$

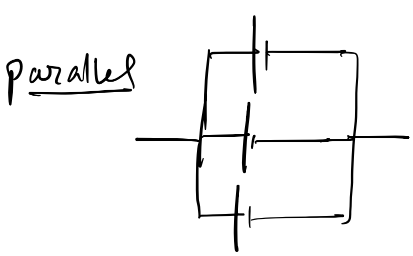
Using voltmeter and external resistance R.

7. Grouping of Cells



$$I = \frac{nE}{R + nr}$$

Series Grouping (n identical cells). Max current when $R \gg nr$.



$$I = \frac{E}{R + r/m} = \frac{mE}{mR + r}$$

Parallel Grouping (m identical cells). Max current when $r/m \gg R$.

$$I = \frac{mnE}{mR + nr}$$

Mixed Grouping (n in series, m rows).

Max Power Transfer (Mixed)

$$R = \frac{nr}{m}$$

Condition for maximum current/power in mixed grouping. External R = Total Internal r.

Parallel Cells (Different EMF)

$$E_{eq} = \frac{\frac{E_1}{r_1} + \frac{E_2}{r_2}}{\frac{1}{r_1} + \frac{1}{r_2}}$$

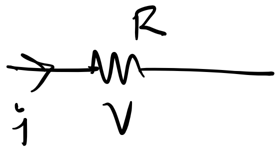
Two cells with different EMF and internal resistance connected in parallel.

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

8. Electrical Power & Energy

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

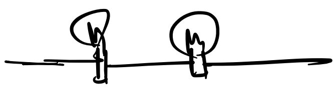
Power dissipated.



Joule's Heating Effect.

$$H = I^2 Rt$$

Bulbs in Series



$$P_{total} = \frac{P_1 P_2}{P_1 + P_2}$$

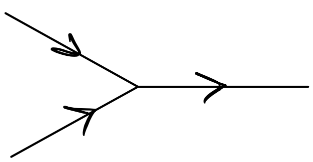
Brightness $\propto P_{consumed} \propto R$. (Low power bulb glows brighter).

Bulbs in Parallel

$$P_{total} = P_1 + P_2$$

Brightness $\propto P_{rated}$. (High power bulb glows brighter).

9. Kirchhoff's Laws



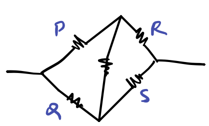
$$\sum I_{in} = \sum I_{out}$$

KCL (Junction Rule). Conservation of Charge.

$$\sum \Delta V = 0$$

KVL (Loop Rule). Conservation of Energy.

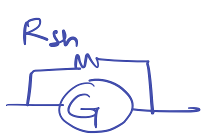
10. Wheatstone Bridge



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

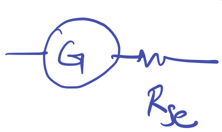
Balanced Condition ($I_g = 0$). Galvanometer shows no deflection.

11. Measuring Instruments



$$S = G\left(\frac{I_g}{I - I_g}\right)$$

Ammeter conversion. S (Shunt) connected in parallel to Galvanometer.



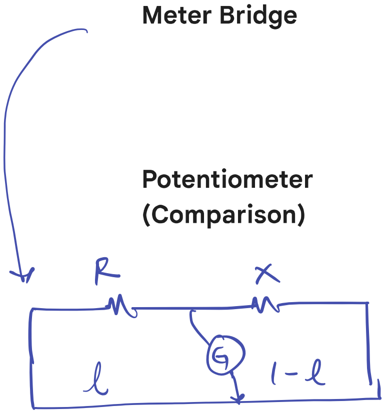
$$R = \frac{V}{I_g} - G$$

Voltmeter conversion. R (High multiplier) connected in series with Galvanometer.

Meter Bridge

$$X = R\left(\frac{100 - l}{l}\right)$$

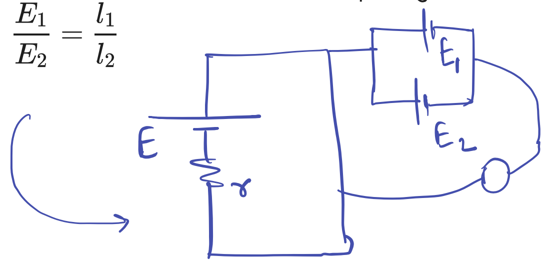
Application of Balanced Wheatstone bridge. X is unknown.



Potentiometer (Comparison)

$$\frac{E_1}{E_2} = \frac{l_1}{l_2}$$

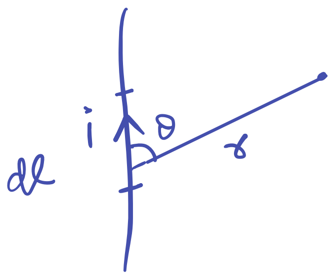
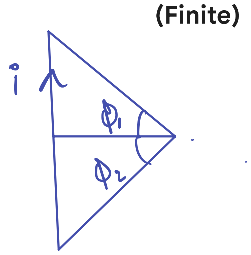
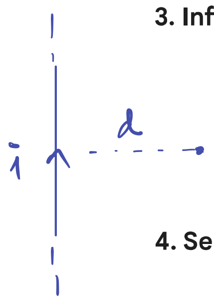
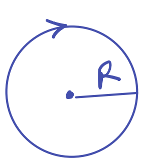
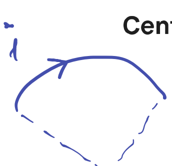
Comparing EMF of two cells.



Potentiometer (Internal r)	$$r = R\left(\frac{l_1}{l_2} - 1\right)$$	l_1 = balancing length for open circuit. l_2 = balancing length when closed with R.
12. Special / Tricky Cases		**Shortcuts for Symmetry & Geometry**
Skeleton Cube Resistance	$$R_{edge} = \frac{7}{12}R$$	Across the **Edge** (Side) of a cube. (Mnemonic: 1-2 edge ends with 12).
	$$R_{face} = \frac{3}{4}R$$	Across **Face Diagonal**. (Mnemonic: 3-4).
	$$R_{body} = \frac{5}{6}R$$	Across **Body Diagonal**. (Mnemonic: 5-6).
Infinite Ladder (Same R)	$$R_{eq} = \frac{R}{2}(1 + \sqrt{5})$$	Series-Parallel repeating units of R. (Golden Ratio).
Symmetry Rule (Mirror)	If circuit is symmetric perpendicular to current flow.	Points on the axis of symmetry are equipotential. Remove connections between them.
Symmetry Rule (Folding)	If circuit is symmetric along the current flow.	Fold the circuit. Overlapping potentials are equal. Parallel resistors can be merged.

Magnetic Effects of Current

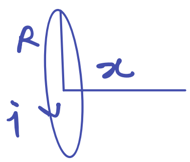
BY AP Sir, Sakaar Classes

Formula Name / Topic	Formula(e)	Conditions / Specific Cases
1. Biot-Savart Law	$d\vec{B} = \frac{\mu_0}{4\pi}\frac{I(d\vec{l}\times\vec{r})}{r^3}$	• Used for small current element $Id\vec{l}$.
	$\lvert d\vec{B}\rvert = \frac{\mu_0}{4\pi}\frac{Idl\sin\theta}{r^2}$	• θ is angle between current element and position vector $\vec{r}$.
		• $\mu_0 = 4\pi \times 10^{-7}\,\mathrm{T\cdot m/A}$.
2. Magnetic Field due to Straight Wire (Finite)	$B = \frac{\mu_0 I}{4\pi d}(\sin\phi_1 + \sin\phi_2)$	• d: Perpendicular distance from wire to point P.
		• ϕ_1, ϕ_2: Angles subtended by ends at point P (measured from the perpendicular).
3. Infinite Straight Wire	$B = \frac{\mu_0 I}{2\pi d}$	• Condition: $\phi_1 = \phi_2 = 90^\circ$.
		• Very long wire relative to distance d.
4. Semi-Infinite Wire	$B = \frac{\mu_0 I}{4\pi d}$	• One end at infinity, point P opposite to the other end ($\phi_1 = 90^\circ, \phi_2 = 0^\circ$).
5. Point on Axis of Straight Wire	$B = 0$	• $d\vec{l}$ and $\vec{r}$ are parallel or anti-parallel ($\theta = 0^\circ$ or 180°).
6. Circular Loop (At Center)	$B = \frac{\mu_0 NI}{2R}$	• N: Number of turns.
		• R: Radius of loop.
7. Circular Arc (At Center)	$B = \frac{\mu_0 I}{4\pi R}\theta$	• θ must be in **Radians**.
		

- For semi-circle: $\theta = \pi \Rightarrow B = \frac{\mu_0 I}{4R}$.
- For quadrant: $\theta = \pi/2 \Rightarrow B = \frac{\mu_0 I}{8R}$.

8. On the Axis of Circular Loop

$$B = \frac{\mu_0 N I R^2}{2(R^2+x^2)^{3/2}}$$



- x: Distance from center along the axis.
- Direction is along the axis (Right Hand Thumb Rule).

9. Axis of Loop (Far Point)

$$B \approx \frac{\mu_0 N I R^2}{2x^3} = \frac{\mu_0}{4\pi}\frac{2M}{x^3}$$

- Condition: $x \gg R$.
- Behaves like a magnetic dipole.

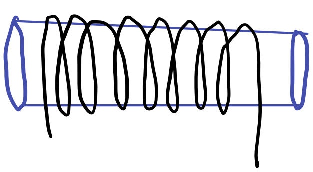
10. Ampere's Circuital Law

$$\oint \vec{B} \cdot d\vec{l} = \mu_0 I_{enclosed}$$

- Line integral over a closed loop.
- $I_{enclosed}$ is net current piercing the loop surface.

11. Solenoid (Ideal/Long)

$$B = \mu_0 n I$$



- Inside the solenoid (near center).
- $n = N/L$ (turns per unit length).
- Field outside is approx 0.

12. Solenoid (Finite Length)

$$B = \frac{\mu_0 n I}{2}(\cos\theta_1 - \cos\theta_2)$$

- θ_1, θ_2 are angles subtended by ends at the point on axis.

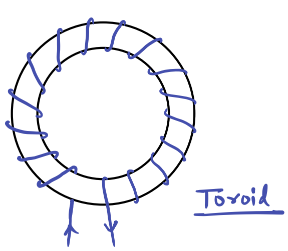
13. Solenoid (At Ends)

$$B = \frac{\mu_0 n I}{2}$$

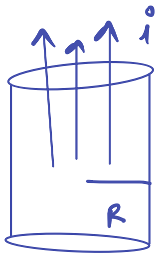
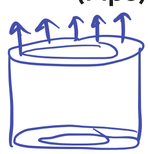
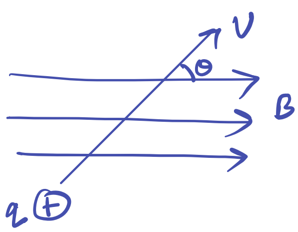
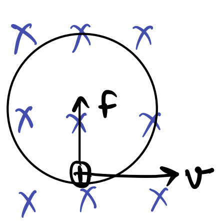
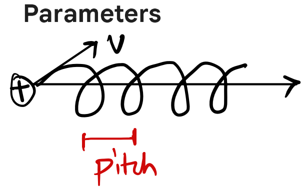
- For a very long solenoid, at the exact edge/end face.

14. Toroid

$$B = \mu_0 n I$$



- $n = \frac{N}{2\pi r}$ (turns per unit length of mean circumference).
- $B = 0$ outside the toroid and in the empty space inside.

15. Solid Cylinder (Thick Wire)	**Outside ($r > R$):** $B = \frac{\mu_0 I}{2\pi r}$	• Current is uniformly distributed over cross-section.
	**Surface ($r = R$):** $B = \frac{\mu_0 I}{2\pi R}$	• Inside field $\propto r$.
	Inside ($r < R$): $B = \frac{\mu_0 I r}{2\pi R^2}$	• Outside field $\propto 1/r$.
16. Hollow Cylinder (Pipe)	**Inside ($r < R$):** $B = 0$	• No current inside the hollow region.
	**Outside ($r > R$):** $B = \frac{\mu_0 I}{2\pi r}$	
17. Magnetic Force on Moving Charge (Lorentz Force)	$\vec{F}_m = q(\vec{v} \times \vec{B})$	• Force is perpendicular to both velocity $\vec{v}$ and field $\vec{B}$.
	$F = qvB \sin\theta$	• If $v \parallel B$, Force = 0.
		• Work done by magnetic force is always **Zero**.
18. Motion in Uniform B-Field (Path)	1. $\theta = 0^\circ, 180^\circ$: **Straight Line**	• Speed v remains constant (Kinetic Energy constant).
	2. $\theta = 90^\circ$: **Circular Path**	
	3. Other θ: **Helical Path**	
19. Circular Motion Parameters	**Radius:** $r = \frac{mv}{qB} = \frac{p}{qB} = \frac{\sqrt{2mK}}{qB}$	• p: Momentum.
		• K: Kinetic Energy.
	**Time Period:** $T = \frac{2\pi m}{qB}$	
		• T and f are independent of speed v and radius r.
	Frequency: $f = \frac{qB}{2\pi m}$	
20. Helical Motion Parameters	**Radius:** $r = \frac{mv_\perp}{qB} = \frac{mv \sin\theta}{qB}$	• $v_\perp$ component responsible for circle.
		

Pitch:
$P = v_{\parallel} \times T = (v \cos\theta)\frac{2\pi m}{qB}$

• $v_{\parallel}$ component moves particle along the axis.

21. Velocity Selector

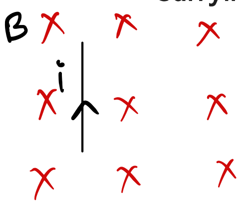
$v = \frac{E}{B}$

• Condition for charge to pass undeflected through crossed $\vec{E}$ and $\vec{B}$ fields ($F_{net} = 0$).

22. Force on Current Carrying Wire

$\vec{F} = I(\vec{l} \times \vec{B})$

• $\vec{l}$ is vector along current direction.



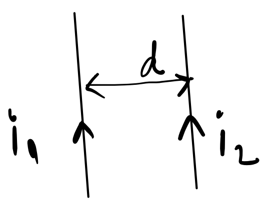
$F = IlB \sin\theta$

• For arbitrary shape in uniform field, $\vec{l}$ is vector from start to end point.

23. Force Between Parallel Wires

$F/l = \frac{\mu_0 I_1 I_2}{2\pi d}$

• Force per unit length.



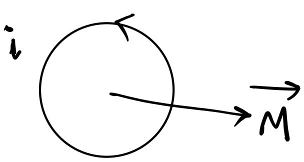
• **Attraction:** Currents in same direction.

• **Repulsion:** Currents in opposite directions.

24. Magnetic Dipole Moment (M)

$\vec{M} = NI\vec{A}$

• Direction given by Right Hand Rule (curl fingers with I, thumb gives $\vec{M}$).

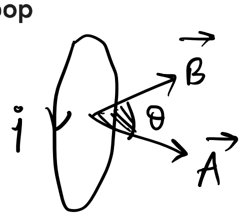


• For revolving electron:
$M = \frac{evr}{2} = \frac{e}{2m}L$.

25. Torque on Current Loop

$\vec{\tau} = \vec{M} \times \vec{B} = NI\vec{A} \times \vec{B}$

• θ is angle between **Area Vector** (normal to plane) and $\vec{B}$.



$\tau = MB \sin\theta$

• If coil plane is parallel to field, $\theta = 90^\circ$ (Max Torque).

26. Potential Energy of Dipole

$U = -\vec{M} \cdot \vec{B} = -MB\cos\theta$

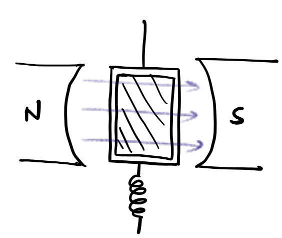
• Stable Equilibrium: $\theta = 0^\circ$ ($U_{min} = -MB$).

• Unstable Equilibrium: $\theta = 180^\circ$ ($U_{max} = +MB$).

27. Moving Coil Galvanometer

$I = \left(\frac{k}{NBA}\right)\phi$

• ϕ: Angle of twist/deflection.



• k: Torsional constant of spring.

• Radial magnetic field ensures linear scale (τ is independent of θ).

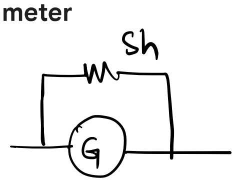
28. Sensitivities

Current: $S_i = \frac{\phi}{I} = \frac{NBA}{k}$

Voltage: $S_v = \frac{\phi}{V} = \frac{NBA}{kR_g}$

• To increase sensitivity: Increase N, B, A or decrease k.

29. Conversion: Galv to Ammeter



$S = \frac{I_g R_g}{I - I_g}$

• Shunt S connected in **Parallel**.

• I: Range of Ammeter required.

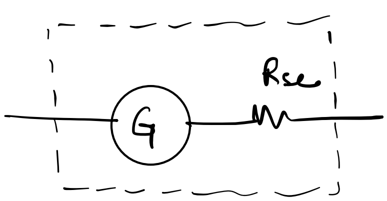
• $R_A \approx S$ (very low).

30. Conversion: Galv to Voltmeter

$R = \frac{V}{I_g} - R_g$

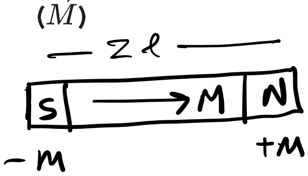
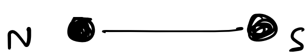
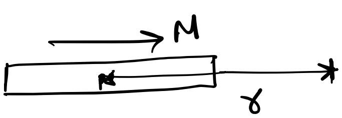
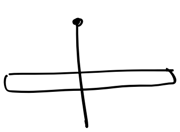
• Resistance R connected in **Series**.

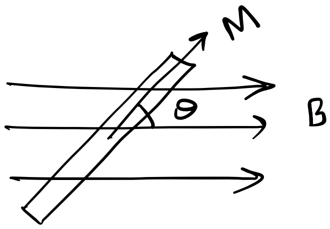
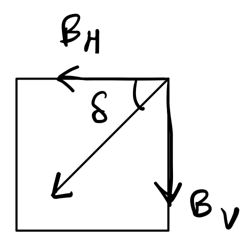
• V: Range of Voltmeter required.



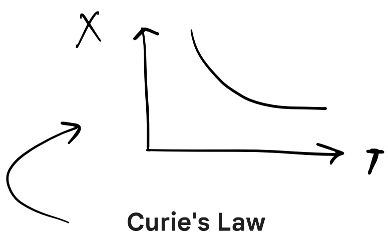
Magnetism and Matter

BY AP Sir, Sakaar Classes

Formula Name / Topic	Formula(e)	Conditions / Specific Use Cases
Magnetic Moment ($\vec{M}$)	$\vec{M} = m \cdot 2\vec{l}$	$\vec{M}$ is a vector from South pole to North pole.
		m = pole strength, $2l$ = magnetic length.
Coulomb's Law in Magnetism	$F = \frac{\mu_0}{4\pi} \frac{m_1 m_2}{r^2}$	Force between two isolated magnetic poles (theoretical). $\mu_0 = 4\pi \times 10^{-7} T \cdot m/A.$
		
Magnetic Field of a Monopole	$B = \frac{\mu_0}{4\pi} \frac{m}{r^2}$	Field at distance r from a single pole of strength m.
Field on Axial Line	$B_{axial} = \frac{\mu_0}{4\pi} \frac{2Mr}{(r^2 - l^2)^2}$	"End-on" position.
		Direction of $\vec{B}$ is along $\vec{M}$.
Field on Axial Line (Short Dipole)	$B_{axial} \approx \frac{\mu_0}{4\pi} \frac{2M}{r^3}$	Used when $r \gg l$ (Standard approximation for most questions).
Field on Equatorial Line	$B_{eq} = \frac{\mu_0}{4\pi} \frac{M}{(r^2 + l^2)^{3/2}}$	"Broad-side on" position.
		Direction of $\vec{B}$ is opposite to $\vec{M}$.
Field on Equatorial Line (Short Dipole)	$B_{eq} \approx \frac{\mu_0}{4\pi} \frac{M}{r^3}$	Used when $r \gg l$. Note that $B_{axial} = 2B_{eq}$ for same distance.
Field at General Point	$B = \frac{\mu_0}{4\pi} \frac{M}{r^3} \sqrt{3\cos^2\theta + 1}$	Short dipole. θ is the angle between $\vec{M}$ and position vector $\vec{r}$.
Direction at General Point	$\tan\alpha = \frac{1}{2}\tan\theta$	α is the angle the magnetic field vector $\vec{B}$ makes with the position vector $\vec{r}$.

Torque on Magnetic Dipole	$\vec{\tau} = \vec{M} \times \vec{B}$	Dipole in a uniform magnetic field.
	$\tau = MB \sin\theta$	Max torque at $\theta = 90^\circ$.
Potential Energy (U)	$U = -\vec{M} \cdot \vec{B} = -MB\cos\theta$	Ref (Zero PE) at $\theta = 90^\circ$.
		Stable Equilibrium: $\theta = 0^\circ$ ($U = -MB$).
		Unstable Equilibrium: $\theta = 180^\circ$ ($U = +MB$).
Work Done in Rotation	$W = \Delta U = MB(\cos\theta_1 - \cos\theta_2)$	Work done by external agent to rotate dipole from angle θ_1 to θ_2 in uniform field.
Gauss's Law for Magnetism	$\oint \vec{B} \cdot d\vec{S} = 0$	Net magnetic flux through any closed surface is zero. (Isolated magnetic monopoles do not exist).
Earth's Magnetic Elements	$B_H = B_{Earth} \cos\delta$	B_H: Horizontal Component. 
	$B_V = B_{Earth} \sin\delta$	B_V: Vertical Component.
		δ: Angle of Dip (Inclination).
Angle of Dip (δ)	$\tan\delta = \frac{B_V}{B_H}$	At Magnetic Equator, $\delta = 0^\circ$ ($B_V = 0$).
		At Magnetic Poles, $\delta = 90^\circ$ ($B_H = 0$).
Apparent Dip (δ')	$\tan\delta' = \frac{\tan\delta}{\cos\alpha}$	Used when the dip circle is in a plane at an angle α to the magnetic meridian.
Perpendicular Dip Planes	$\cot^2\delta = \cot^2\delta_1 + \cot^2\delta_2$	δ = True dip.
		δ_1, δ_2 are apparent dips in two mutually perpendicular vertical planes.

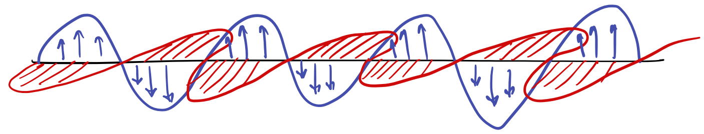
Magnetization ($\vec{M}$)	$M = \frac{m_{net}}{V}$	Net magnetic moment per unit volume. Unit: A/m.
Magnetic Intensity ($\vec{H}$)	$\vec{H} = \frac{\vec{B}}{\mu_0} - \vec{M}$	B is the total magnetic field inside the material. Unit: A/m.
Magnetic Susceptibility (χ)	$\chi = \frac{M}{H}$	Measures how easily a substance is magnetized. Dimensionless.
Permeability Relations	$\mu = \mu_0(1+\chi)$	μ_r is Relative Permeability.
	$\mu_r = 1 + \chi$	Diamagnetic: $\chi < 0$ (small), $\mu_r < 1$.
		Paramagnetic: $\chi > 0$ (small), $\mu_r > 1$.
		Ferromagnetic: $\chi \gg 0$ (large), $\mu_r \gg 1$.



Curie's Law	$\chi = \frac{C}{T}$ or $\chi T = \text{const}$	Only for Paramagnetic materials. C is Curie's constant.
Curie-Weiss Law	$\chi = \frac{C}{T - T_c}$	For Ferromagnetic materials above Curie Temperature ($T > T_c$).
Oscillation Magnetometer	$T = 2\pi\sqrt{\frac{I}{MB_H}}$	Time period of a bar magnet oscillating in Earth's field.
		I = Moment of Inertia.
Comparison of Moments	$\frac{M_1}{M_2} = \frac{T_2^2}{T_1^2}$	Comparing two magnets with same moment of inertia I.
Cutting a Magnet (Transverse)	$m' = m$, $L' = L/2$, $M' = M/2$	Cutting perpendicular to length. Pole strength remains same.
Cutting a Magnet (Longitudinal)	$m' = m/2$, $L' = L$, $M' = M/2$	Cutting along the length. Pole strength becomes half.
Sum and Difference Method	$\frac{M_1}{M_2} = \frac{T_2^2 + T_1^2}{T_2^2 - T_1^2}$	Vibration Magnetometer.
		T_1: Like poles together (Sum).

		T_2: Unlike poles together (Diff).
Tangent Galvanometer	$I = K \tan\theta$ $K = \frac{2RB_H}{\mu_0 N}$	K is the Reduction Factor. Used to measure current. Field at center $B = B_H \tan\theta$.
Deflection Magnetometer (Tan A)	$\frac{M}{B_H} = \frac{4\pi}{\mu_0}\frac{(d^2-l^2)^2}{2d}\tan\theta$	End-on position (Arms East-West).
Deflection Magnetometer (Tan B)	$\frac{M}{B_H} = \frac{4\pi}{\mu_0}(d^2+l^2)^{3/2}\tan\theta$	Broad-side position (Arms North-South).
Hysteresis Loss	$W = \text{Area of B-H Loop} \times V \times f$	Energy loss per second. $V = \text{Volume}$, $f = \text{frequency}$. Area unit is J/m^3.

EM Waves



BY AP Sir, Sakaar Classes

Formula Name / Topic	Formula	Condition / Context
1. Maxwell's Equations		
Gauss's Law (Electrostatics)	$\oint \mathbf{E} \cdot d\mathbf{A} = \frac{Q_{in}}{\epsilon_0}$	valid for closed surface (Gaussian surface). Relates electric flux to enclosed charge.
Gauss's Law (Magnetism)	$\oint \mathbf{B} \cdot d\mathbf{A} = 0$	Always true. Indicates magnetic monopoles do not exist; magnetic field lines are closed loops.
Faraday's Law (EMI)	$\oint \mathbf{E} \cdot d\mathbf{l} = -\frac{d\Phi_B}{dt}$	Relates induced electric field to the rate of change of magnetic flux.
Ampere-Maxwell Law	$\oint \mathbf{B} \cdot d\mathbf{l} = \mu_0 I_c + \mu_0 \epsilon_0 \frac{d\Phi_E}{dt}$	I_c is conduction current, $\frac{d\Phi_E}{dt}$ is related to displacement current. Valid for time-varying electric fields.
2. Displacement Current		
Displacement Current (I_d)	$I_d = \epsilon_0 \frac{d\Phi_E}{dt} = \epsilon_0 A \frac{dE}{dt}$	Used when Electric flux Φ_E varies with time (e.g., between capacitor plates during charging/discharging).
Total Current	$I = I_c + I_d$	Continuity requires I_c (in wire) = I_d (in gap) for a capacitor circuit.
3. Wave Properties		
Speed of Light (Vacuum)	$c = \frac{1}{\sqrt{\mu_0 \epsilon_0}} \approx 3 \times 10^8$ m/s	In free space/vacuum.
Speed of Light (Medium)	$v = \frac{1}{\sqrt{\mu \epsilon}} = \frac{c}{\sqrt{\mu_r \epsilon_r}} = \frac{c}{n}$	In a material medium with refractive index n.
Refractive Index (n)	$n = \sqrt{\mu_r \epsilon_r}$	Relation between optical and electromagnetic properties.

Relation between E and B	$\frac{E_0}{B_0} = c$ or $E = cB$	E and B are instantaneous values; E_0, B_0 are peak values. Magnitudes only.
Wave Equations	$E_y = E_0 \sin(kx - \omega t)$	Wave propagating in $+x$ direction. E along y, B along z.
	$B_z = B_0 \sin(kx - \omega t)$	
Angular Frequency (ω)	$\omega = 2\pi\nu = \frac{2\pi}{T}$	ν is frequency in Hz.
Propagation Constant (k)	$k = \frac{2\pi}{\lambda} = \frac{\omega}{c}$	Also called Wave Number.
Direction of Propagation	Direction of vector $\mathbf{E} \times \mathbf{B}$	The wave travels in the direction perpendicular to both E and B.
4. Energy Density		
Electric Energy Density (u_E)	$u_E = \frac{1}{2}\epsilon_0 E^2$	Instantaneous energy per unit volume due to Electric Field.
Magnetic Energy Density (u_B)	$u_B = \frac{1}{2\mu_0} B^2$	Instantaneous energy per unit volume due to Magnetic Field.
Average Total Energy Density (u_{avg})	$u_{avg} = \frac{1}{2}\epsilon_0 E_0^2 = \frac{B_0^2}{2\mu_0}$	**Important:** Contribution from E and B is equal ($u_{E,avg} = u_{B,avg}$).
5. Intensity & Momentum		
Intensity (I)	$I = u_{avg} \times c = \frac{1}{2}\epsilon_0 E_0^2 c$	Power per unit area (P/A). Energy crossing unit area per unit time.
Intensity in terms of B_0	$I = \frac{B_0^2 c}{2\mu_0}$	Alternative form using magnetic field amplitude.
Momentum (p)	$p = \frac{U}{c}$	Total momentum delivered when energy U is absorbed by a surface.
Poynting Vector ($\mathbf{S}$)	$\mathbf{S} = \frac{1}{\mu_0}(\mathbf{E} \times \mathbf{B})$	Magnitude represents Intensity ($

Specific Formulae for Specific Questions (Problem Solving)

Case / Question Type	Formula to Use	Context
Radiation Pressure (P_{rad})		
Perfectly Absorbing Surface	$P_{rad} = \frac{I}{c}$	Surface absorbs all radiation (e.g., black body). Momentum transfer $\Delta p = U/c$.
Perfectly Reflecting Surface	$P_{rad} = \frac{2I}{c}$	Surface reflects all radiation (e.g., mirror). Momentum transfer $\Delta p = 2U/c$.
Point Source Intensity	$I = \frac{P_{source}}{4\pi r^2}$	Calculates intensity at distance r from a bulb/source of power P.
Line Source Intensity	$I = \frac{P_{source}}{2\pi rL}$	Calculates intensity at distance r from a long line source (e.g., tube light) of length L.
RMS Values	$E_{rms} = \frac{E_0}{\sqrt{2}}, B_{rms} = \frac{B_0}{\sqrt{2}}$	Used when calculating heating effects or average power/intensity.
Force on a Surface	$F = P_{rad} \times A$	Force exerted by EM wave on area A. Substitute proper P_{rad} (absorbing/reflecting).
EM Spectrum (Wavelengths)	Radio > Micro > IR > Visible > UV > X-Ray > Gamma	**Radio:** > 0.1m **Visible:** 400nm - 700nm **Gamma:** $<10^{-3}$nm
Phase Difference	$\Delta\phi = 0$	Phase difference between Electric and Magnetic fields in an EM wave is **always zero**. They peak together.

Dual Nature of Radiation and Matter

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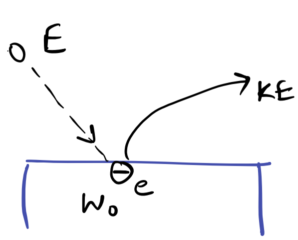
Formula / Topic Name	Formula	Conditions & Specific Use Cases
1. Energy of a Photon	$E = h\nu = \frac{hc}{\lambda}$	$h = 6.63 \times 10^{-34}$ J s
		$c = 3 \times 10^8$ m/s
		Shortcut: $E(\text{eV}) = \frac{12400}{\lambda(\mathring{A})} \approx \frac{1240}{\lambda(\text{nm})}$
2. Momentum of a Photon	$p = \frac{E}{c} = \frac{h\nu}{c} = \frac{h}{\lambda}$	Valid for photons (rest mass is zero). Used to relate wavelength and momentum.
3. Relativistic Mass of Photon	$m = \frac{E}{c^2} = \frac{h\nu}{c^2} = \frac{h}{c\lambda}$	Photon rest mass $m_0 = 0$. This is the "dynamic mass" or equivalent mass while moving.
4. Number of Photons Emitted	$n = \frac{E_{total}}{E_{one\_photon}} = \frac{P \times t}{h\nu} = \frac{P\lambda t}{hc}$	P = Power of source (Watts), t = time.
		Rate of emission (N): $N = \frac{P}{E}$.
5. Intensity of Radiation (I)	$I = \frac{\text{Energy}}{\text{Area} \times \text{time}} = \frac{P}{A} = \frac{nh\nu}{At}$	Assumes point source radiating uniformly.
		For a point source at distance r, $I \propto \frac{1}{r^2}$.
		For a line source, $I \propto \frac{1}{r}$.
6. Einstein's Photoelectric Eq.	$K_{max} = E - \phi_0$	Law of conservation of energy.
	$K_{max} = h\nu - h\nu_0$	Valid only if Incident Energy (E) > Work Function (ϕ_0).
	$K_{max} = \frac{hc}{\lambda} - \frac{hc}{\lambda_0}$	

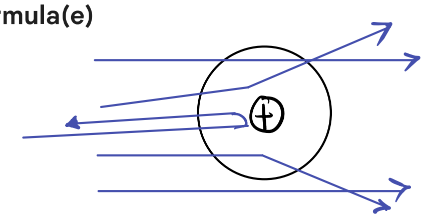
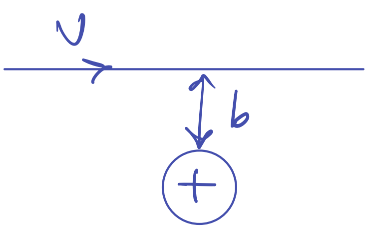
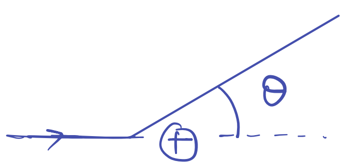
7. Work Function (ϕ_0)	$\phi_0 = h\nu_0 = \frac{hc}{\lambda_0}$	ν_0 = Threshold frequency λ_0 = Threshold wavelength. Constant for a specific metal surface.
8. Stopping Potential (V_s)	$eV_s = K_{max}$ $V_s = \frac{h}{e}\nu - \frac{\phi_0}{e}$	V_s is the negative potential required to stop the fastest electron. Independent of Intensity, depends on Frequency.
9. Slope of V_s vs ν Graph	$\text{Slope} = \frac{h}{e}$	The graph is a straight line not passing through origin. Intercept on V_s axis = $-\frac{\phi_0}{e}$. Universal constant slope for all metals.
10. Radiation Force/Pressure	**Perfectly Absorbing Surface:** $F = \frac{IA}{c} = \frac{P}{c}$, Pressure $= \frac{I}{c}$ **Perfectly Reflecting Surface:** $F = \frac{2IA}{c} = \frac{2P}{c}$, Pressure $= \frac{2I}{c}$	Normal incidence. If light hits at angle θ to normal: Absorbing: Pressure $= \frac{I}{c}\cos^2\theta$ Reflecting: Pressure $= \frac{2I}{c}\cos^2\theta$.
11. de Broglie Wavelength	$\lambda = \frac{h}{p} = \frac{h}{mv} = \frac{h}{\sqrt{2mK}}$	General formula for matter waves. K = Kinetic Energy.

12. λ for Charged Particle	$\lambda = \frac{h}{\sqrt{2mqV}}$	Particle of charge q, mass m, accelerated through potential difference V (from rest).
13. λ for Electron	$\lambda_e = \frac{12.27}{\sqrt{V}} \mathring{A}$	**Specific Shortcut.** V must be in Volts. Result is in Angstroms. Alternative: $\lambda \approx \sqrt{\frac{150}{V}} \mathring{A}$.
14. λ for Proton	$\lambda_p = \frac{0.286}{\sqrt{V}} \mathring{A}$	Specific Shortcut for Protons.
15. λ for Alpha Particle	$\lambda_\alpha = \frac{0.101}{\sqrt{V}} \mathring{A}$	Specific Shortcut for α-particle (He^{2+}).
16. λ for Gas Molecule	$\lambda = \frac{h}{\sqrt{3mk_BT}}$	k_B = Boltzmann constant, T = Absolute Temp (Kelvin). Based on $K_{avg} = \frac{3}{2}k_BT$.
17. Bohr's Quantization (de Broglie)	$2\pi r_n = n\lambda$	Condition for stationary orbits. Circumference = integral multiple of wavelength.
18. Ratio of λ (Question type)	$\frac{\lambda_1}{\lambda_2} = \sqrt{\frac{m_2K_2}{m_1K_1}} = \sqrt{\frac{m_2q_2V_2}{m_1q_1V_1}}$	Used when comparing two different particles or same particle at different potentials.
19. X-Ray Cut-off Wavelength	$\lambda_{min} = \frac{hc}{eV}$ $\lambda_{min}(\mathring{A}) = \frac{12400}{V(\text{volts})}$	Continuous X-ray spectrum (Bremsstrahlung). Depends only on accelerating voltage V.
20. Moseley's Law	$\sqrt{\nu} = a(Z - b)$	Characteristic X-rays. Z = Atomic number. a, b are screening constants.

For K_α line, $b = 1$.

Atoms

BY AP Sir, Sakaar Classes

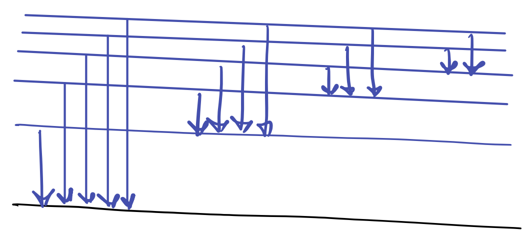
Topic / Formula Name	Formula(e)	Conditions / Usage / Specific Cases
1. Rutherford's α-Scattering		
Distance of Closest Approach (r_0)	$$r_0 = \frac{1}{4\pi\epsilon_0} \cdot \frac{2Ze^2}{K}$$	Used when an α-particle (charge $2e$) is fired at a nucleus (charge Ze) with Kinetic Energy K.
	or	**Condition:** Head-on collision ($\theta = 180^\circ$). At r_0, entire KE converts to Electrostatic PE.
	$$r_0 = \frac{4kZe^2}{mv^2}$$	
Impact Parameter (b)	$$b = \frac{1}{4\pi\epsilon_0} \cdot \frac{Ze^2 \cot(\theta/2)}{K}$$	b is the perpendicular distance of the velocity vector from the nucleus center.
		θ is the scattering angle. If $b = 0, \theta = 180^\circ$ (Head-on).
Scattering Probability (N)	$$N(\theta) \propto \frac{1}{\sin^4(\theta/2)}$$	Gives the number of α-particles scattered at a specific angle θ.
2. Bohr's Model (General)		**Valid only for Hydrogen-like species (1 electron system: H, He$^+, Li^{2+}$).**
Angular Momentum Quantization	$$L = mvr_n = \frac{nh}{2\pi}$$	The electron can revolve only in those orbits where angular momentum is an integral multiple of $h/2\pi$.

Frequency Condition	$h\nu = E_{higher} - E_{lower}$	Energy emitted/absorbed when electron jumps between orbits.
3. Bohr's Parameters [redacted] Orbit)		
Radius of Orbit (r_n)	$$r_n = \frac{\epsilon_0 n^2 h^2}{\pi m Z e^2}$$ $$r_n = 0.529 \frac{n^2}{Z} \text{ Å}$$	**Proportionality:** $r \propto \frac{n^2}{Z}$ Used to find the size of the atom in excited states.
Velocity of Electron (v_n)	$$v_n = \frac{Ze^2}{2\epsilon_0 nh}$$ $$v_n = 2.18 \times 10^6 \frac{Z}{n} \text{ m/s} \approx \frac{c}{137} \cdot \frac{Z}{n}$$	**Proportionality:** $v \propto \frac{Z}{n}$ Velocity decreases in higher orbits.
Frequency of Revolution (f)	$$f = \frac{v_n}{2\pi r_n} \propto \frac{Z^2}{n^3}$$	Number of revolutions per second.
Time Period (T)	$$T = \frac{1}{f} \propto \frac{n^3}{Z^2}$$	Time taken for one complete revolution.
Magnetic Field at Center (B)	$$B = \frac{\mu_0 I}{2r} \propto \frac{Z^3}{n^5}$$	Magnetic field produced by the revolving electron (treating it as a current loop).
4. Energy of Electron		
Total Energy (E_n)	$$E_n = -\frac{mZ^2 e^4}{8\epsilon_0^2 n^2 h^2}$$	**Proportionality:** $E \propto -\frac{Z^2}{n^2}$ Total energy is always negative, implying a bound state.

$$E_n = -13.6\frac{Z^2}{n^2}\ \text{eV}$$

Kinetic Energy (K_n)	$$K_n = \left	E_n \right
Potential Energy (U_n)	$U_n = 2E_n = -27.2\frac{Z^2}{n^2}\ \text{eV}$	PE is negative and its magnitude is double the Total Energy.
Relation between E, K, U	$K = -E$ $U = 2E$ $U = -2K$	**Important for Graph Questions:** If Total Energy increases (becomes less negative), KE decreases and PE increases.

5. Hydrogen Spectrum



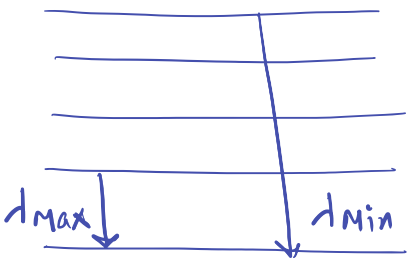
Rydberg's Formula (Wave number $\bar{\nu}$)	$\frac{1}{\lambda} = \bar{\nu} = RZ^2\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$	**Rydberg Constant (R):** $\approx 1.097 \times 10^7\ \text{m}^{-1}$ (or $\approx \frac{1}{911\ \text{Å}}$).
		Condition: Transition from n_2 (higher) to n_1 (lower).

Specific Spectral Series	**Transition ($n_2 \to n_1$)**	**Region of Spectrum**
Lyman Series	$n_2 = 2, 3, \cdots \to n_1 = 1$	Ultraviolet (UV) Region
Balmer Series	$n_2 = 3, 4, \cdots \to n_1 = 2$	Visible Region
Paschen Series	$n_2 = 4, 5, \cdots \to n_1 = 3$	Infrared (Near IR)
Brackett Series	$n_2 = 5, 6, \cdots \to n_1 = 4$	Infrared (Mid IR)
Pfund Series	$n_2 = 6, 7, \cdots \to n_1 = 5$	Infrared (Far IR)

Max/Min Wavelengths

$$\lambda_{min} = \frac{1}{RZ^2(\frac{1}{n_1^2})}$$

λ_{min} corresponds to max energy transition ($n_2 = \infty \rightarrow n_1$).



(Series Limit)

λ_{max} corresponds to min energy transition ($n_2 = n_1 + 1 \rightarrow n_1$).

$$\lambda_{max} = \frac{1}{RZ^2(\frac{1}{n_1^2} - \frac{1}{(n_1+1)^2})}$$

6. Atomic Transitions & Recoil

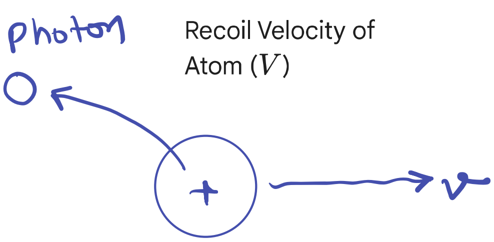
Number of Spectral Lines (N_E)

$$N_E = \frac{(n_2 - n_1)(n_2 - n_1 + 1)}{2}$$

Total number of possible emission lines when electron jumps from n_2 to n_1.

If jumping to ground state ($n_1 = 1$), $N = \frac{n(n-1)}{2}$.

Recoil Velocity of Atom (V)



$$V = \frac{h}{\lambda M} = \frac{\Delta E}{Mc}$$

When an atom emits a photon, it recoils to conserve momentum.

M = Mass of atom.

Excitation Energy

$$E_{excitation} = E_{final} - E_{ground}$$

Energy required to take an electron from ground state to an excited state.

Ionization Energy

$$E_{ionization} = E_{\infty} - E_{ground} = +13.6\frac{Z^2}{n^2}\ \text{eV}$$

Energy required to remove the electron completely ($n \rightarrow \infty$) from state n.

7. Reduced Mass Correction

Modified Rydberg Constant (R')

$$R' = \frac{R}{1 + \frac{m_e}{M_{nucleus}}}$$

Used when the mass of the nucleus is **not** considered infinite (e.g., Positronium, Muonic Hydrogen).

Replace m with $\mu = \frac{m_e M}{[illegible]}$ in

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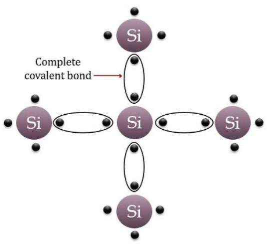
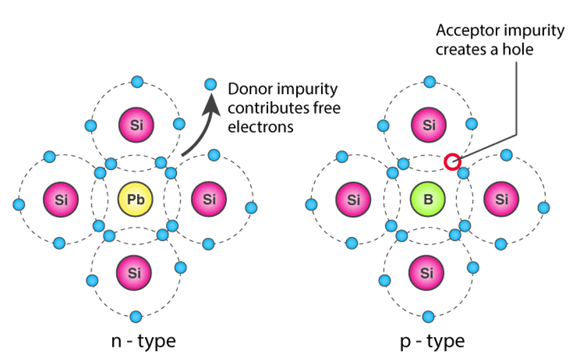
Topic / Formula Name	Formula	Conditions / Notes / Specific Use
1. Nuclear Radius	$R = R_0 A^{1/3}$	Used to calculate the radius of a nucleus. - $R_0 \approx 1.2 \times 10^{-15}\ \mathrm{m}(1.2\ \mathrm{fm})$ - A = Mass Number
2. Nuclear Density	$\rho = \frac{\text{Mass}}{\text{Volume}} \approx 2.3 \times 10^{17}\ \mathrm{kg/m}^3$	**Condition:** Nuclear density is independent of Mass Number (A). It is roughly constant for all nuclei.
3. Mass-Energy Equivalence	$E = mc^2$	Einstein's equation. Energy released when mass m is converted to energy.
Conversion Factor	$1\ \text{amu} \approx 931.5\ \text{MeV}$	Used to convert mass defect directly into Binding Energy in MeV.
4. Mass Defect (Δm)	$\Delta m = [Zm_p + (A - Z)m_n] - M_{nucleus}$	Difference between the sum of masses of nucleons and the actual mass of the nucleus. m_p: mass of proton, m_n: mass of neutron.
5. Binding Energy (B.E.)	$B.E. = \Delta m \times c^2$ OR $B.E. = \Delta m(\text{in amu}) \times 931.5\ \text{MeV}$	The energy required to break the nucleus into constituent nucleons.

6. Binding Energy per Nucleon	$\text{B.E. per nucleon} = \frac{B.E.}{A}$	Determines stability. Higher B.E./nucleon $\implies$ More stable nucleus (max for Fe-56).
7. Radioactive Decay Law	$N = N_0 e^{-\lambda t}$	N: Nuclei remaining at time t
		N_0: Initial number of nuclei
		λ: Decay constant
Activity (R or A)	$R = -\frac{dN}{dt} = \lambda N$	Rate of decay. Unit: Becquerel (Bq) or Curie (Ci).
	$R = R_0 e^{-\lambda t}$	Use when asked for "count rate" or "activity".
8. Half-Life ($T_{1/2}$)	$T_{1/2} = \frac{\ln 2}{\lambda} = \frac{0.693}{\lambda}$	Time taken for half the nuclei to decay.
9. Mean Life / Average Life (τ)	$\tau = \frac{1}{\lambda} = \frac{T_{1/2}}{0.693} = 1.44 T_{1/2}$	Average time a nucleus exists.
10. Fraction Remaining	$\frac{N}{N_0} = \left(\frac{1}{2}\right)^n$	Here, $n = \frac{t}{T_{1/2}}$ (number of half-lives).
		Shortcut: Useful for integer numbers of half-lives.
11. Alpha (α) Decay	${}_Z^A X \rightarrow {}_{Z-2}^{A-4} Y + {}_2^4 \text{He} + Q$	Parent nucleus emits a Helium nucleus.
		Mass No. decreases by 4, Atomic No. decreases by 2.
12. Beta Minus (β^-) Decay	${}_Z^A X \rightarrow {}_{Z+1}^{A} Y + e^- + \bar{\nu}$	Neutron turns into proton.
		Atomic No. increases by 1. Antineutrino ($\bar{\nu}$) emitted.

13. Beta Plus (β^{+}) Decay	${}_{Z}^{A}X \rightarrow {}_{Z-1}^{A}Y + e^{+} + \nu$	Proton turns into neutron.
		Atomic No. decreases by 1. Neutrino (ν) emitted.
14. Q-Value of Reaction	$Q = (M_{reactants} - M_{products})c^2$	If $Q > 0$, reaction is exothermic (releases energy).
		If $Q < 0$, reaction is endothermic.
Q-value (α-decay specific)	$Q = \frac{M_Y}{M_Y + m_\alpha} E_{total}$	Used to find Kinetic Energy of α-particle ($K_\alpha \approx \frac{A-4}{A} Q$).
15. Parallel Decay	$\lambda_{eff} = \lambda_1 + \lambda_2$	Condition: A nucleus decays into two different products simultaneously with decay constants λ_1 and λ_2.
	$T_{eff} = \frac{T_1 T_2}{T_1 + T_2}$	
16. Radioactive Equilibrium	$\lambda_A N_A = \lambda_B N_B$	Condition: Rate of formation of B (from A) = Rate of decay of B. (Secular Equilibrium).
17. Number of Nuclei (N)	$N = n \times N_A = \frac{m}{M} \times N_A$	To find N_0 from mass m (in grams).

Semiconductors

BY AP Sir, Sakaar Classes

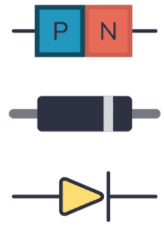
Formula / Topic Name	Formula(e)	Conditions / Specific Use Cases
Intrinsic Semiconductors 	1. $n_e = n_h = n_i$ 2. $I = I_e + I_h$ 3. $J = \sigma E$	1. Pure semiconductor (Si, Ge) at thermal equilibrium. 2. Total current is sum of electron and hole currents.
Mass Action Law	$n_e n_h = n_i^2$	Valid for both intrinsic and extrinsic (doped) semiconductors at thermal equilibrium.
Conductivity (σ) & Resistivity (ρ)	1. $\sigma = e(n_e\mu_e + n_h\mu_h)$ 2. $\rho = \frac{1}{\sigma} = \frac{1}{e(n_e\mu_e+n_h\mu_h)}$	Used to calculate conductivity/resistivity when carrier concentration (n) and mobility (μ) are known.
Mobility (μ)	$\mu = \frac{v_d}{E}$	v_d = drift velocity, E = Electric field. Ratio of drift velocity to applied electric field.
Extrinsic N-Type	1. $n_e \approx N_d \gg n_h$ 2. $n_h = \frac{n_i^2}{N_d}$	Doped with Pentavalent impurity (N_d = Donor conc.). Electrons are majority carriers. 

Extrinsic P-Type

1. $n_h \approx N_a \gg n_e$

2. $n_e = \frac{n_i^2}{N_a}$

Doped with Trivalent impurity (N_a = Acceptor conc.). Holes are majority carriers.



Dynamic Resistance (Diode)

$r_d = \frac{\Delta V}{\Delta I}$

Used in forward bias characteristics to find AC resistance at a specific operating point.

Diode Current Equation

$I = I_s(e^{\frac{eV}{k_B T}} - 1)$

I_s = Saturation current. Forward bias ($V > 0$). Often approximated as $I \propto e^V$.

Half Wave Rectifier (HWR)

1. $I_{dc} = \frac{I_0}{\pi}$

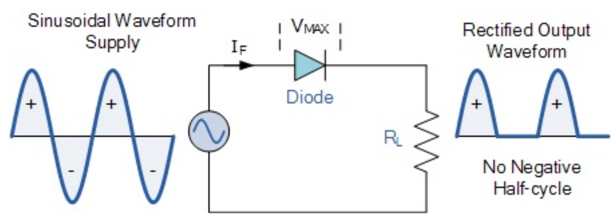
2. $I_{rms} = \frac{I_0}{2}$

3. Efficiency $\eta = \frac{40.6\%}{1 + r_f/R_L}$

4. Ripple Factor $\gamma = 1.21$

5. PIV $= V_0$

Used when only one half of AC cycle is rectified. I_0 is peak current. r_f is diode forward resistance.



Full Wave Rectifier (FWR)

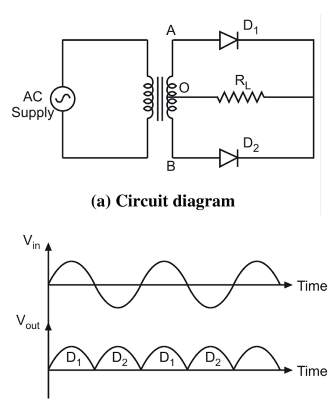
1. $I_{dc} = \frac{2I_0}{\pi}$

2. $I_{rms} = \frac{I_0}{\sqrt{2}}$

3. Efficiency $\eta = \frac{81.2\%}{1 + r_f/R_L}$

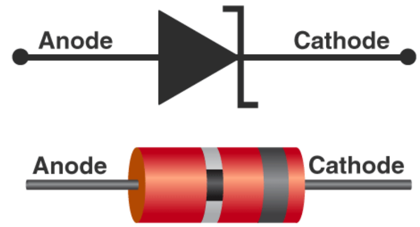
4. Ripple Factor $\gamma = 0.48$

Used for center-tap or bridge rectifiers (Bridge PIV $= V_0$). Converts full AC cycle to DC.



(a) Circuit diagram

(b) Input/output waveforms

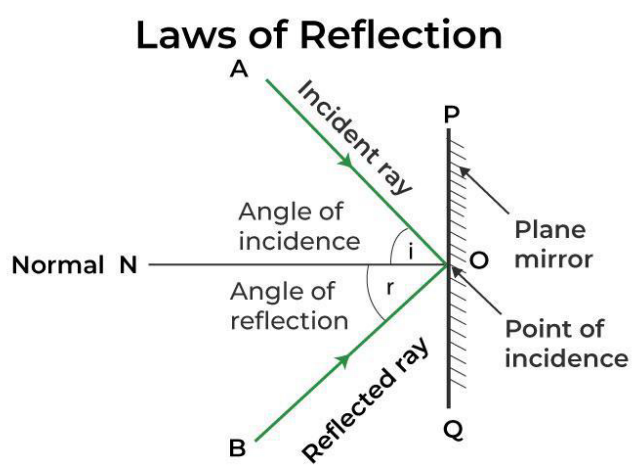
	5. PIV $= 2V_0$ (Center Tap)	
Zener Diode (Regulator)	$I_Z = I - I_L$	Used as Voltage Regulator in Reverse Bias. V_Z is constant breakdown voltage.
	$V_{in} = IR_s + V_Z$	 (Zener diode)
	$P_Z = V_Z I_Z$	
Transistor Currents (BJT)	$I_E = I_B + I_C$	Fundamental conservation of charge in any transistor configuration (CE, CB, CC).
Current Gains	1. $\alpha_{dc} = \frac{I_C}{I_E}$ (Common Base)	α is usually 0.95 to 0.99.
	2. $\beta_{dc} = \frac{I_C}{I_B}$ (Common Emitter)	β is usually 20 to 100+.
Relation between α and β	1. $\beta = \frac{\alpha}{1-\alpha}$	Essential for converting gains between CB and CE configurations.
	2. $\alpha = \frac{\beta}{1+\beta}$	
AC Current Gain	$\beta_{ac} = \left(\frac{\Delta I_C}{\Delta I_B}\right)_{V_{CE}=\text{const}}$	Used for small signal analysis (amplifiers).
Transconductance (g_m)	$g_m = \frac{\Delta I_C}{\Delta V_{BE}} = \frac{\beta_{ac}}{R_{in}}$	Measure of transfer characteristic in amplifiers.

Voltage Gain (A_v) - CE Amp	$A_v = \frac{V_{out}}{V_{in}} = -\beta_{ac} \frac{R_{out}}{R_{in}}$	Negative sign indicates 180° phase shift in Common Emitter amplifier.
Power Gain (A_p)	$A_p = A_v \times A_i = \beta_{ac}^2 \frac{R_{out}}{R_{in}}$	Power amplification in CE mode.
Logic Gates - OR	$Y = A + B$	Output is High (1) if *any* input is High.
Logic Gates - AND	$Y = A \cdot B$	Output is High (1) only if *all* inputs are High.
Logic Gates - NOT	$Y = \bar{A}$	Inverts input. 0 $\rightarrow$ 1, 1 $\rightarrow$ 0.
Logic Gates - NOR	$Y = \overline{A + B}$	OR followed by NOT. Universal Gate.
Logic Gates - NAND	$Y = \overline{A \cdot B}$	AND followed by NOT. Universal Gate.
Logic Gates - XOR	$Y = A \oplus B = \bar{A}B + A\bar{B}$	Output is High if inputs are different.
De Morgan's Theorems	1. $\overline{A + B} = \bar{A} \cdot \bar{B}$ 2. $\overline{A \cdot B} = \bar{A} + \bar{B}$	Used to simplify Boolean logic expressions in questions involving NAND/NOR realization.

Ray Optics

BY AP Sir, Sakaar Classes

Formula Name / Topic	Formula(e)	Conditions / Notes
REFLECTION (Plane Mirrors)		
Law of Reflection	$i = r$	Angle of incidence = Angle of reflection. Measured from the normal.
Deviation (δ)	$\delta = 180^\circ - 2i$	Single reflection from a plane mirror.
Rotation of Mirror	Reflected ray rotates by 2θ	Keeping incident ray fixed, if mirror rotates by θ.
Number of Images (n)	Let $m = \frac{360^\circ}{\theta}$	Two plane mirrors inclined at angle θ.
	1. If m is even: $n = m - 1$	
	2. If m is odd:	
	- Object on bisector: $n = m - 1$	
	- Object not on bisector: $n = m$	

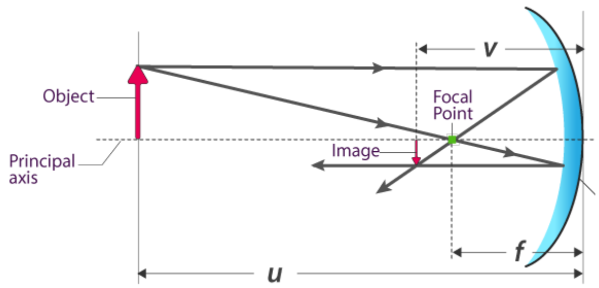


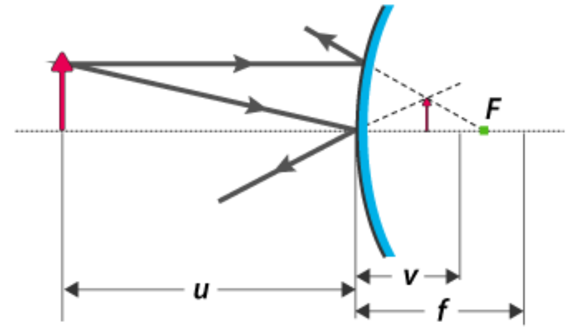
Formula Name / Topic	Formula(e)	Conditions / Notes
Minimum Mirror Size	$H_{mirror} = \frac{H_{person}}{2}$	To see full height of a person.
REFLECTION (Spherical Mirrors)		
Focal Length & Radius	$f = \frac{R}{2}$	Valid for paraxial rays (small aperture mirrors).

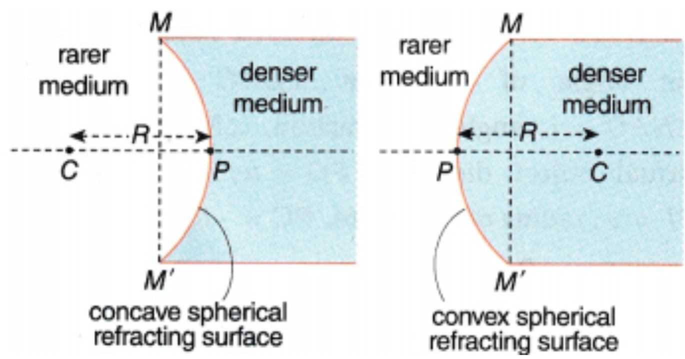
Mirror Formula	$\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$	u, v, f, R must be put with sign convention. Concave $f(-)$, Convex $f(+)$.
Lateral Magnification (m)	$m = -\frac{v}{u} = \frac{h_i}{h_o} = \frac{f}{f-u} = \frac{f-v}{f}$	m is (-) for real/inverted, (+) for virtual/erect.
Longitudinal Magnification	$m_L = -(\frac{v}{u})^2 = -m^2$	For small objects placed along the principal axis.
Velocity of Image	$V_{image} = -(\frac{v}{u})^2 V_{object}$	Motion along principal axis.
Newton's Formula	$x_1 x_2 = f^2$	x_1, x_2 are distances of object and image from the **focus** (not pole).
REFRACTION (Plane Surfaces)		
Snell's Law	$\mu_1 \sin i = \mu_2 \sin r$	μ_1 is medium of incidence, μ_2 is medium of refraction.
Refractive Index	$\mu = \frac{c}{v} = \frac{\lambda_{vac}}{\lambda_{med}}$	Absolute refractive index.
Relative Refractive Index	${}^1\mu_2 = \frac{\mu_2}{\mu_1} = \frac{v_1}{v_2} = \frac{\lambda_1}{\lambda_2}$	Refractive index of medium 2 w.r.t medium 1.
Apparent Depth (d_{app})	$d_{app} = \frac{d_{real}}{\mu_{rel}}$	Observer looking normally into a different medium.
	where $\mu_{rel} = \frac{\mu_{object}}{\mu_{observer}}$	
Normal Shift (Δx)	$\Delta x = d(1 - \frac{1}{\mu})$	Object in denser medium (μ), observer in air. Shift is in direction of incident ray.
Lateral Shift	$x = \frac{t \sin(i-r)}{\cos r}$	Light passing through a glass slab of thickness t.
Multiple Slabs Apparent Depth	$d_{app} = \frac{t_1}{\mu_1} + \frac{t_2}{\mu_2} + ...$	Observer in air viewing through composite slabs.
TIR (Total Internal Reflection)		
Critical Angle (C)	$\sin C = \frac{\mu_R}{\mu_D}$ (usually $\frac{1}{\mu}$)	Ray travels from Denser (μ_D) to Rarer (μ_R).

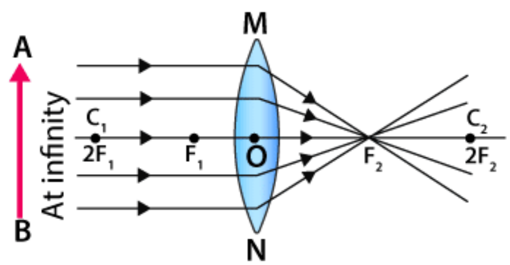
Condition for TIR	$i > C$	Ray must travel from Denser to Rarer medium.
Circle of Illuminance	$R = \frac{h}{\sqrt{\mu^2-1}}$	Radius of bright circle on surface for a source at depth h.
REFRACTION (Curved Surfaces)		
Refraction Formula	$\frac{\mu_2}{v} - \frac{\mu_1}{u} = \frac{\mu_2-\mu_1}{R}$	Single spherical surface. μ_1 (incidence), μ_2 (refraction). Sign convention applies.
Power of Surface	$P = \frac{\mu_2-\mu_1}{R}$	Single refracting surface.
LENSES		
Lens Maker's Formula	$\frac{1}{f} = (\mu_{rel} - 1)(\frac{1}{R_1} - \frac{1}{R_2})$	R_1 is radius of surface facing incident light.
	$\mu_{rel} = \frac{\mu_{lens}}{\mu_{surr}}$	
Thin Lens Formula	$\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$	Valid for thin lenses. Sign convention applies.
Magnification (m)	$m = \frac{v}{u} = \frac{h_i}{h_o} = \frac{f}{f+u} = \frac{f-v}{f}$	Convex lens: Real (-), Virtual (+). Concave: Always Virtual (+).
Power of Lens (P)	$P = \frac{1}{f(m)}$ or $\frac{100}{f(cm)}$	Unit is Diopter (D).
Combination of Lenses	$\frac{1}{F_{eq}} = \frac{1}{f_1} + \frac{1}{f_2} + ...$	Lenses in contact.
	$P_{eq} = P_1 + P_2 + ...$	
Lenses Separated by Distance d	$\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2} - \frac{d}{f_1 f_2}$	Two thin lenses separated by distance d.
Cutting a Lens	1. Vertical Cut: $f' = 2f, P' = P/2$	1. Along principal axis.
	2. Horizontal Cut: $f' = f, P' = P$	2. Perpendicular to principal axis.

Silvering of Lens	$P_{eq} = 2P_L + P_M$	Behaves like a mirror. P_L is lens power, P_M is mirror power ($P_M = -1/f_m = -2/R$).
	$F_{eq} = -\frac{1}{P_{eq}}$	
Displacement Method	1. $f = \frac{D^2 - x^2}{4D}$	To find f of convex lens. D = distance between object & screen ($D > 4f$), x = displacement of lens.
	2. $O = \sqrt{I_1 I_2}$	
PRISM		
Angle of Prism (A)	$A = r_1 + r_2$	r_1, r_2 are angles of refraction inside prism.
Deviation (δ)	$\delta = (i + e) - A$	i = incidence, e = emergence.
Minimum Deviation (δ_m)	$i = e$ and $r_1 = r_2 = A/2$	Ray passes symmetrically through the prism.
	$\mu = \frac{\sin(\frac{A+\delta_m}{2})}{\sin(\frac{A}{2})}$	
Condition for No Emergence	$A > 2C$	Where C is critical angle. Ray undergoes TIR at 2nd face.
Small Angle Prism	$\delta = A(\mu - 1)$	For thin prisms ($A < 10^\circ$).
Dispersion	$\theta = \delta_V - \delta_R = A(\mu_V - \mu_R)$	Angular dispersion between Violet and Red.
Dispersive Power (ω)	$\omega = \frac{\theta}{\delta_y} = \frac{\mu_V - \mu_R}{\mu_y - 1}$	$\mu_y \approx \frac{\mu_V + \mu_R}{2}$ (Mean refractive index). Independent of A.
Dispersion without Deviation	$\frac{A'}{A} = -\frac{\mu_y - 1}{\mu'_y - 1}$	Combination of two prisms (Crown & Flint) to cancel mean deviation.
Deviation without Dispersion	$\frac{A'}{A} = -\frac{\mu_V - \mu_R}{\mu'_V - \mu'_R}$	Combination to cancel angular dispersion (Achromatic combination).
OPTICAL INSTRUMENTS		
Simple Microscope	1. $m = 1 + \frac{D}{f}$	1. Image at Least Distance of Distinct Vision (D=25cm).

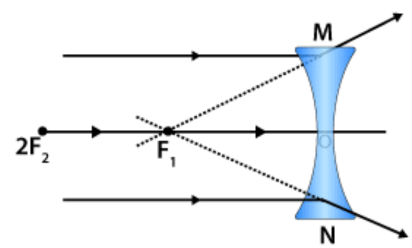




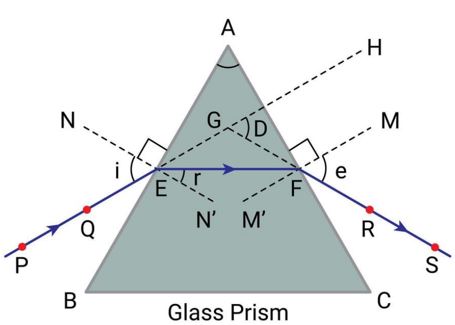




Convex Lens

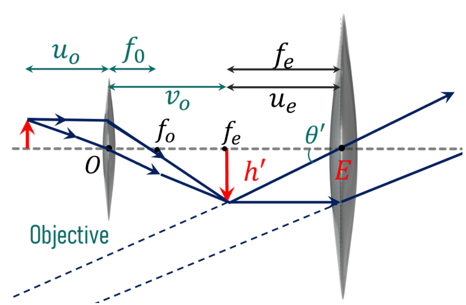


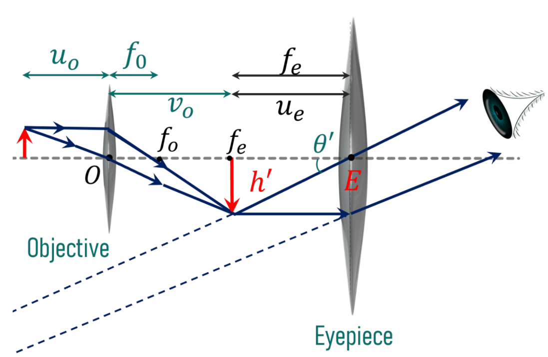
Concave Lens



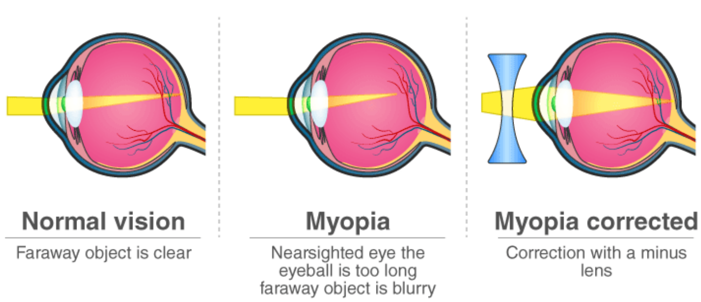
Glass Prism

PE : Incident Ray	∠i : Angle of Incidence
EF : Refracted Ray	∠r : Angle of Refraction
FS : Emergent Ray	∠e : Angle of Emergence
∠A : Angle of the Prism	∠D : Angle of Deviation





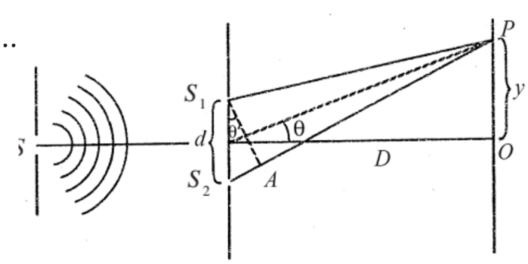
	2. $m = \frac{D}{f}$	2. Image at infinity (Relaxed eye).
Compound Microscope	$m = m_o \times m_e$	Total magnification.
Comp. Micro (Specifics)	1. $m \approx -\frac{L}{f_o}(1 + \frac{D}{f_e})$	1. Image at D. ($L \approx$ tube length).
	2. $m \approx -\frac{L}{f_o}(\frac{D}{f_e})$	2. Image at ∞.
Astronomical Telescope	1. $m = -\frac{f_o}{f_e}$	1. Normal adjustment (Image at ∞). Length $L = f_o + f_e$.
	2. $m = -\frac{f_o}{f_e}(1 + \frac{f_e}{D})$	2. Image at D.
Resolving Power (Microscope)	$RP = \frac{2\mu \sin\theta}{1.22\lambda}$	$\mu \sin\theta$ = Numerical Aperture.
Resolving Power (Telescope)	$RP = \frac{a}{1.22\lambda}$	a = aperture (diameter) of objective.
DEFECTS OF VISION		
Myopia (Near-sightedness)	$f = -x$ (concave lens)	Can see near, can't see far. x = far point distance of defected eye.
Hypermetropia	$P = \frac{1}{0.25} - \frac{1}{y}$	Can see far, can't see near. y = near point of



Wave Optics Formula Sheet

BY AP Sir, Sakaar Classes

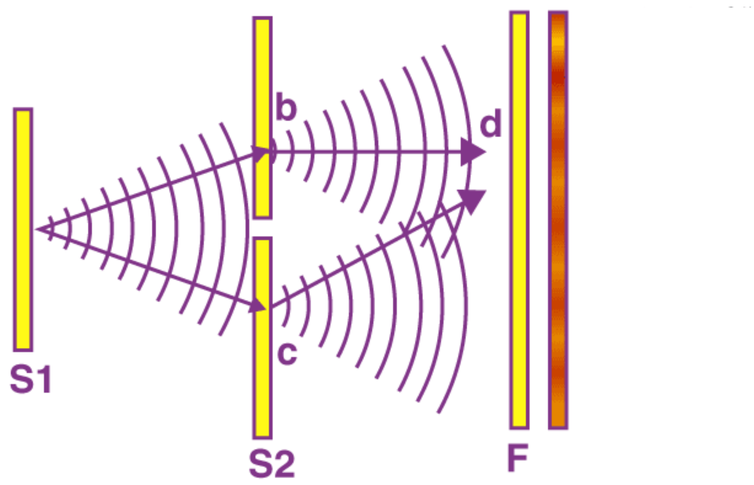
Topic / Formula Name	Formula(e)	Conditions / Context
1. Wave Basics & Intensity		
Relation between Path & Phase Difference	$\Delta\phi = \frac{2\pi}{\lambda}\Delta x$	$\Delta\phi$: Phase difference
		Δx: Path difference
Resultant Amplitude (A_{res})	$A_{res} = \sqrt{A_1^2 + A_2^2 + 2A_1A_2\cos\phi}$	Superposition of two waves with amplitudes A_1, A_2 and phase diff ϕ.
Resultant Intensity (I_{res})	$I_{res} = I_1 + I_2 + 2\sqrt{I_1I_2}\cos\phi$	General interference formula.
Intensity Ratio (I_{max}/I_{min})	$\frac{I_{max}}{I_{min}} = \left(\frac{\sqrt{I_1}+\sqrt{I_2}}{\sqrt{I_1}-\sqrt{I_2}}\right)^2 = \left(\frac{A_1+A_2}{A_1-A_2}\right)^2$	Used when comparing bright and dark fringe intensities.
Slit Width & Intensity	$\frac{I_1}{I_2} = \frac{w_1}{w_2} = \frac{A_1^2}{A_2^2}$	Intensity is proportional to slit width (w) and square of amplitude.
2. Interference (YDSE)		
Condition for Maxima (Bright Fringe)	$\Delta x = n\lambda$	Constructive Interference.
	$\Delta\phi = 2n\pi$	$n = 0, 1, 2...$
Condition for Minima (Dark Fringe)	$\Delta x = (2n-1)\frac{\lambda}{2}$	Destructive Interference.
	$\Delta\phi = (2n-1)\pi$	$n = 1, 2, 3...$



Position of n^{th} Bright Fringe (y_n)	$y_n = \frac{n\lambda D}{d}$	From central maxima.
		$D \gg d$.
Position of n^{th} Dark Fringe (y'_n)	$y'_n = \frac{(2n-1)\lambda D}{2d}$	From central maxima.
		$D \gg d$.
Fringe Width (β)	$\beta = \frac{\lambda D}{d}$	Distance between two consecutive bright or dark fringes. Independent of n.
Angular Fringe Width (θ)	$\theta = \frac{\beta}{D} = \frac{\lambda}{d}$	Measured in radians. Independent of screen distance D.
Optical Path Difference	$\Delta x_{opt} = \mu x$	Path traveled in medium of refractive index μ is equivalent to μx in vacuum.
Shift due to Glass Slab	$\Delta y = \frac{D}{d}(\mu - 1)t$	When a slab of thickness t and R.I. μ is placed in front of one slit. Pattern shifts towards the slab side.
	Shift in path $\Delta x = (\mu - 1)t$	
3. Diffraction (Single Slit)		
Condition for Minima	$a \sin\theta = n\lambda$	a: Slit width.
		Note: Formula looks like maxima of YDSE but is for minima here.
Condition for Maxima (Secondary)	$a \sin\theta = (2n + 1)\frac{\lambda}{2}$	For secondary maxima ($n = 1, 2...$). Intensity decreases as n increases.
Linear Width of Central Maxima	$W_0 = \frac{2\lambda D}{a}$	It is double the width of secondary maxima/fringes.
Angular Width of Central Maxima	$\theta_0 = \frac{2\lambda}{a}$	Spread of the central bright spot.

Fresnel Distance (Z_F)	$Z_F = \frac{a^2}{\lambda}$	Distance up to which ray optics is a good approximation.
4. Polarization		
Malus's Law	$I = I_0 \cos^2 \theta$	I_0: Intensity of polarized light incident on analyzer.
		θ: Angle between polarizer and analyzer axes.
Unpolarized light passing through Polarizer	$I = \frac{I_0}{2}$	If initial light intensity is I_0 (unpolarized), output is always half.
Brewster's Law	$\mu = \tan i_p$	Condition for reflected light to be completely plane polarized.
		i_p: Polarizing angle (Brewster angle).
Critical Angle vs Brewster Angle	$\sin i_c = \frac{1}{\tan i_p}$	Relating Total Internal Reflection (TIR) and Polarization.
5. Resolving Power		
Resolving Power of Microscope	$R.P. = \frac{2\mu \sin \theta}{1.22\lambda}$	$\mu \sin \theta$: Numerical Aperture.
		Limit of resolution = $1/R.P.$
Resolving Power of Telescope	$R.P. = \frac{a}{1.22\lambda}$	a: Diameter of the objective lens aperture.
6. Specific Cases / Tricky Qs		
Immersion in Liquid	$\beta' = \frac{\beta_{air}}{\mu}$	If the whole YDSE apparatus is immersed in liquid of R.I. μ, fringe width decreases.
Shape of Interference Fringes	Hyperbolic	On a screen placed perpendicular to the line joining sources.

Shape of Diffraction Fringes	Straight lines	For a single slit diffraction pattern.
Missing Wavelengths in YDSE	$\frac{n_1\lambda_1 D}{d} = \frac{n_2\lambda_2 D}{d}$	Condition for two different wavelengths to coincide at the same position y.
Number of Fringes Shifted (Slab)	$N = \frac{(\mu-1)t}{\lambda}$	Number of fringes that cross the central line when a slab is introduced.
Doppler Effect in Light	$\frac{\Delta\nu}{\nu} = -\frac{\Delta\lambda}{\lambda} = \frac{v_{radial}}{c}$	For $v \ll c$.



Young's Double Slits Experiment