Units, Dimensions, and Measurements Formulae for NEET & JEE

by AP Sir, Director Sakaar PCMB Classes

Formula / Topic Name	Formula(e) & Expressions	Conditions & Usage Notes
1. Dimensional Analysis		
Fundamental Quantities	Mass $[M]$, Length $[L]$, Time $[T]$, Current $[A]$, Temp $[K]$, Amount of Substance $[mol]$, Luminous Intensity $[cd]$	Base dimensions from which all others are derived.
Order of Magnitude	Express number as $N = a \times 10^b$	Used to estimate the size of a quantity.
	If $a \leq \sqrt{10}(\approx 3.16)$, Order $= b$	Example: $4 \times 10^5 \rightarrow$ Since $4 > 3.16$, Order is 10^6.
	If $a > \sqrt{10}$, Order $= b + 1$	
2. Significant Figures		
Counting Rules	1. All non-zero digits are significant.	0.007 (1 SF)
	2. Zeros between non-zeros are significant.	2.05 (3 SF)
	3. Leading zeros are **never** significant.	2.500 (4 SF)
	4. Trailing zeros with a decimal point are significant.	1200 (Ambiguous, assume 2 unless specified).
Rounding Off	- Digit > 5: Round up	Example ($= 5$):
	- Digit < 5: No change	$2.45 \rightarrow 2.4$ (4 is even)

	- Digit $= 5$: Round to nearest **even** number.	$2.35 \rightarrow 2.4$ (round up to even)
Arithmetic Operations	**Add/Sub**: Result has same **decimal places** as the least precise term.	Add: $12.11 + 18.0 = 30.1$ (1 dec. place)
	Mul/Div: Result has same **sig figs** as the least precise term.	Mul: $2.5 \times 1.25 = 3.1$ (2 SF)
3. Vernier Caliper		
Least Count (L.C.)	$L.C. = 1MSD - 1VSD$	Where N is total divisions on Vernier scale.
	Standard: $L.C. = \frac{1MSD}{N}$	Common L.C. = 0.1 mm or 0.01 cm.
Reading	$\text{Reading} = MSR + (VSR \times L.C.)$	MSR: Main Scale Reading immediately left of zero.
		VSR: Coinciding Vernier division.
Zero Error	$\text{True Reading} = \text{Observed} - \text{Zero Error}$	**Negative Error Calculation**:
	Positive: Zero of VS is right of MS zero.	Error $= -(N - \text{coinciding div}) \times L.C.$
	Negative: Zero of VS is left of MS zero.	
4. Screw Gauge		
Pitch	$\text{Pitch} = \frac{\text{Distance moved on Main Scale}}{\text{Number of full rotations}}$	Usually 1 mm or 0.5 mm. Distance screw moves in 1 rotation.
Least Count (L.C.)	$L.C. = \frac{\text{Pitch}}{\text{Total Circular Scale Divisions (CSD)}}$	Common L.C. = 0.01 mm or 0.001 cm.
Reading	$\text{Reading} = MSR + (CSR \times L.C.)$	MSR: Reading visible on linear scale.

		CSR: Circular division coinciding with reference line.
Zero Error	**Positive**: Zero of CS is below reference line.	Always subtract the error (keeping signs in mind).
	Negative: Zero of CS is above reference line.	

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Topic: Vectors (Physics)

Formula Name / Topic	Formula(e)	Conditions / Usage
1. Magnitude of a Vector	If $\vec{A} = A_x\hat{i} + A_y\hat{j} + A_z\hat{k}$: $\lvert\vec{A}\rvert = \sqrt{A_x^2 + A_y^2 + A_z^2}$	Used to find the size/length of a vector from its Cartesian components.
2. Unit Vector	$\hat{n} = \frac{\vec{A}}{\lvert\vec{A}\rvert}$	Represents direction only. Magnitude is always 1.
3. Vector Addition (Parallelogram Law)	**Resultant (R):** $R = \sqrt{A^2 + B^2 + 2AB\cos\theta}$ **Direction (α with $\vec{A}$):** $\tan\alpha = \frac{B\sin\theta}{A + B\cos\theta}$	θ is the angle between $\vec{A}$ and $\vec{B}$ (tail-to-tail). $R_{max} = A + B$ (at 0°), $R_{min} = \lvert A - B\rvert$ (at 180°).
4. Vector Subtraction	**Magnitude:** $\lvert\vec{A} - \vec{B}\rvert = \sqrt{A^2 + B^2 - 2AB\cos\theta}$ **Direction:** $\tan\alpha = \frac{B\sin\theta}{A - B\cos\theta}$	Used for relative velocity ($\Delta\vec{v}$). θ is the angle between original vectors.
5. Resolution of Components	$A_x = A\cos\theta$	θ is the angle made with the X-axis.

	$A_y = A\sin\theta$	
6. Direction Cosines	$l = \frac{A_x}{A}, \quad m = \frac{A_y}{A}, \quad n = \frac{A_z}{A}$	l, m, n are cosines of angles with X, Y, Z axes.
	$l^2 + m^2 + n^2 = 1$	
7. Dot Product (Scalar)	$\vec{A} \cdot \vec{B} = AB\cos\theta$	Result is Scalar.
	$\vec{A} \cdot \vec{B} = A_x B_x + A_y B_y + A_z B_z$	**Perpendicular if:** $\vec{A} \cdot \vec{B} = 0$.
8. Angle Between Vectors	$\cos\theta = \frac{\vec{A}\cdot\vec{B}}{\lvert\vec{A}\rvert\lvert\vec{B}\rvert}$	Vectors must be tail-to-tail.
9. Cross Product (Vector)	**Magnitude:** $\lvert\vec{A} \times \vec{B}\rvert = AB\sin\theta$	Result is Vector $\perp$ to $\vec{A}$ and $\vec{B}$.
		Parallel if: $\vec{A} \times \vec{B} = 0$.
	Determinant Form:	
	$\vec{A} \times \vec{B} = \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ A_x & A_y & A_z \\ B_x & B_y & B_z \end{vmatrix}$	
10. Lami's Theorem	$\frac{A}{\sin\alpha} = \frac{B}{\sin\beta} = \frac{C}{\sin\gamma}$	Only for 3 concurrent forces in equilibrium.
11. Relative Velocity	$\vec{v}_{AB} = \vec{v}_A - \vec{v}_B$	Velocity of A w.r.t B.
12. Rain-Man Concept	$\vec{v}_{rm} = \vec{v}_r - \vec{v}_m$	θ with vertical.
	$\tan\theta = \frac{v_m}{v_r}$	
13. River Boat: Min Time	$t_{min} = \frac{d}{v_b}$	Head perpendicular to flow.
	Drift $x = v_r \times t_{min}$	
14. River Boat: Shortest Path	$\sin\theta = \frac{v_r}{v_b}$	Head upstream at angle θ.

	$t = \frac{a}{\sqrt{v_b^2 - v_r^2}}$	Cond: $v_b > v_r$.
15. Area of Triangle	Area $= \frac{1}{2}\lvert\vec{A} \times \vec{B}\rvert$	$\vec{A}, \vec{B}$ are adjacent sides.
16. Area of Parallelogram	Sides: $\lvert\vec{A} \times \vec{B}\rvert$	
	Diagonals: $\frac{1}{2}\lvert\vec{d}_1 \times \vec{d}_2\rvert$	
17. Vol. of Parallelepiped	$V = \lvert\vec{A} \cdot (\vec{B} \times \vec{C})\rvert$	Coplanar if Volume = 0.
	$V = \begin{vmatrix} A_x & A_y & A_z \\ B_x & B_y & B_z \\ C_x & C_y & C_z \end{vmatrix}$	

Motion in One Dimension - Important Formulae for NEET & JEE

BY AP Sir, Sakaar Classes

Topic / Formula Name	Formula(e)	Conditions / Notes
1. Average Velocity & Speed	$$v_{avg} = \frac{\Delta x}{\Delta t} = \frac{x_f - x_i}{t_f - t_i}$$ $$\text{Speed}_{avg} = \frac{\text{Total Path Length}}{\text{Total Time}}$$	Valid for any type of motion (uniform or non-uniform). Δx is displacement.
Special Case: Equal Distances	$$v_{avg} = \frac{2v_1 v_2}{v_1 + v_2}$$	When a body covers equal distances with different speeds v_1 and v_2. (Harmonic Mean)
Special Case: Equal Time Intervals	$$v_{avg} = \frac{v_1 + v_2}{2}$$	When a body travels for equal time intervals with different speeds v_1 and v_2. (Arithmetic Mean)
2. Instantaneous Velocity & Speed	$$\vec{v}_{inst} = \lim_{\Delta t \to 0} \frac{\Delta \vec{x}}{\Delta t} = \frac{d\vec{x}}{dt}$$ $$\text{Speed}_{inst} =	\vec{v}_{inst}
3. Instantaneous Acceleration	$$a = \frac{dv}{dt} = \frac{d^2x}{dt^2}$$ $$a = v\frac{dv}{dx}$$	Used for variable acceleration. The form $v(dv/dx)$ is crucial when v is a function of x.

4. Equations of Kinematics (Scalar Form)	1. $$v = u + at$$ 2. $$s = ut + \frac{1}{2}at^2$$ 3. $$v^2 = u^2 + 2as$$ 4. $$s = \left(\frac{u+v}{2}\right)t$$	**STRICTLY for Constant Acceleration ($a = \text{const}$).** u: initial velocity, v: final velocity, a: acceleration, s: displacement, t: time.
5. Displacement in n^{th} Second	$$S_{n^{th}} = u + \frac{a}{2}(2n-1)$$	Displacement covered strictly during the n^{th} second of motion. Only for constant acceleration.
6. Motion Under Gravity (Free Fall)	1. $$v = u - gt$$ 2. $$h = ut - \frac{1}{2}gt^2$$ 3. $$v^2 = u^2 - 2gh$$	Sign Convention (Upward +ve): $a = -g$, Displacement h is +ve if up, -ve if down. For dropped object: $u = 0$.
7. Max Height & Time of Flight	$$H_{max} = \frac{u^2}{2g}$$	For a particle thrown vertically upward with speed u returning to the same level.

$$T_{flight} = \frac{2u}{g}$$

8. Stopping Distance	$$d_{stop} = \frac{u^2}{2a}$$	Distance traveled before coming to rest ($v = 0$) with retardation a.
9. Relative Velocity in 1D	$$v_{AB} = v_A - v_B$$ $$a_{AB} = a_A - a_B$$	Velocity/Acceleration of A with respect to B. Signs are crucial (+ve for one direction, -ve for opposite).
10. Graphical Interpretations	1. Slope of $x - t$ graph = Velocity (v) 2. Slope of $v - t$ graph = Acceleration (a) 3. Area under $v - t$ graph = Displacement (Δx) 4. Area under Speed-time graph = Distance 5. Area under $a - t$ graph = Change in velocity (Δv)	Valid for all types of motion.
11. Variable Acceleration (Integration)	$$v = \int a\,dt$$ $$x = \int v\,dt$$	Use definite integrals with limits when acceleration is a function of time ($a = f(t)$).

Key Tips for Solving Problems:

- **Sign Convention:** Always choose a positive direction (usually right or up). Any vector (displacement, velocity, acceleration) opposite to this is negative.

- **Vector Form:** For complex problems, use $\vec{v} = \vec{u} + \vec{a}t$.
- **Differentiation vs Integration:**
  - $x \xrightarrow{\text{diff}} v \xrightarrow{\text{diff}} a$
  - $a \xrightarrow{\text{int}} v \xrightarrow{\text{int}} x$

Motion in 2D and Projectile Motion

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Formula Name / Topic	Formula(e)	Conditions / Usage
1. General Motion in 2D		
Position Vector	$\vec{r} = x\hat{i} + y\hat{j}$	Cartesian coordinates at time t
Velocity Vector	$\vec{v} = \frac{d\vec{r}}{dt} = v_x\hat{i} + v_y\hat{j}$	Instantaneous velocity
Acceleration Vector	$\vec{a} = \frac{d\vec{v}}{dt} = a_x\hat{i} + a_y\hat{j}$	Instantaneous acceleration
2. Projectile Motion (Ground to Ground)		**Assumptions:** Air resistance neglected, g is constant downwards.
Components of Initial Velocity	$u_x = u\cos\theta$	θ is angle with horizontal
	$u_y = u\sin\theta$	
Motion Parameters (x & y)	$a_x = 0$, $v_x = u\cos\theta$ (constant)	x-motion is uniform; y-motion is under gravity
	$a_y = -g$	
Time of Flight (T)	$$T = \frac{2u\sin\theta}{g} = \frac{2u_y}{g}$$	Projectile lands at same vertical level as launch
Maximum Height (H)	$$H = \frac{u^2\sin^2\theta}{2g} = \frac{u_y^2}{2g}$$	Vertical component of velocity becomes zero at max height
Horizontal Range (R)	$$R = \frac{u^2\sin 2\theta}{g} = \frac{2u_xu_y}{g}$$	Distance between launch and landing point on same level
Condition for Max Range	$\theta = 45^\circ \Rightarrow R_{max} = \frac{u^2}{g}$	For a given initial speed u

Relation between H and R	$$R \tan\theta = 4H$$	Useful for direct relation problems
Equation of Trajectory	$$y = x\tan\theta - \frac{gx^2}{2u^2\cos^2\theta}$$ OR $$y = x\tan\theta\left(1 - \frac{x}{R}\right)$$	To find y given x (eliminating t)
Instantaneous Velocity	$\vec{v} = u\cos\theta\hat{i} + (u\sin\theta - gt)\hat{j}$ $	\vec{v}
Angle with Horizontal (α)	$\tan\alpha = \frac{v_y}{v_x} = \frac{u\sin\theta - gt}{u\cos\theta}$	Direction of motion at time t
3. Horizontal Projectile (From Tower)		**Condition:** Thrown horizontally ($u_y = 0$) from height h
Time of Flight	$$T = \sqrt{\frac{2h}{g}}$$	Time to reach ground
Horizontal Range	$$R = u \times T = u\sqrt{\frac{2h}{g}}$$	Horizontal distance covered
Velocity at Ground	$$v = \sqrt{u^2 + 2gh}$$	Conservation of energy or vector sum
4. Projectile on Inclined Plane		**Incline angle α, Projection angle θ (w.r.t incline)**
Time of Flight (Incline)	$$T = \frac{2u\sin\theta}{g\cos\alpha}$$	Component of g perpendicular to plane is $g\cos\alpha$

Range on Incline (R_{inc})	$$R_{inc} = \frac{2u^2 \sin\theta \cos(\theta + \alpha)}{g \cos^2 \alpha}$$	Projecting UP the incline
Range on Incline (R_{inc})	$$R_{inc} = \frac{2u^2 \sin\theta \cos(\theta - \alpha)}{g \cos^2 \alpha}$$	Projecting DOWN the incline

5. Relative Motion in 2D

Relative Velocity	$\vec{v}_{AB} = \vec{v}_A - \vec{v}_B$	Velocity of A with respect to B
Rain-Man Problem	$\vec{v}_{rm} = \vec{v}_r - \vec{v}_m$	$\vec{v}_{rm}$ is how rain appears to the man
River-Boat: Crossing River	$\vec{v}_{b,g} = \vec{v}_{b,r} + \vec{v}_{r,g}$	$\vec{v}_{b,r}$ = velocity of boat in still water
Condition: Shortest Path	$\sin\theta = \frac{v_r}{v_{br}}$ (upstream)	Drift = 0 (Requires $v_{br} > v_r$)

Newton's Laws of Motion

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Formula Name / Topic	Formula(e)	Conditions / Usage
Newton's Second Law (General)	$\vec{F}_{ext} = \frac{d\vec{p}}{dt}$	Valid for all systems (even variable mass).
Newton's Second Law (Constant Mass)	$\vec{F}_{net} = m\vec{a}$	Valid only when mass m is constant and in an Inertial Frame.
Linear Momentum	$\vec{p} = m\vec{v}$	Quantity of motion contained in a body.
Impulse (J)	$\vec{J} = \int_{t_1}^{t_2} \vec{F}_{ext} dt = \Delta\vec{p}$ $\vec{J} = \vec{F}_{avg} \cdot \Delta t$	Used when a large force acts for a short time. $\Delta\vec{p} = \vec{p}_f - \vec{p}_i$.
Impulse-Momentum Theorem	$\text{Area under } F - t \text{ graph} = \Delta p$	Used to find change in momentum from a Force-Time graph.
Equilibrium of Forces	$\sum \vec{F} = 0 \implies \vec{a} = 0$	Body is at rest or moving with constant velocity.
Lami's Theorem	$\frac{F_1}{\sin\alpha} = \frac{F_2}{\sin\beta} = \frac{F_3}{\sin\gamma}$	Valid for 3 coplanar, concurrent forces in equilibrium.
Third Law (Action-Reaction)	$\vec{F}_{AB} = -\vec{F}_{BA}$	Action and reaction act on different bodies simultaneously.
Apparent Weight in Lift (Moving Up)	$N = m(g + a)$	Lift accelerating upwards with acceleration a.
Apparent Weight in Lift (Moving Down)	$N = m(g - a)$	Lift accelerating downwards with acceleration a ($a < g$).

Apparent Weight (Free Fall)	$N = 0$	Lift cable breaks ($a = g$). Weightlessness.
Conservation of Linear Momentum	$\vec{p}_{initial} = \vec{p}_{final}$ $m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$	Valid if net external force on the system is zero ($\vec{F}_{ext} = 0$).
Rocket Propulsion (Thrust & Accel)	$F_{thrust} = u_{rel}\left(-\frac{dm}{dt}\right)$ $a = \frac{u_{rel}}{m}\left(-\frac{dm}{dt}\right) - g$	u_{rel} is exhaust speed relative to rocket. $-\frac{dm}{dt}$ is rate of fuel consumption.
Rocket Velocity (at time t)	$v = u_{rel}\ln\left(\frac{m_0}{m_t}\right) - gt$	m_0: initial mass, m_t: mass at time t. Neglecting initial velocity v_0.
Force by Liquid Jet (Thrust on Pipe)	$F = v\frac{dm}{dt} = \rho A v^2$	Reaction force on a pipe ejecting liquid of density ρ through area A.
Force by Liquid Jet (Striking Wall)	$F = \rho A v^2$ (Stops) $F = 2\rho A v^2$ (Reflects)	Force exerted by a jet striking a vertical wall normally.
Connected Bodies (Atwood Machine)	$a = \left(\frac{m_2 - m_1}{m_1 + m_2}\right)g$ $T = \left(\frac{2m_1m_2}{m_1 + m_2}\right)g$	Massless, frictionless pulley and string. $m_2 > m_1$.

Block on Smooth Inclined Plane	$a = g \sin\theta$	Sliding down a frictionless incline of angle θ.
	$N = mg \cos\theta$	
Static Friction (f_s)	$f_s \le \mu_s N$ $f_{s,max} = \mu_s N$ (Limiting Friction)	Self-adjusting force. Prevents relative motion. N is Normal reaction.
Kinetic Friction (f_k)	$f_k = \mu_k N$	Opposes relative motion when bodies are actually sliding.
Angle of Friction (λ)	$\tan\lambda = \mu_s$	Angle between Normal reaction and Resultant of contact forces.
Angle of Repose (α)	$\tan\alpha = \mu_s$	Min angle of incline at which block starts sliding. ($\alpha = \lambda$).
Acceleration on Rough Incline (Down)	$a = g(\sin\theta - \mu_k \cos\theta)$	Block sliding down a rough inclined plane.
Acceleration on Rough Incline (Up)	$a = g(\sin\theta + \mu_k \cos\theta)$	Block pushed up a rough inclined plane (retardation).
Centripetal Force	$F_c = \frac{mv^2}{r} = m\omega^2 r$	Net radial force required for circular motion directed towards center.
Safe Turn on Level Road	$v_{max} = \sqrt{\mu_s r g}$	Vehicle turning on a flat horizontal road. Friction provides centripetal force.
Banking of Roads (Smooth)	$\tan\theta = \frac{v^2}{rg}$	Friction ignored. Ideal banking angle.
Banking of Roads (With Friction)	$v_{max} = \sqrt{rg\left(\frac{\mu_s + \tan\theta}{1 - \mu_s \tan\theta}\right)}$	Maximum safe speed on a banked rough road.

Bending of Cyclist	$$\tan\theta = \frac{v^2}{rg}$$	Cyclist leans inward to provide necessary centripetal force.
Pseudo Force	$\rightarrow$	Applied to an object when observing

Work, Power, and Energy

BY AP Sir, Sakaar Classes

Formula Name / Topic	Formula	Condition / Notes
1. Work Done (Constant Force)	$W = \vec{F} \cdot \vec{S} = FS\cos\theta$	Force $\vec{F}$ is constant. θ is angle between $\vec{F}$ and displacement $\vec{S}$.
2. Work Done (Variable Force)	$W = \int_{x_1}^{x_2} F_x dx$	Force varies with position.
	$W = \int \vec{F} \cdot d\vec{r}$	
3. Work from Graph	$W = \text{Area under } F\text{-}x \text{ graph}$	Area between force curve and displacement axis (Area above axis is +, below is -).
4. Kinetic Energy (KE)	$K = \frac{1}{2}mv^2 = \frac{p^2}{2m}$	$p = mv$ is linear momentum. Relation between KE and Momentum is crucial.
5. Work-Energy Theorem	$W_{\text{net}} = \Delta K = K_f - K_i$	Valid for **all** frames (inertial/non-inertial). W_{net} is work by ALL forces (conservative, non-conservative, pseudo).
6. Gravitational Potential Energy (PE)	$U = mgh$	Near Earth's surface where g is constant. Ref level at ground ($U = 0$).
7. Spring Potential Energy	$U = \frac{1}{2}kx^2$	x is elongation or compression from **natural length**. k is spring constant.
8. Conservative Force & PE Relation	$F = -\frac{dU}{dx}$	Only defined for conservative forces (Gravity, Electrostatic, Spring).
	$\Delta U = -W_{conservative}$	

9. Conservation of Mechanical Energy	$K_i + U_i = K_f + U_f$	Condition: Only conservative forces do work ($W_{ext} = 0, W_{nc} = 0$).
10. Work by Non-Conservative Forces	$W_{nc} = \Delta E_{mech} = (K_f + U_f) - (K_i + U_i)$	Used when friction or air resistance is present.
11. Average Power	$P_{avg} = \frac{\Delta W}{\Delta t}$	Total work done divided by total time taken.
12. Instantaneous Power	$P = \vec{F} \cdot \vec{v} = Fv\cos\theta$	Rate of work at a specific instant.
13. Vertical Circular Motion (Critical)	$v_{top} \geq \sqrt{gR}$, $v_{bottom} \geq \sqrt{5gR}$	Condition to complete a full vertical circle (String/Loop).
14. Vertical Circular Motion (Tension)	$T_{bottom} - T_{top} = 6mg$	Difference in tension between lowest and highest point.
15. Coefficient of Restitution (e)	$e = \frac{v_{sep}}{v_{app}} = \frac{v_2 - v_1}{u_1 - u_2}$	$e = 1$ (Elastic), $0 < e < 1$ (Inelastic), $e = 0$ (Perfectly Inelastic). Along Line of Impact.
16. Elastic Collision (1D)	$v_1 = \left(\frac{m_1 - m_2}{m_1 + m_2}\right) u_1 + \left(\frac{2m_2}{m_1 + m_2}\right) u_2$	Momentum and KE are conserved.
17. Perfectly Inelastic Collision	$V_{common} = \frac{m_1 u_1 + m_2 u_2}{m_1 + m_2}$	Bodies stick together ($e = 0$). Max loss of KE.
18. Loss in KE (Collision)	$\Delta K = \frac{1}{2} \frac{m_1 m_2}{m_1 + m_2} (u_1 - u_2)^2 (1 - e^2)$	General formula for KE loss in any head-on collision.
19. Equilibrium Conditions	Stable: $U'' > 0$, Unstable: $U'' < 0$, Neutral: $U'' = 0$	$U'' = d^2U/dx^2$. At equilibrium, Net Force is zero.
20. Chain Pulling Problem	$W = \frac{MgL}{2n^2}$	Work to pull a chain hanging $1/n$ th part off a table back onto the table.
21. Stopping Distance	$d_s = \frac{v^2}{2\mu g}$	Vehicle stopping distance with friction coefficient μ.

22. Power of a Pump/Motor	$P = \frac{dm}{dt}gh + \frac{1}{2}\frac{dm}{dt}v^2$	Power to lift water rate dm/dt to height h and eject with velocity v.
23. Rebound Height	$h_n = e^{2n}h_0$	Height after n^{th} bounce. Total distance $= h_0\left(\frac{1+e^2}{1-e^2}\right)$.
24. Spring-Block (Sudden Release)	$x_{max} = \frac{2mg}{k}$	If a block of mass m attached to a spring is released suddenly from natural length.
25. Bullet Penetration	$F_{avg} \cdot d = \frac{1}{2}mv^2$	Work done by resistive force = Change in KE.
26. Oblique Collision	$v \sin\alpha = u \sin\theta$	Comp. of velocity $\perp$ to line of impact is unchanged. Along line of impact, use e.

CIRCULAR MOTION

BY AP Sir, Sakaar Classes

Formula / Topic Name	Formula	Conditions / Usage
1. Kinematics of Circular Motion		
Angular Velocity (ω)	$$\omega_{avg} = \frac{\Delta\theta}{\Delta t}$$	Rate of change of angular displacement.
	$$\omega_{inst} = \frac{d\theta}{dt}$$	
Linear Velocity (v)	$$v = r\omega$$	Relation between linear speed (v) and angular speed (ω) for a particle at radius r.
Angular Acceleration (α)	$$\alpha = \frac{d\omega}{dt} = \frac{d^2\theta}{dt^2}$$	Rate of change of angular velocity.
Tangential Acceleration (a_t)	$$a_t = r\alpha = \frac{dv}{dt}$$	Responsible for changing the **magnitude** of velocity (speed). Zero in U.C.M.
Centripetal (Radial) Acceleration (a_c or a_r)	$$a_c = \frac{v^2}{r} = r\omega^2 = v\omega$$	Responsible for changing the **direction** of velocity. Always directs towards center.
Net Acceleration (a_{net})	$$a_{net} = \sqrt{a_c^2 + a_t^2}$$	Vector sum of radial and tangential acceleration.
Angle of Net Acceleration (ϕ)	$$\tan\phi = \frac{a_c}{a_t}$$	ϕ is the angle made by net acceleration with the tangential direction.
Equations of Circular Motion	$$\omega = \omega_0 + \alpha t$$	**Condition:** Only valid when Angular Acceleration (α) is **constant**.

$$\theta = \omega_0 t + \frac{1}{2}\alpha t^2$$

$$\omega^2 = \omega_0^2 + 2\alpha\theta$$

2. Dynamics of Circular Motion

Centripetal Force (F_c)	$F_c = \frac{mv^2}{r} = mr\omega^2$	Real force required to keep a body in circular motion (provided by Tension, Friction, Normal, etc.).
Centrifugal Force (Pseudo Force)	$F_{cf} = \frac{mv^2}{r}$	Acts radially outward. **Condition:** Only applicable in a **rotating (non-inertial) reference frame**.

3. Banking of Roads & Turning

Bending of Cyclist	$\tan\theta = \frac{v^2}{rg}$	θ with vertical. Condition for no skidding while turning.
Car on Level Circular Road (No Banking)	$v_{max} = \sqrt{\mu_s rg}$	Maximum safe speed to avoid skidding. μ_s = coefficient of static friction.
Banked Road (Frictionless)	$\tan\theta = \frac{v^2}{rg}$	Optimum speed $v_{opt} = \sqrt{rg\tan\theta}$. No wear and tear on tires.
Banked Road (With Friction) - Max Speed	$v_{max} = \sqrt{rg\left(\frac{\mu_s + \tan\theta}{1 - \mu_s\tan\theta}\right)}$	Speed limit to avoid slipping **outwards** (up the incline).
Banked Road (With Friction) - Min Speed	$v_{min} = \sqrt{rg\left(\frac{\tan\theta - \mu_s}{1 + \mu_s\tan\theta}\right)}$	Speed limit to avoid slipping **inwards** (down the incline).

4. Conical Pendulum

Angular Velocity	$$\omega = \sqrt{\frac{g}{L\cos\theta}} = \sqrt{\frac{g}{h}}$$	L = length of string, h = vertical height of point of suspension from circle center.
Time Period (T)	$$T = 2\pi\sqrt{\frac{L\cos\theta}{g}} = 2\pi\sqrt{\frac{h}{g}}$$	Time for one complete revolution.
Tension in String	$$T_{tension} = \frac{mg}{\cos\theta} = mL\omega^2$$	
5. Vertical Circular Motion (String)		
Velocity at any point	$$v = \sqrt{u^2 - 2gh}$$	u = speed at bottom, h = height from bottom.
Tension at any point	$$T = \frac{mv^2}{r} + mg\cos\theta$$	θ is angle with vertical downward direction.
Critical Velocity (Top)	$$v_{top} = \sqrt{gR}$$	Minimum speed at top to keep string taut ($T_{top} \geq 0$).
Critical Velocity (Bottom)	$$v_{bottom} = \sqrt{5gR}$$	Minimum speed at bottom to complete the full circle.
Critical Velocity (Horizontal Point)	$$v_{mid} = \sqrt{3gR}$$	Speed at the point where string is horizontal.
Tension Difference	$$T_{bottom} - T_{top} = 6mg$$	Valid for any vertical circular motion under gravity.
Condition for Oscillation	$$0 < v_{bottom} \leq \sqrt{2gR}$$	Particle oscillates like a pendulum (doesn't reach horizontal level).
Condition for Leaving Circle	$$\sqrt{2gR} < v_{bottom} < \sqrt{5gR}$$	Particle leaves the circular path in the upper half (T becomes 0 before v).
6. Specific Formulae for Questions		

"Death Well" (Rotor)	$$v_{min} = \sqrt{\frac{gR}{\mu}}$$	Min speed to prevent falling. Friction acts upwards balancing weight.
Vehicle on Convex Bridge	$$v_{max} = \sqrt{gR}$$	Max speed to maintain contact with the bridge (Normal reaction $N = 0$).
Radius of Curvature (Projectile)	$$R_{curv} = \frac{v^2}{a_\perp}$$	At top of trajectory: $$R = \frac{u^2 \cos^2 \theta}{g}$$
Toppling of Car on Turn	$$v_{max} = \sqrt{\frac{gra}{h}}$$	$2a$ = distance between wheels (track width), h = height of Center of Mass. Condition: Topples if $v > v_{max}$.

Rotational Motion

BY AP Sir, Sakaar Classes

Formula / Topic Name	Formula(e)	Conditions / When to use
1. KINEMATICS OF ROTATION		
Angular Displacement	$\theta = \frac{l}{r}$	Angle in radians, l = arc length.
Angular Velocity	$\omega_{avg} = \frac{\Delta\theta}{\Delta t}$	Rate of change of angular position.
	$\omega_{inst} = \frac{d\theta}{dt}$	
Angular Acceleration	$\alpha_{avg} = \frac{\Delta\omega}{\Delta t}$	Rate of change of angular velocity.
	$\alpha_{inst} = \frac{d\omega}{dt} = \omega\frac{d\omega}{d\theta}$	
Equations of Kinematics	1. $\omega = \omega_0 + \alpha t$	**Strictly valid only when angular acceleration (α) is CONSTANT.**
	2. $\Delta\theta = \omega_0 t + \frac{1}{2}\alpha t^2$	
	3. $\omega^2 = \omega_0^2 + 2\alpha\Delta\theta$	
	4. $\theta_{nth} = \omega_0 + \frac{\alpha}{2}(2n - 1)$	
Linear vs Angular Variables	$v = \omega r$	v is tangential velocity.
	$a_t = \alpha r$ (Tangential acc.)	a_t changes speed.
	$a_c = \omega^2 r$ (Centripetal acc.)	a_c changes direction (always exists if $\omega \neq 0$).

$a_{net} = \sqrt{a_t^2 + a_c^2}$

2. MOMENT OF INERTIA (MOI)		
Discrete System	$I = \sum m_i r_i^2$	r_i is perpendicular distance from the axis of rotation.
Continuous Bodies	$I = \int r^2 dm$	Requires integration.
Radius of Gyration (k)	$I = Mk^2 \Rightarrow k = \sqrt{\frac{I}{M}}$	Distance where total mass is theoretically concentrated to give same I.
Perpendicular Axis Theorem	$I_z = I_x + I_y$	**Valid ONLY for planar (2D) bodies** (laminar objects). Axes x, y must be in the plane; z perpendicular to plane.
Parallel Axis Theorem	$I_{axis} = I_{CM} + Md^2$	Valid for **any** 3D or 2D body.
		d = perpendicular distance between parallel axes.
		One axis MUST pass through Center of Mass (CM).
3. MOI OF STANDARD BODIES	**(Axis through Center, unless specified)**	
Ring / Hollow Cylinder	$I = MR^2$	Axis perpendicular to plane (Ring) or along geometrical axis (Cylinder).
Disc / Solid Cylinder	$I = \frac{MR^2}{2}$	Axis perpendicular to plane (Disc) or along geometrical axis (Cylinder).

Thin Rod	$I = \frac{ML^2}{12}$ (Center)	Axis perpendicular to length.
	$I = \frac{ML^2}{3}$ (End)	
Solid Sphere	$I = \frac{2}{5}MR^2$	Axis along diameter.
Hollow Sphere (Shell)	$I = \frac{2}{3}MR^2$	Axis along diameter.
Rectangular Plate	$I = \frac{M(a^2+b^2)}{12}$	Axis perpendicular to plate, through center.
4. TORQUE (τ)		
Vector Definition	$\vec{\tau} = \vec{r} \times \vec{F}$	\tau
	$	
Newton's 2nd Law (Rotation)	$\vec{\tau}_{net} = I\vec{\alpha}$	Valid for rigid bodies rotating about a fixed axis or about CM.
	$\vec{\tau}_{net} = \frac{d\vec{L}}{dt}$	
Couple	$\tau = F \times d$	Two equal and opposite forces. Torque is independent of the choice of origin.
Rotational Equilibrium	$\sum \vec{F}_{ext} = 0$ AND $\sum \vec{\tau}_{ext} = 0$	Body is neither accelerating translationally nor rotationally.
5. ANGULAR MOMENTUM (L)		
Point Mass	$\vec{L} = \vec{r} \times \vec{p} = m(\vec{r} \times \vec{v})$	About a specific origin.
	$L = mvr_{\perp}$	

Rigid Body (Fixed Axis)	$L = I\omega$	Axis must be fixed or passing through CM.
Combined Motion (Rolling)	$\vec{L} = \vec{L}_{CM} + \vec{L}_{aboutCM} = M(\vec{r}_{cm} \times \vec{v}_{cm}) + I_{cm}\vec{\omega}$	General formula for a body moving and rotating.
Conservation of Angular Momentum	$I_1\omega_1 = I_2\omega_2$	**Condition:** Net external torque on the system is ZERO ($\tau_{ext} = 0$).
6. WORK, POWER, ENERGY		
Rotational Kinetic Energy	$K_{rot} = \frac{1}{2}I\omega^2$	Pure rotation about an axis.
Work Done	$W = \int \tau d\theta = \vec{\tau} \cdot \Delta\vec{\theta}$	Analogous to $W = \vec{F} \cdot \vec{d}$.
Power	$P = \vec{\tau} \cdot \vec{\omega}$	Instantaneous power delivered by torque.
Work-Energy Theorem	$W_{ext} = \Delta K = K_f - K_i$	Work done by all torques equals change in Rotational KE.
7. ROLLING MOTION		
Condition for Pure Rolling	$v_{cm} = \omega R$	Velocity of the bottom-most point (contact point) is zero relative to ground.
	$a_{cm} = \alpha R$	
Total Kinetic Energy	$K_{total} = K_{trans} + K_{rot}$	Useful factor $\beta = (1 + \frac{k^2}{R^2})$.
	$K_{total} = \frac{1}{2}Mv_{cm}^2 + \frac{1}{2}I_{cm}\omega^2$	Ring: $\beta = 2$, Disc: $\beta = 1.5$, Solid Sphere: $\beta = 1.4$.
	$K_{total} = \frac{1}{2}Mv_{cm}^2(1 + \frac{k^2}{R^2})$	
8. ROLLING ON INCLINED PLANE	**(Specific Question Formulae)**	**Body rolling down from rest without slipping.**

Acceleration	$a = \frac{g\sin\theta}{1+\frac{I}{MR^2}} = \frac{g\sin\theta}{\beta}$	Standard NEET/JEE result. Solid sphere accelerates fastest (lowest β).
Velocity at bottom	$v = \sqrt{\frac{2gh}{1+\frac{k^2}{R^2}}}$	Depends only on height h and shape factor $\frac{k^2}{R^2}$, not Mass or Radius.
Time to reach bottom	$t = \sqrt{\frac{2L(1+\frac{k^2}{R^2})}{g\sin\theta}}$	L = length of incline. Ring takes max time, Solid sphere takes min time.
Min Friction Coefficient	$\mu_{min} = \frac{\tan\theta}{1+\frac{MR^2}{I}}$	Condition to prevent slipping while rolling down.
9. COLLISION & TOPPLING		
Angular Impulse (J)	$J = \int \tau dt = \Delta L$	Change in Angular Momentum.
Rod hit by particle	$L_i = L_f$ (about hinge/pivot) $mvx = (\frac{ML^2}{3} + mx^2)\omega$	Use Conservation of Angular Momentum about the pivot point to find ω after impact.

Centre of Mass and Collisions

BY AP Sir, Sakaar Classes

Formula Name / Topic	Formula(e)	Conditions / Usage
1. Position of COM (Two Particles)	$$X_{cm} = \frac{m_1x_1 + m_2x_2}{m_1 + m_2}$$	System of two point masses m_1, m_2 at positions x_1, x_2.
2. Position Vector of COM (Discrete)	$$\vec{R}_{cm} = \frac{m_1\vec{r}_1 + m_2\vec{r}_2 + ... + m_n\vec{r}_n}{M_{total}}$$	General system of n discrete particles.
3. Coordinate Formulae (3D)	$$X_{cm} = \frac{\sum m_ix_i}{\sum m_i}$$, $$Y_{cm} = \frac{\sum m_iy_i}{\sum m_i}$$, $$Z_{cm} = \frac{\sum m_iz_i}{\sum m_i}$$	To find specific coordinates (x, y, z) of the COM.
4. COM of Continuous Bodies	$$X_{cm} = \frac{1}{M}\int x\,dm$$, $$Y_{cm} = \frac{1}{M}\int y\,dm$$	Used for rigid bodies (rods, discs, etc.) where mass is distributed continuously.
5. Linear Mass Density (λ)	$$dm = \lambda\,dx$$	Used for 1D objects like rods/wires.
6. Areal Mass Density (σ)	$$dm = \sigma\,dA$$	Used for 2D objects like plates/discs/shells.

7. Volumetric Mass Density (ρ)	$dm = \rho \, dV$	Used for 3D objects like spheres/cones.
8. COM: Uniform Semi-Circular Ring	$Y_{cm} = \frac{2R}{\pi}$	Center of base is at origin. Symmetric axis is Y-axis.
9. COM: Uniform Semi-Circular Disc	$Y_{cm} = \frac{4R}{3\pi}$	Center of base is at origin.
10. COM: Hollow Hemisphere	$Y_{cm} = \frac{R}{2}$	From the center of the base.
11. COM: Solid Hemisphere	$Y_{cm} = \frac{3R}{8}$	From the center of the base.
12. COM: Hollow Cone	$Y_{cm} = \frac{h}{3}$	From the center of the base.
13. COM: Solid Cone	$Y_{cm} = \frac{h}{4}$	From the center of the base.
14. COM: Cavity Problems (Negative Mass)	$\vec{r}_{cm} = \frac{M_{original}\vec{r}_1 - M_{removed}\vec{r}_2}{M_{original} - M_{removed}}$	When a part is removed from a rigid body. $\vec{r}_1$ is COM of original, $\vec{r}_2$ is COM of removed part.
15. Velocity of COM	$\vec{v}_{cm} = \frac{m_1\vec{v}_1 + m_2\vec{v}_2 + ...}{M_{total}}$	Velocity of the system's center of mass.
16. Acceleration of COM	$\vec{a}_{cm} = \frac{\vec{F}_{ext}}{M_{total}}$	Newton's 2nd Law applied to the whole system.
17. Momentum Conservation (System)	$\vec{P}_{initial} = \vec{P}_{final}$	Valid ONLY if **External Force** ($\vec{F}_{ext}$) on the system is **Zero**.
18. Displacement of COM	$\Delta\vec{r}_{cm} = \frac{m_1\Delta\vec{r}_1 + m_2\Delta\vec{r}_2}{M}$	If $\vec{F}_{ext} = 0$ initially at rest, then $\Delta\vec{r}_{cm} = 0$. (e.g., Boat & Dog problems).

19. Impulse ($\vec{J}$)	$$\vec{J} = \int \vec{F} dt = \Delta \vec{P} = \vec{P}_f - \vec{P}_i$$	Change in momentum caused by a large force over a short time.
20. Coefficient of Restitution (e)	$$e = \frac{\text{Velocity of Separation}}{\text{Velocity of Approach}} = \frac{v_2 - v_1}{u_1 - u_2}$$	Defined along the **Line of Impact**. $0 \le e \le 1$.
21. Head-on Elastic Collision ($e = 1$)	$$v_1 = \left(\frac{m_1 - m_2}{m_1 + m_2}\right) u_1 + \left(\frac{2m_2}{m_1 + m_2}\right) u_2$$	Final velocity of mass 1. Conservation of KE & Momentum holds.
22. Head-on Elastic Collision ($e = 1$)	$$v_2 = \left(\frac{m_2 - m_1}{m_1 + m_2}\right) u_2 + \left(\frac{2m_1}{m_1 + m_2}\right) u_1$$	Final velocity of mass 2.
23. Elastic Collision: Equal Masses	$$v_1 = u_2, \quad v_2 = u_1$$	If $m_1 = m_2$, velocities are **exchanged**.
24. Perfectly Inelastic Collision ($e = 0$)	$$V_{common} = \frac{m_1 u_1 + m_2 u_2}{m_1 + m_2}$$	Particles stick together and move with common velocity. Max KE loss.
25. Inelastic Collision ($0 < e < 1$)	$$v_1 = \frac{m_1 u_1 + m_2 u_2 - m_2 e(u_1 - u_2)}{m_1 + m_2}$$	General formula for 1D collision.
26. Loss in KE (Head-on)	$$\Delta K = \frac{1}{2} \left(\frac{m_1 m_2}{m_1 + m_2}\right) (u_1 - u_2)^2 (1 - e^2)$$	Energy dissipated as heat/sound. Zero if $e = 1$ (Elastic).
27. Oblique Collision (2D)	Along Line of Impact (LOI): $$e = \frac{v_{2n} - v_{1n}}{u_{1n} - u_{2n}}$$	Momentum is conserved along LOI and Tangential axis (if smooth). Restitution eq applies ONLY along LOI.
28. Rocket Propulsion (Thrust)	$$F_{thrust} = v_{rel} \left(-\frac{dm}{dt}\right)$$	Force on rocket due to ejected gas. v_{rel} is velocity of gas w.r.t rocket.
29. Rocket		Velocity at time t (ignoring

ELASTICITY

BY AP Sir, Sakaar Classes

Formula Name / Topic	Formula	Condition / Context / Use Case
Normal Stress (σ)	$\sigma = \frac{F_\perp}{A}$	Restoring force ($F_\perp$) acting per unit area perpendicular to the cross-section.
Tangential / Shear Stress (σ_t)	$\sigma_t = \frac{F_\parallel}{A}$	Force ($F_\parallel$) acting parallel to the surface area. Causes shape change without volume change.
Longitudinal Strain (ε_l)	$\varepsilon_l = \frac{\Delta L}{L}$	Change in length per unit original length (Tensile or Compressive).
Shearing Strain (ϕ)	$\phi \approx \tan\phi = \frac{x}{L}$	Relative displacement (x) between parallel layers separated by distance L.
Volumetric Strain (ε_v)	$\varepsilon_v = -\frac{\Delta V}{V}$	Change in volume per unit original volume. Negative sign indicates decrease in volume with pressure increase.
Hooke's Law	$\text{Stress} \propto \text{Strain}$ $\text{Stress} = E \times \text{Strain}$	Valid only within the **Proportional Limit**. E is the Modulus of Elasticity.
Young's Modulus (Y)	$Y = \frac{\text{Longitudinal Stress}}{\text{Longitudinal Strain}}$ $Y = \frac{FL}{A\Delta l} = \frac{mgL}{\pi r^2 \Delta l}$	Used for solids (wires, rods) undergoing length change. Specific for a material.
Bulk Modulus (B or K)	$B = \frac{-P}{\Delta V/V} = -V\frac{\Delta P}{\Delta V}$	Relates volume change to pressure change. Applicable to solids, liquids, and gases.
Compressibility (K)	$K = \frac{1}{B}$	Reciprocal of Bulk Modulus.

Modulus of Rigidity / Shear Modulus (η or G)	$\eta = \frac{\text{Shear Stress}}{\text{Shear Strain}} = \frac{F}{A\phi}$	Resistance to change in shape. Only for solids.
Poisson's Ratio (σ)	$\sigma = -\frac{\text{Lateral Strain}}{\text{Longitudinal Strain}}$	Theoretical limits: -1 to 0.5.
	$\sigma = \frac{\Delta D/D}{\Delta L/L}$	Practical limits: 0 to 0.5.
Work Done in Stretching (Strain Energy U)	$U = \frac{1}{2} \times F \times \Delta l$	Total potential energy stored in a stretched wire.
	$U = \frac{1}{2} \times \text{stress} \times \text{strain} \times \text{Volume}$	
Energy Density (u)	$u = \frac{1}{2} \times \text{stress} \times \text{strain}$	Energy stored per unit volume.
	$u = \frac{1}{2}Y(\text{strain})^2 = \frac{(\text{stress})^2}{2Y}$	
Elongation due to Self Weight	$\Delta l = \frac{MgL}{2AY} = \frac{\rho g L^2}{2Y}$	Extension of a hanging rod/wire due to its own gravity. M=mass, ρ=density. Note the factor **2** in denominator (acts at Center of Mass).
Thermal Stress	$\sigma_{\text{thermal}} = Y\alpha\Delta T$	Rod fixed between rigid supports.
	Force $F = YA\alpha\Delta T$	α = coeff. of linear expansion, ΔT = temp change.
Analogy with Spring Constant (k)	$k = \frac{YA}{L}$	Treating a wire as a spring ($F = kx$). Useful for series/parallel combination of wires.
Wires in Series	$\frac{1}{k_{eq}} = \frac{1}{k_1} + \frac{1}{k_2}$	Composite wire with same Force/Tension acting on both segments.
	$\Delta l_{net} = \Delta l_1 + \Delta l_2$	

Wires in Parallel	$k_{eq} = k_1 + k_2$ $F_{net} = F_1 + F_2$	Composite wire where extensions are forced to be equal ($\Delta l_1 = \Delta l_2$).
Interatomic Force Constant (k_a)	$k_a = Y \times r_0$	r_0 is the equilibrium interatomic distance.
Depression of a Beam (Cantilever)	$\delta = \frac{WL^3}{3YI_g}$	Beam fixed at one end, loaded (W) at the other. I_g is Geometrical Moment of Inertia.
Depression of Beam (Supported at ends)	$\delta = \frac{WL^3}{48YI_g}$	Beam supported at both ends, load W in the center.
Torsion of a Cylinder	$C = \frac{\pi\eta r^4}{2L}$	Restoring couple per unit twist (Torsional rigidity).
Breaking Stress	$\text{Breaking Force} = \text{Breaking Stress} \times A$	Breaking stress depends on material, not dimensions. Breaking Force depends on area.
Relation: Y, B, σ	$Y = 3B(1 - 2\sigma)$	Relates Young's, Bulk Modulus and Poisson's ratio.
Relation: Y, η, σ	$Y = 2\eta(1 + \sigma)$	Relates Young's, Rigidity Modulus and Poisson's ratio.
Relation: Y, B, η	$\frac{9}{Y} = \frac{1}{B} + \frac{3}{\eta}$	Useful when σ is not given.
Relation: σ in terms of B, η	$\sigma = \frac{3B-2\eta}{6B+2\eta}$	Calculation of Poisson's ratio from moduli.

Quick Tips for Numerical Questions (NEET/JEE)

1. **Wire Cut into n parts:** If a wire of Young's Modulus Y is cut into n equal parts, the Young's Modulus of each part remains Y (Material property), but the spring constant becomes nk.
2. **% Change questions:** If strain is small ($< 5\%$), use $\frac{\Delta R}{R} \times 100$. For volume of wire $V = A \times L$ (constant), $\frac{\Delta A}{A} = -\frac{\Delta L}{L}$ (ignoring σ effects for simple resistance type q's) or use conservation of volume $A_1 L_1 = A_2 L_2$.
3. **Adiabatic vs Isothermal Modulus:**

Fluid Mechanics & Surface Tension

BY AP Sir, Sakaar Classes

Fluid Properties & Hydrostatics

Formula Name / Topic	Formula	Condition / Note
Density & Relative Density (RD)	$\rho = \frac{m}{V}$	$\rho_{\text{water}} = 1000\,\text{kg/m}^3$. RD has no units.
	$\text{RD} = \frac{\rho_{\text{substance}}}{\rho_{\text{water at }4^\circ\text{C}}}$	
Pressure at Depth	$P = P_0 + h\rho g$	P_0: Atmospheric Pressure
		h: Depth below free surface.
Gauge Pressure	$P_g = P_{\text{absolute}} - P_{\text{atm}} = h\rho g$	Pressure due to fluid column only.
Pascal's Law	$\frac{F_1}{A_1} = \frac{F_2}{A_2}$	Pressure applied to enclosed fluid is transmitted undiminished.
Force on Vertical Dam Wall	$F = \frac{1}{2}\rho g w H^2$	w: Width, H: Depth. Force acts at $H/3$ from bottom.
Archimedes' Principle	$F_B = V_{\text{in}} \cdot \rho_L \cdot g$	V_{in}: Submerged volume
		ρ_L: Density of Liquid.
Condition for Floatation	$mg = F_B$	Body floats if $\rho_S \le \rho_L$. Weight of body = Weight of fluid displaced.
	$\frac{V_{\text{in}}}{V_{\text{total}}} = \frac{\rho_S}{\rho_L}$	
Accelerated Fluid (Horizontal)	$\tan\theta = \frac{a}{g}$	θ: Angle of free surface with horizontal.
Accelerated Fluid (Vertical)	$P = P_0 + h\rho(g_{\text{eff}})$	$g_{\text{eff}} = g + a$ (up), $g_{\text{eff}} = g - a$ (down).

Rotating Fluid (Vortex)	$y = \frac{\omega^2 x^2}{2g}$	Parabolic meniscus shape.

Fluid Dynamics

Formula Name / Topic	Formula	Condition / Note
Equation of Continuity	$A_1 v_1 = A_2 v_2$	Conservation of Mass. Incompressible, non-viscous flow.
Bernoulli's Principle	$P + \rho g h + \frac{1}{2}\rho v^2 = \text{Constant}$	Conservation of Energy per unit volume. Ideal fluid.
Torricelli's Law	$v = \sqrt{2gh}$	h: Depth of hole from top.
Horizontal Range of Efflux	$R = 2\sqrt{h(H-h)}$	$R_{\max} = H$ when hole is at $H/2$.
Time to empty tank	$t = \frac{A}{a}\sqrt{\frac{2}{g}}(\sqrt{H_1} - \sqrt{H_2})$	A: Tank area, a: Hole area.
Venturimeter	$Q = A_1 A_2 \sqrt{\frac{2gh}{A_1^2 - A_2^2}}$	h: Height diff in manometer.

Viscosity

Formula Name / Topic	Formula	Condition / Note
Newton's Law of Viscosity	$F = -\eta A \frac{dv}{dx}$	η: Coeff. of viscosity, $\frac{dv}{dx}$: Velocity gradient.
Stoke's Law	$F = 6\pi\eta r v$	Viscous drag on sphere of radius r.
Terminal Velocity	$v_T = \frac{2}{9}\frac{r^2(\rho-\sigma)g}{\eta}$	Constant max velocity. ρ: sphere, σ: fluid.
Poiseuille's Equation	$Q = \frac{\pi P r^4}{8\eta l}$	Volume flow rate in capillary tube.
Reynolds Number	$R_e = \frac{\rho v d}{\eta}$	$R_e < 1000$: Laminar, $R_e > 2000$: Turbulent.

Surface Tension

Formula Name / Topic	Formula	Condition / Note

Surface Tension	$T = \frac{F}{L}$	Force per unit length.
Surface Energy	$U = T \times \Delta A$	ΔA: Change in area.
Work done (Liquid Drop)	$W = T \cdot 4\pi(r_2^2 - r_1^2)$	Single surface.
Work done (Soap Bubble)	$W = T \cdot 8\pi(r_2^2 - r_1^2)$	Two surfaces (inner & outer).
Excess Pressure (Drop)	$\Delta P = \frac{2T}{R}$	Pressure inside > outside.
Excess Pressure (Bubble)	$\Delta P = \frac{4T}{R}$	Two free surfaces.
Capillary Rise	$h = \frac{2T\cos\theta}{r\rho g}$	Jurist's Law. θ: Contact angle.
Force to lift wire frame	$F = 2Tl + mg$	Surface tension acts on both sides.
Force to lift Ring	$F \approx 4\pi rT + mg$	Ring of radius r.
Splitting of Drops	$\Delta U = 4\pi R^2 T(n^{1/3} - 1)$	Energy absorbed (Temp falls).
Coalescence of Drops	$E_{\text{released}} = 4\pi T(nr^2 - R^2)$	Energy released (Temp rises).

"Success is the sum of small efforts, repeated day in and day out."

Oscillations (Simple Harmonic Motion)

BY AP Sir, Sakaar Classes

Formula / Topic Name	Formula(e)	Conditions / Notes
1. Standard Equation of SHM	$\frac{d^2x}{dt^2} + \omega^2 x = 0$	Differential equation condition for any particle executing SHM.
2. Displacement	$x = A\sin(\omega t + \phi)$ or $x = A\cos(\omega t + \phi)$	General displacement from mean position. ϕ: Initial phase (epoch). Use $\sin$ if starts from mean, $\cos$ if from extreme.
3. Angular Frequency	$\omega = \frac{2\pi}{T} = 2\pi f = \sqrt{\frac{k}{m}}$	ω: Angular frequency (rad/s). Depends on system properties (k, m), not amplitude.
4. Velocity (v)	$v = \frac{dx}{dt} = A\omega\cos(\omega t + \phi)$ $v = \pm\omega\sqrt{A^2 - x^2}$	$v_{max} = A\omega$ (at mean position, $x = 0$). $v_{min} = 0$ (at extreme position, $x = \pm A$).
5. Acceleration (a)	$a = \frac{dv}{dt} = -\omega^2 A\sin(\omega t + \phi)$ $a = -\omega^2 x$	Direction is always towards mean position. $a_{max} = \omega^2 A$ (at extreme). $a_{min} = 0$ (at mean).

6. Restoring Force	$F = -kx$	Linear SHM condition. Force is proportional to displacement and opposite in direction.
	$F = -m\omega^2 x$	
7. Phase Difference	$\Delta\phi = \phi_2 - \phi_1$	Time diff $\Delta t = \frac{T}{2\pi}\Delta\phi$.
		Path diff $\Delta x = \frac{\lambda}{2\pi}\Delta\phi$ (Wave context).
8. Kinetic Energy (KE)	$K = \frac{1}{2}mv^2 = \frac{1}{2}m\omega^2(A^2 - x^2)$	Max at mean position ($K_{max} = \frac{1}{2}kA^2$).
	$K = \frac{1}{2}kA^2 \cos^2(\omega t + \phi)$	Zero at extreme position.
9. Potential Energy (PE)	$U = \frac{1}{2}kx^2 = \frac{1}{2}m\omega^2 x^2$	Assuming $U = 0$ at mean position.
	$U = \frac{1}{2}kA^2 \sin^2(\omega t + \phi)$	Max at extreme ($U_{max} = \frac{1}{2}kA^2$).
10. Total Energy (TE)	$E = K + U = \frac{1}{2}m\omega^2 A^2 = \frac{1}{2}kA^2$	TE is constant (conserved) in undamped SHM.
		$E \propto A^2$ and $E \propto f^2$.
11. Average Energies	$< K >_{cycle} = < U >_{cycle} = \frac{1}{4}kA^2$	Over one complete cycle of oscillation.
	$< E >_{cycle} = \frac{1}{2}kA^2$	
12. Spring-Mass System (Horizontal/Vertical)	$T = 2\pi\sqrt{\frac{m}{k}}$	Period is independent of g and amplitude.
		k: Spring constant.
13. Springs in Series	$\frac{1}{k_{eq}} = \frac{1}{k_1} + \frac{1}{k_2} + \ldots$	End-to-end connection. Force is same, extension adds up.
14. Springs in Parallel	$k_{eq} = k_1 + k_2 + \ldots$	Side-by-side or mass between two fixed springs. Extensions are same.

15. Cutting a Spring	$k \cdot l = \text{constant} \implies k \propto \frac{1}{l}$	If spring of length l is cut into n equal parts, stiffness of each part becomes nk.
16. Two Block System (Reduced Mass)	$T = 2\pi\sqrt{\frac{\mu}{k}}$	Where reduced mass $\mu = \frac{m_1 m_2}{m_1+m_2}$. Blocks oscillate relative to center of mass.
17. Simple Pendulum	$T = 2\pi\sqrt{\frac{l}{g_{eff}}}$	For small angular amplitude ($\theta < 5°$). l: Length from pivot to CM of bob.
18. Pendulum in Lift	**Accelerating Up:** $g_{eff} = g + a$ $T = 2\pi\sqrt{\frac{l}{g+a}}$ **Accelerating Down:** $g_{eff} = g - a$ $T = 2\pi\sqrt{\frac{l}{g-a}}$	If lift falls freely ($a = g$), $g_{eff} = 0$, $T \to \infty$ (No oscillation).
19. Pendulum in Truck/Car	$g_{eff} = \sqrt{g^2 + a^2}$ $T = 2\pi\sqrt{\frac{l}{(g^2+a^2)^{1/2}}}$	Truck moving horizontally with acceleration a. Mean position shifts by $\tan\theta = a/g$.
20. Pendulum with Charged Bob	$g_{eff} = g + \frac{qE}{m}$ (E field down) $g_{eff} = g - \frac{qE}{m}$ (E field up)	Electric field E applied vertically.
21. Pendulum of Infinite Length	$T = 2\pi\sqrt{\frac{1}{g(\frac{1}{l}+\frac{1}{R_e})}}$	If $l \approx R_e$ (Earth's radius). If $l \to \infty$, $T = 2\pi\sqrt{\frac{R_e}{g}} \approx 84.6 \text{ min.}$

22. Second's Pendulum	$T = 2 \text{ seconds}$	Length $l \approx 0.993 \text{ m}$ (on Earth).
23. Physical Pendulum	$T = 2\pi\sqrt{\frac{I}{mgd}}$	I: Moment of Inertia about pivot.
		d: Distance between pivot and Center of Mass.
24. Torsional Pendulum	$T = 2\pi\sqrt{\frac{I}{C}}$	I: MOI of disc/body.
		C: Torsional constant (Nm/rad) of the wire.
25. Superposition (Same freq)	$x_{res} = A\sin(\omega t + \theta)$	δ: Phase difference between two waves.
	$A = \sqrt{A_1^2 + A_2^2 + 2A_1A_2\cos\delta}$	$\tan\theta = \frac{A_1 \sin\phi_1 + A_2 \sin\phi_2}{A_1 \cos\phi_1 + A_2 \cos\phi_2}$
26. Liquid in U-Tube	$T = 2\pi\sqrt{\frac{h}{g}}$ or $T = 2\pi\sqrt{\frac{L}{2g}}$	h: Height of liquid column in one arm at equilibrium.
		L: Total length of liquid column.
27. Body Floating in Liquid	$T = 2\pi\sqrt{\frac{m}{A\rho g}} = 2\pi\sqrt{\frac{h_{submerged}}{g}}$	A: Cross-sectional area. ρ: Density of liquid.
		Slightly depressed and released.
28. Tunnel through Earth	$T = 2\pi\sqrt{\frac{R_e}{g}} \approx 84.6 \text{ min}$	Particle dropped in a tunnel along diameter or chord. (Assuming uniform density).
29. Ball in Concave Dish	$T = 2\pi\sqrt{\frac{R-r}{g}}$	R: Radius of curvature of dish. r: Radius of ball.
		For small oscillations ($r \ll R$, $T \approx 2\pi\sqrt{R/g}$).
30. Piston in Cylinder	$T = 2\pi\sqrt{\frac{mV}{PA^2}}$	V: Volume, P: Pressure, A: Area of piston.

		(Adiabatic process usually considered, add factor γ in denominator for adiabatic).
31. Amplitude with	$A_n = A_0 f^n$ where $f < 1$	If amplitude decays by a constant

Wave Motion (Mechanical Waves)

BY AP Sir, Sakaar Classes

1. Basics of Wave Motion & Progressive Waves

Formula / Topic Name	Formula	Conditions / Usage Notes
General Plane Progressive Wave Equation	$y = A\sin(\omega t \pm kx + \phi)$	y: Displacement, A: Amplitude, ω: Angular freq, k: Propagation constant. **(-) sign**: Wave moving in +x direction. **(+) sign**: Wave moving in -x direction.
Angular Frequency (ω)	$\omega = 2\pi f = \frac{2\pi}{T}$	f: Frequency (Hz), T: Time period.

Propagation Constant (k)	$$k = \frac{2\pi}{\lambda}$$	$$\lambda$$: Wavelength. Represents phase change per unit length.
Wave Velocity (v)	$$v = f\lambda = \frac{\omega}{k}$$	Speed at which the disturbance travels through the medium.
Particle Velocity (v_p)	$$v_p = \frac{\partial y}{\partial t} = \omega A \cos(\omega t \pm kx)$$	Velocity of a particle oscillating about its mean position.
Relation: Particle vs Wave Velocity	$$v_p = -v \times \text{(slope of y-x graph)}$$ $$v_p = -v\left(\frac{\partial y}{\partial x}\right)$$	Used to find the direction of particle motion if the wave shape is known.
Particle Acceleration (a_p)	$$a_p = \frac{\partial^2 y}{\partial t^2} = -\omega^2 y$$	Maximum acceleration $$a_{max} = \omega^2 A$$ occurs at extreme positions ($$y = \pm A$$).
Phase Difference ($\Delta\phi$)	$$\Delta\phi = \frac{2\pi}{\lambda}\Delta x$$ $$\Delta\phi = \frac{2\pi}{T}\Delta t$$	Relation between Phase difference and Path difference (Δx) or Time difference (Δt).

2. Speed of Waves in Media

Formula / Topic Name	Formula	Conditions / Usage Notes

Speed of Transverse Wave on String	$v = \sqrt{\frac{T}{\mu}}$	T: Tension in string, μ: Linear mass density (m/L). **Imp:** Ensure μ is mass per unit length, not volume density.
Speed of Sound (General)	$v = \sqrt{\frac{E}{\rho}}$	E: Modulus of Elasticity, ρ: Density of medium.
Speed in Solids (Rod)	$v = \sqrt{\frac{Y}{\rho}}$	Y: Young's Modulus.
Speed in Fluids (Liquids/Gases)	$v = \sqrt{\frac{B}{\rho}}$	B: Bulk Modulus.
Newton's Formula (Gases)	$v = \sqrt{\frac{P}{\rho}}$	Assumed Isothermal process. (Incorrect historically, gives lower value).
Laplace Correction (Gases)	$v = \sqrt{\frac{\gamma P}{\rho}} = \sqrt{\frac{\gamma RT}{M}}$	Assumed Adiabatic process.

		$\gamma = C_p/C_v$ (Adiabatic index). T: Temp in Kelvin, M: Molar mass.
Effect of Temperature on Sound Speed	$v \propto \sqrt{T}$ $\frac{v_1}{v_2} = \sqrt{\frac{T_1}{T_2}}$	Speed increases with temperature.
Effect of Humidity	$v_{moist} > v_{dry}$	Moist air is less dense than dry air ($\rho_{moist} < \rho_{dry}$), so speed increases.

3. Superposition & Interference

Formula / Topic Name	Formula	Conditions / Usage Notes
Resultant Amplitude (A_{res})	$A_{res} = \sqrt{A_1^2 + A_2^2 + 2A_1A_2\cos\phi}$	ϕ is the phase difference between two interfering waves.
Resultant Intensity (I_{res})	$I_{res} = I_1 + I_2 + 2\sqrt{I_1I_2}\cos\phi$	Since $I \propto A^2$.

Constructive Interference (Maxima)	Condition: $$\phi = 2n\pi$$ Path diff $$\Delta x = n\lambda$$ $$A_{max} = A_1 + A_2$$ $$I_{max} = (\sqrt{I_1} + \sqrt{I_2})^2$$	Where $$n = 0, 1, 2, ...$$
Destructive Interference (Minima)	Condition: $$\phi = (2n - 1)\pi$$ Path diff $$\Delta x = (2n - 1)\frac{\lambda}{2}$$ $$A_{min} = \|\|A_1 - A_2$$ $$I_{min} = (\sqrt{I_1} - \sqrt{I_2})	Where $$n = 1, 2, 3, ...$$
Ratio of Intensities	$$\frac{I_{max}}{I_{min}} = \left(\frac{A_1 + A_2}{A_1 - A_2}\right)^2$$	Useful for questions given amplitude ratio $$r = A_1/A_2$$.

4. Stationary (Standing) Waves

Formula / Topic Name	Formula	Conditions / Usage Notes
General Equation	$$y = 2A\sin(kx)\cos(\omega t)$$	Or $$y = 2A\cos(kx)\sin(\omega t)$$. Amplitude of particle at $$x$$ is $$A(x) = 2A\sin(kx)$$.
Nodes & Antinodes	**Nodes:** Zero amplitude points. **Antinodes:** Max amplitude points.	Distance between consecutive Node & Node or Antinode & Antinode = $$\lambda/2$$. Distance between Node & Antinode = $$\lambda/4$$.
String Fixed at Both Ends	$$f_n = \frac{nv}{2L} = n\left(\frac{1}{2L}\sqrt{\frac{T}{\mu}}\right)$$	$$n = 1, 2, 3...$$ (Number of loops). $$n = 1$$: Fundamental/1st Harmonic.

		$$n = 2$$: 2nd Harmonic/1st Overtone. All harmonics are present.
String Fixed at One End	$$f_n = \frac{(2n-1)v}{4L}$$	$$n = 1, 2, 3...$$ Only odd harmonics are present ($$f_1, 3f_1, 5f_1...$$).
Sonometer Law	$$f \propto \frac{1}{L}$$, $$f \propto \sqrt{T}$$, $$f \propto \frac{1}{\sqrt{\mu}}$$	Used for comparing frequencies when length or tension changes.

5. Organ Pipes (Sound Columns)

Formula / Topic Name	Formula	Conditions / Usage Notes
Open Organ Pipe	$$f_n = \frac{nv}{2L}$$	Open at both ends. Similar to string fixed at both ends. All harmonics present ($$1 : 2 : 3...$$

		).
Closed Organ Pipe	$$f_n = \frac{(2n-1)v}{4L}$$	Closed at one end. Similar to string fixed at one end. Only odd harmonics present ($1 : 3 : 5...$).
End Correction (e)	$$e \approx 0.6r$$	r : Radius of pipe. Antinode forms slightly outside the open end.
Corrected Lengths	Open Pipe: $$L_{eff} = L + 2e$$ Closed Pipe: $$L_{eff} = L + e$$	Use these lengths in frequency formulas for precise calculation.
Resonance Tube	$$v = 2f(L_2 - L_1)$$	L_1 : First resonance length ($\lambda/4$). L_2 : Second resonance length ($3\lambda/4$). Eliminates end correction error.

6. Beats & Doppler Effect

Formula / Topic Name	Formula	Conditions / Usage Notes
Beat Frequency (f_b)	$$f_b = \|f_1 - f_2$$	Number of beats per second. Requires $$f_1 \approx f_2$$.
Tuning Fork Loading/Filing	**Waxing (Loading):** Mass $\uparrow$, Freq $\downarrow$. **Filing:** Mass $\downarrow$, Freq $\uparrow$.	Used to determine unknown frequency based on change in beat frequency.
Doppler Effect (General)	$$f' = f_0 \left(\frac{v \pm v_o}{v \mp v_s} \right)$$	f' : Apparent freq, f_0 : Source freq. v

		: Speed of sound. v_o : Observer velocity. v_s : Source velocity.
Doppler Sign Convention	**Numerator (v_o):** (+) if Observer moves TOWARDS source.	"Towards" tends to increase frequency.
	Denominator (v_s): (-) if Source moves TOWARDS observer.	"Away" tends to decrease frequency.
Effect of Wind (v_w)	$$f' = f_0 \left(\frac{(v \pm v_w) \pm v_o}{(v \pm v_w) \mp v_s} \right)$$	Add v_w to v if wind blows Source $\to$ Observer. Subtract if wind blows Observer $\to$ Source.

7. Intensity & Energy Density

Formula / Topic Name	Formula	Conditions / Usage Notes
Intensity (I)	$$I = 2\pi^2 f^2 A^2 \rho v$$	Power per unit area. Depends on square of frequency and amplitude.
Intensity vs Distance	**Point Source:**	Spherical wavefronts vs Cylindrical wavefronts.

Thermal Expansion and Calorimetry

BY AP Sir, Sakaar Classes

Formula Name / Topic	Formula(e)	Conditions / Notes
Linear Expansion	$\Delta L = L_0 \alpha \Delta T$ $L_f = L_0(1 + \alpha \Delta T)$	Valid for small temperature changes (ΔT). α is the coefficient of linear expansion.
Superficial (Area) Expansion	$\Delta A = A_0 \beta \Delta T$ $A_f = A_0(1 + \beta \Delta T)$	β is the coefficient of superficial expansion.
Volume Expansion	$\Delta V = V_0 \gamma \Delta T$ $V_f = V_0(1 + \gamma \Delta T)$	γ is the coefficient of volume expansion.
Relation between Coefficients	$\alpha : \beta : \gamma = 1 : 2 : 3$ $\beta = 2\alpha, \quad \gamma = 3\alpha$	strictly valid for isotropic solids (properties same in all directions).
Anisotropic Expansion	$\gamma = \alpha_x + \alpha_y + \alpha_z$	For non-isotropic solids where α differs along x, y, z axes.
Variation of Density	$\rho' = \frac{\rho_0}{1+\gamma \Delta T} \approx \rho_0(1 - \gamma \Delta T)$	Approximation valid when $\gamma \Delta T \ll 1$. ρ' decreases as T increases.
Thermal Stress	Stress $= Y \alpha \Delta T$ Force $= Y A \alpha \Delta T$	Rod held between rigid supports preventing expansion. Y is Young's Modulus.
Pendulum Clock (Time Period)	New Period: $T' = T(1 + \frac{1}{2}\alpha \Delta \theta)$	Due to length change $L' = L(1 + \alpha \Delta \theta)$. $\Delta \theta$ is temp change.

Time Lost/Gained (Pendulum)	$\Delta t = \frac{1}{2}\alpha\Delta\theta \times t$	If temp increases, clock expands, slows down (Loses time). If temp drops, gains time.
	Loss/day $= \frac{1}{2}\alpha\Delta\theta \times 86400$	
Bimetallic Strip	$R \approx \frac{d}{(\alpha_1-\alpha_2)\Delta T}$	Radius of curvature R when two strips of thickness d bend. $\alpha_1 > \alpha_2$.
Expansion of Liquids	$\gamma_{real} = \gamma_{app} + \gamma_{vessel}$	γ_{real} is actual expansion; γ_{app} is what we see in a container.
	$\gamma_{app} = \gamma_{real} - 3\alpha_{vessel}$	
Barometer Correction	$H_0 = H_{obs}[1 - (\gamma_{Hg} - \alpha_{scale})\Delta T]$	H_0 is true height at $0°C$. Corrects for both Hg expansion and scale expansion.
Specific Heat Capacity	$Q = ms\Delta T$ or $Q = mc\Delta T$	Heat required to change temp without phase change. s or c is specific heat.
Molar Heat Capacity	$Q = nC\Delta T$	n = number of moles. C = Molar heat capacity.
Heat Capacity (Thermal Capacity)	$H = ms$ or $H = \frac{Q}{\Delta T}$	Heat required to raise temp of the *whole body* by $1°C$.
Latent Heat (Phase Change)	$Q = mL$	Used during melting (L_f) or boiling (L_v). Temp remains constant.
Water Equivalent	$W = ms$	Mass of water that absorbs same heat as the body for same ΔT. (Unit: grams/kg)
Principle of Calorimetry	Heat Lost = Heat Gained	System must be isolated (no heat loss to surroundings).
	$\sum m_i s_i(T_i - T_{mix}) = \sum m_j s_j(T_{mix} - T_j)$	
Mixture Temperature	$T_{mix} = \frac{m_1s_1T_1+m_2s_2T_2}{m_1s_1+m_2s_2}$	For mixing two substances of same state (e.g., liquid + liquid).

Steam + Ice Mixture	Check heat available vs heat required step-by-step.	1. Heat released by steam to 100° water (mL_v). 2. Heat to cool water. Compare with ice melting req.
Newton's Law of Cooling (Exact)	$\frac{T-T_s}{T_0-T_s} = e^{-kt}$	T_s = Surroundings temp. T_0 = Initial temp. T = Temp at time t.
Newton's Law (Approx)	$\frac{T_1-T_2}{t} = K\left[\frac{T_1+T_2}{2} - T_s\right]$	Valid only when temp difference $(T - T_s)$ is small (approx $< 30^\circ C$).
Stefan's Law	$E = \sigma A e T^4$	Rate of energy radiated. e = emissivity ($0 \leq e \leq 1$).
Net Rate of Heat Loss (Radiation)	$\frac{dQ}{dt} = \sigma A e(T^4 - T_s^4)$	Body at temp T placed in surroundings at temp T_s. If $T > T_s$, heat is lost.
Growth of Ice (Ice Formation Time)	$t = \frac{\rho L}{2K\theta}(x_2^2 - x_1^2)$	Time taken to increase thickness from x_1 to x_2. θ = temp difference (Air - $0^\circ C$). K = Thermal conductivity.

Kinetic Theory of Gases and Thermodynamics

BY AP Sir, Sakaar Classes

1. Kinetic Theory of Gases (KTG) & Gas Laws

Formula Name / Topic	Formula(e)	Conditions / specific usage
Ideal Gas Equation	$PV = nRT$	**General Ideal Gas Law.**
	$PV = \frac{m}{M}RT$	n: moles, m: mass, M: Molar mass, ρ: density, N: number of molecules, k_B: Boltzmann constant ($1.38 \times 10^{-23} J/K$).
	$P = \rho \frac{RT}{M}$	
	$PV = Nk_BT$	
Boyle's Law	$P \propto \frac{1}{V} \implies P_1V_1 = P_2V_2$	**Constant Temperature (T)** (Isothermal).
		Graph P vs $1/V$ is a straight line through origin.
Charles's Law	$V \propto T \implies \frac{V_1}{T_1} = \frac{V_2}{T_2}$	**Constant Pressure (P)** (Isobaric).
		T must be in Kelvin.
Gay-Lussac's Law	$P \propto T \implies \frac{P_1}{T_1} = \frac{P_2}{T_2}$	**Constant Volume (V)** (Isochoric).
		Pressure Law. T must be in Kelvin.
Avogadro's Law	$V \propto n \implies \frac{V_1}{n_1} = \frac{V_2}{n_2}$	**Constant P and T.**
		Equal volumes of gases contain equal number of molecules.

Dalton's Law of Partial Pressure	$P_{total} = P_1 + P_2 + ... + P_n$	For non-reacting gas mixture.
	$P_i = x_i P_{total}$	$x_i = \frac{n_i}{n_{total}}$ (Mole fraction).
Graham's Law of Diffusion	$r \propto \frac{1}{\sqrt{M}} \implies \frac{r_1}{r_2} = \sqrt{\frac{M_2}{M_1}} = \sqrt{\frac{\rho_2}{\rho_1}}$	r: Rate of diffusion/effusion.
		Lighter gases diffuse faster.
		At const P and T.
Pressure of an Ideal Gas	$P = \frac{1}{3}\rho v_{rms}^2$	v_{rms}: Root Mean Square speed.
	$P = \frac{1}{3}\frac{mN}{V}v_{rms}^2$	Pressure depends on density and square of RMS speed.
	$P = \frac{2}{3}E$ (where E is K.E. per unit volume)	E: Total translational K.E. per unit volume.
Root Mean Square Speed (v_{rms})	$v_{rms} = \sqrt{\frac{3RT}{M}} = \sqrt{\frac{3k_BT}{m_{molecule}}} = \sqrt{\frac{3P}{\rho}}$	Speed effective in calculating kinetic energy.
		Note: T must be in Kelvin, M in kg/mol.
		For mixture: $v_{rms(mix)} = \sqrt{\frac{n_1M_1v_1^2+n_2M_2v_2^2}{n_1M_1+n_2M_2}}$
Average Speed (v_{avg})	$v_{avg} = \sqrt{\frac{8RT}{\pi M}} = \sqrt{\frac{8k_BT}{\pi m}}$	Arithmetic mean of speeds.
		$v_{avg} \approx 0.92 v_{rms}$
Most Probable Speed (v_{mp})	$v_{mp} = \sqrt{\frac{2RT}{M}} = \sqrt{\frac{2k_BT}{m}}$	Speed possessed by maximum fraction of molecules.
		Ratio $v_{mp} : v_{avg} : v_{rms} = \sqrt{2} : \sqrt{8/\pi} : \sqrt{3}$

Kinetic Energy (Translational)	Per molecule: $K.E. = \frac{3}{2}k_B T$	depends **ONLY** on Temperature (T).
	Per mole: $K.E. = \frac{3}{2}RT$	Independent of nature of gas.
Degrees of Freedom (f)	Monoatomic: $f = 3$ (3 trans)	Used to calculate internal energy and C_v.
	Diatomic (rigid): $f = 5$ (3 trans + 2 rot)	**Note:** For NEET/JEE, unless specified "high temp", take Diatomic $f = 5$.
	Diatomic (vib at high T): $f = 7$	
	Triatomic (linear): $f = 5$ (rigid) / 7 (vib)	
	Triatomic (non-linear): $f = 6$	
Law of Equipartition of Energy	Energy associated with each D.O.F = $\frac{1}{2}k_B T$ (per molecule)	Total Internal Energy (U) depends on f.
Internal Energy (U)	$U = \frac{f}{2}nRT$	For an ideal gas, U is a function of T only.
		Change: $\Delta U = \frac{f}{2}nR\Delta T = nC_v\Delta T$
Mean Free Path (λ)	$\lambda = \frac{1}{\sqrt{2}\pi d^2 n_v}$	d: diameter of molecule, n_v: number density (N/V).
		$\lambda \propto \frac{T}{P}$ (since $n_v = P/k_B T$).
Mixture of Gases	$M_{mix} = \frac{n_1 M_1 + n_2 M_2}{n_1 + n_2}$	Used when non-reacting gases are mixed.
	$C_{v(mix)} = \frac{n_1 C_{v1} + n_2 C_{v2}}{n_1 + n_2}$	
	$\gamma_{mix} = \frac{C_{p(mix)}}{C_{v(mix)}}$	

2. Thermodynamics

Formula Name / Topic	Formula(e)	Conditions / specific usage
First Law of Thermodynamics (FLOT)	$dQ = dU + dW$	**Conservation of Energy.**
	$Q = \Delta U + W$	Sign Convention (Chemistry opposite for W):
		Heat added to system: $Q > 0$
		Work done BY gas (expansion): $W > 0$
		Internal Energy increases: $\Delta U > 0$
Work Done (General)	$W = \int_{V_1}^{V_2} P\, dV$	Area under P-V curve on Volume axis gives Work Done.
Mayer's Relation	$C_P - C_V = R$	Valid for Ideal Gas (per mole).
		$C_P > C_V$ because work is done in isobaric expansion.
Specific Heat Ratio (γ)	$\gamma = \frac{C_P}{C_V} = 1 + \frac{2}{f}$	Monoatomic $\gamma = 5/3 = 1.67$
		Diatomic $\gamma = 7/5 = 1.4$
		Triatomic $\gamma = 4/3 = 1.33$
Bulk Modulus of Gas (B)	**General:** $B = -V \frac{dP}{dV}$	Resistance to compression.
	Isothermal (B_T): $B_T = P$	Adiabatic elasticity is γ times Isothermal elasticity ($B_S = \gamma B_T$).
	Adiabatic (B_S): $B_S = \gamma P$	
		Isobaric (P=const): $B = 0$.

		Isochoric (V=const): $B = \infty$.
Isochoric Process (V const)	$W = 0$	Volume constant ($\Delta V = 0$).
	$Q = \Delta U = nC_V \Delta T$	Gay-Lussac's Law holds.
	$\frac{P_1}{T_1} = \frac{P_2}{T_2}$	
Isobaric Process (P const)	$W = P(V_2 - V_1) = nR(T_2 - T_1)$	Pressure constant.
	$Q = nC_P \Delta T$	Charles's Law holds.
	$\frac{V_1}{T_1} = \frac{V_2}{T_2}$	Fraction of heat into internal energy: $1/\gamma$.
		Fraction of heat into work: $1 - 1/\gamma$.
Isothermal Process (T const)	$W = nRT\ln(\frac{V_2}{V_1}) = 2.303nRT\log(\frac{V_2}{V_1})$	Temperature constant ($\Delta T = 0$).
	$W = nRT\ln(\frac{P_1}{P_2})$	Internal energy change is zero for ideal gas.
	$\Delta U = 0 \implies Q = W$	Boyle's Law ($P_1V_1 = P_2V_2$).
Adiabatic Process ($Q = 0$)	Equation: $PV^\gamma = \text{const}$	No heat exchange ($dQ = 0$).
	$TV^{\gamma-1} = \text{const}$	Occurs suddenly/quickly or in insulated containers.
	$P^{1-\gamma}T^\gamma = \text{const}$	
Work in Adiabatic Process	$W = \frac{P_1V_1 - P_2V_2}{\gamma - 1} = \frac{nR(T_1 - T_2)}{\gamma - 1}$	Since $Q = 0$, $W = -\Delta U$.

		Expansion causes cooling ($T_2 < T_1$).
		Compression causes heating.
Slope of P-V Graph	Isothermal Slope: $\frac{dP}{dV} = -\frac{P}{V}$	Adiabatic curve is steeper than Isothermal by a factor of γ.
	Adiabatic Slope: $\frac{dP}{dV} = -\gamma\frac{P}{V}$	
Polytropic Process	$PV^x = \text{const}$	General process.
		Molar Heat Capacity: $C = C_V + \frac{R}{1-x}$
		Work: $W = \frac{nR(T_1-T_2)}{x-1}$
Cyclic Process	$\Delta U_{net} = 0$	Work = Area enclosed by the loop.
	$Q_{net} = W_{net}$	Clockwise = +ve Work (Engine).
		Anticlockwise = -ve Work (Refrigerator).
Efficiency of Heat Engine (η)	$\eta = \frac{\text{Work Output}}{\text{Heat Input}} = \frac{W}{Q_{in}}$	Q_{in}: Heat absorbed from source.
	$\eta = 1 - \frac{Q_{out}}{Q_{in}}$	Q_{out}: Heat rejected to sink.
Carnot Engine	$\eta = 1 - \frac{T_{sink}}{T_{source}}$	**Maximum theoretical efficiency.**
		T must be in Kelvin.
		Valid for reversible cycle only.

Refrigerator (COP - β)	$\beta = \frac{\text{Heat Extracted}}{\text{Work Input}} = \frac{Q_{cold}}{W}$	Coefficient of Performance.
	$\beta = \frac{Q_{cold}}{Q_{hot} - Q_{cold}} = \frac{T_{cold}}{T_{hot} - T_{cold}}$	Relationship with efficiency: $\beta = \frac{1-\eta}{\eta}$
Entropy (ΔS)	$\Delta S = \int \frac{dQ_{rev}}{T}$	Measure of disorder.
	Ideal Gas: $\Delta S = nC_v \ln(\frac{T_2}{T_1}) + nR \ln(\frac{V_2}{V_1})$	Adiabatic Reversible: $\Delta S = 0$ (Isentropic).
		Phase Change: $\Delta S = \frac{mL}{T}$
Free Expansion	$W = 0, Q = 0, \Delta U = 0, \Delta T = 0$	Expansion against vacuum ($P_{ext} = 0$).
		Neither isothermal nor adiabatic in strict sense, but $\Delta T = 0$ for ideal gas.

Note from AP Sir:

- Always check units: Pressure in Pa (N/m^2), Volume in m^3, Temperature in Kelvin (K).
- $R = 8.314\, J/(mol \cdot K)$ when using SI units.
- $R = 0.0821\, (L \cdot atm)/(mol \cdot K)$ when Pressure is atm and Volume is Liters.