FORMULA SHEET (11^{th} Class)

Ultimate KCET Crash Course 2026

Subject: Physics
Chapter: All Chapters

Units and Measurements

Physical Quantities

A physical quantity is any quantity that can be measured.

Physical Quantity = Numerical value × Unit

SI Base Units

Physical Quantity	Symbol	SI Unit	Unit Symbol
Length	l	metre	m
Mass	m	kilogram	kg
Time	t	Second	s
Electric current	I	Ampere	A
Temperature	T	kelvin	K
Amount of substance	n	mole	mol
Luminous intensity	Iv	candela	cd

Derived Units (Important)

Quantity	Formula	SI unit
Area	$A = l \times b$	m^2
Volume	$V = l \times b \times h$	m^3
Speed	$v = \frac{d}{t}$	m/s
Acceleration	$a = \frac{v-u}{t}$	m/s^2
Force	$F = ma$	Newton
Energy	$E = F.d$	Joule
Power	$P = \frac{E}{t}$	Watt (W)

Dimensional Formula

$[Q] = M^a L^b T^C$

Where:

M = mass

L = length

T = time

a, b, c = powers

Examples

Quantity	Dimensional Formula
Velocity	$\left[LT^{-1}\right]$
Acceleration	$\left[LT^{-2}\right]$
Force	$\left[MLT^{-2}\right]$
Energy	$\left[ML^2T^{-2}\right]$
Power	$\left[ML^2T^{-3}\right]$
Pressure	$\left[ML^{-1}T^{-2}\right]$

Conversion of Units

$$\text{New value} = \text{Old value} \times \left(\frac{\text{Old unit}}{\text{New unit}}\right)$$

Significant Figures (Rules)

- All non-zero digits are significant
- Zeros between non-zero digits are significant
- Leading zeros are not significant
- Trailing zeros after decimal are significant

Rounding Rule

- If next digit $< 5 \rightarrow$ ignore
- If $\geq 5 \rightarrow$ increase previous digit by

Errors in Measurement

Absolute Error

$\Delta x = | x_{measured} - x_{treu} |$

Mean Absolute Error

$$\Delta x_{measured} = \frac{\sum |\Delta x|}{n}$$

Relative Error

$$\frac{\Delta x}{x}$$

Percentage Error

Percentage error $= \frac{\Delta x}{x} \times 100$

Error in Calculations

(a) Addition / Subtraction $\Delta Z = \Delta A + \Delta B$

(b) Multiplication / Division $\frac{\Delta Z}{Z} = \frac{\Delta A}{A} + \frac{\Delta B}{B}$

(C) Power $\frac{\Delta Z}{Z} = n\frac{\Delta A}{A}$

Vernier Calipers

Least Count LC = 1 MSD – 1 VSD

Reading Reading = MSR + (VSR × LC)

Screw Gauge

Least Count $LC = \frac{\text{Pitch}}{\text{No. of divisions}}$

Reading Reading = PSR + (CSR×LC)

Symbol Meanings (Quick)

Symbol	Meaning
l,b,h	length, breadth, height
d	distance
t	time
u,v	initial & final velocity
a	acceleration
F	force
E	energy
P	power
Δx	absolute error
MSR	Main scale reading
VSR	Vernier scale reading
PSR	Pitch scale reading
CSR	Circular scale reading

Motion in a Straight Line

Fundamental Definitions

Formula	Description	Meaning of Symbols
Average Velocity: $v_{avg} = \frac{\Delta x}{\Delta t}$	Total displacement divided by the total time interval.	Δx : Change in position (**Displacement**) (m)
		Δt : Time interval (s)
Average Speed: $s_{avg} = \frac{\text{Total Distance}}{\Delta t}$	Total path length divided by the total time interval.	Total distance: Total path length traveled (m)
Instantaneous Velocity: $v = \frac{dx}{dt}$	The rate of change of position with respect to time. (Vector)	dx/dt: Derivative of position (x) w.r.t time (t)
Instantaneous Acceleration: $a = \frac{dv}{dt} = \frac{d^2x}{dt^2}$	The rate of change of velocity with respect to time. (Vector)	dv/dt: Derivative of velocity (v) w.r.t time (t)
		d^2x/dt^2: Second derivative of position w.r.t time

Kinematic Equations for Uniform Acceleration

These equations are only valid when acceleration (a) is constant.

Formula	Description	Meaning of Symbols
1. **Velocity-Time Relation:** $v = u + at$	Final velocity after time t.	u: Initial velocity (m/s)
		v: Final velocity (m/s)
2. **Position-Time Relation:** $s = ut + \1/2\ at^2$	Displacement (s) in time t.	a: Constant acceleration (m/s^2)
		t: Time interval (s)
3. **Velocity-Displacement Relation (Torricelli's):** $v^2 = u^2 + 2as$	Final velocity after displacement s.	s: Displacement (m)
4. **Displacement in the nth second** $S_n = u + \frac{a}{2}(2n-1)$	Displacement traveled *only* during the n^{th} second.	n: The specific second (e.g., 3^{nd}, 5^{th})

Motion Under Gravity (Free Fall)

This is a special case of uniform acceleration where a is constant and equal to the acceleration due to gravity (g). (Assuming upward is positive and downward is negative, or vice-versa, consistently.)

Acceleration: $a = -g$ (always pointing downwards)

$g \approx 9.8 \mathrm{m/s^2} \text{or} 10 \mathrm{m/s^2}$ (as specified in the problem)

Maximum Height (H max): The final velocity (v) at the highest point is zero.

$$H_{max} = \frac{u^2}{2g}$$

Time of Ascent (t_a) : Time taken to reach maximum height.

$$t_a = \frac{u}{g}$$

Time of Flight (T): Total time in air ($T = t_a + t_d$, where t_d is time of descent).

$$T = 2u/g$$

The kinematic equations become:

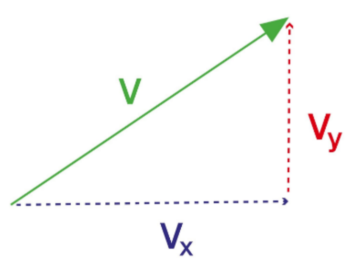
$$v = u - gt$$

$$h = ut - \frac{1}{2}gt^2$$

$$v^2 = u^2 - 2gh$$

Relative Velocity

Relative velocity is the velocity of an object A with respect to an object B



Formula	Description	Meaning of Symbols
Velocity of A w.r.t B: $v_{AB} = v_A - v_B$	Vector difference between the individual velocities.	v_{AB}: Relative velocity of A w.r.t B

Formula	Description	Meaning of Symbols
		v_A: Absolute velocity of object A
		v_B: Absolute velocity of object B

**For two objects moving in the same direction: The magnitude of relative velocity is $|v_A - v_B|$

**For two objects moving in the opposite direction: The magnitude of relative velocity is $|V_A + v_B|$.

Graph Type	Slope Represents	Area Under Graph Represents
Position-Time (x–t)	Velocity ($v = dx/dt$)	N/A
Velocity-Time (v—-t)	Acceleration ($a = dv/dt$)	Displacement $\left(\Delta x = \int v dt\right)$
Acceleration-Time (a–t)	Jerk	Change in Velocity $\left(\Delta v = \int a dt\right)$

Motion in a Plane

Vectors

Vectors are the foundation of 2D motion

Concept	Formula	Symbol Meanings
Magnitude	$	A
Resultant (Sum)	$R=\sqrt{P^2+Q^2+2PQ\cos\theta}$	P, Q: Magnitudes; θ: Angle between them
Direction of R	$\tan\alpha=\frac{Q\sin\theta}{P+Q\cos\theta}$	α : Angle of R with vector P
Dot Product	$A.B=ABcos\theta$	Result is a scalar
Cross Product	$	$A.B=ABcos\theta$

Projectile Motion (Ground-to-Ground)

Assumes a particle is projected with velocity u at an angle θ to the horizontal.

Time of Flight (T)

$$T=\frac{2u\sin\theta}{g}$$

Maximum Height (H):

$$H=\frac{u^2\sin^2\theta}{2g}$$

Horizontal Range (R)

$$R=\frac{u^2\sin 2\theta}{g}$$

Note: Max range occurs at θ = 45°.

Equation of Trajectory:

$$y=x\tan\theta=\frac{gx^2}{2u^2\cos^2\theta}$$

Symbols:
u: Initial velocity
θ: Angle of projection
g: Acceleration due to gravity $\left(\approx 9.8m/s^2\right)$:
x, y: Horizontal and vertical coordinates at time t.

Horizontal Projectile (From Height h)
When an object is thrown horizontally from a tower of height h.

Time to reach ground: $t = \sqrt{\frac{2h}{g}}$

Horizontal Range: $R = u\sqrt{\frac{2h}{g}}$

Velocity at any time $t : v = \sqrt{u^2 + (gt)^2}$

Uniform Circular Motion (UCM)

Motion in a circle with constant speed.

Quantity	Formula	Symbol Meanings
Angular Velocity	$\omega = \frac{v}{r} = 2\pi f$	v: Linear velocity; r: Radius; f: Frequency
Centripetal Accel.	$a_c = \frac{v^2}{r} = \omega^2 r$	Always directed toward the center
Centripetal Force	$F_e = \frac{mv^2}{r}$	m: Mass of the object
Time Period	$T = \frac{2\pi}{\omega}$	Time for one full revolution

Relative Motion In 2d

Useful for "Rain-Man" or "River-Boat" problems.

Velocity of A w.r.t B: $v_{AB} = v_A - v_B$

River Crossing (Shortest Path): $\sin\theta = \frac{v_r}{v_m}$

(v_r: River velocity, v_m: Man's velocity in still water)

River Crossing (Shortest Time): $t = d/v_m$

(d: Width of the river)

Would you like me to generate a set of practice problems based on these formulas?

Newton's Law Motion

Newton's Second Law & Momentum

Newton's laws form the backbone of classical mechanics. The most mathematically significant is the Second Law.

- Linear Momentum: $p = mv$
- Newton's second Law : $F_{net} = \frac{dp}{dt} = ma$ (for constant mass)
- Impulse (J): $J = \int F dt = \Delta p = m(v_f - v_i)$

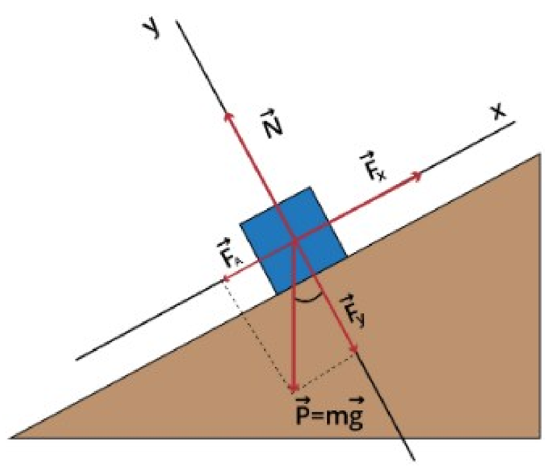
Symbols:

- m : Mass of the object
- v : Velocity
- a : Acceleration
- F_{net} : Net external force
- t : Time

Common Forces & Free Body Diagrams (FBD)

When solving problems, identifying the forces acting on a body is crucial.

- Weight (W): $W = \text{mg}$
- Normal Force (N or R): Acts perpendicular to the surface of contact.
- Tension (T): Acts along a string/rope, always pulling away from the body.
- Spring Force (F_s): $F_s = -kx$ (Hooke's Law)



Friction

Friction opposes the relative motion (or the tendency of motion) between two surfaces.

- Static Friction (f_s) / $0 \leq f_s \leq \mu_s N$
- Limiting Friction (f_{max}) : $f_{max} = \mu_s N$
- Kinetic Friction (f_k) $f_k = \mu_k N$
- Angle of Friction (λ): $(\lambda): \tan\lambda = \mu_S$
- Angle of Repose (α): The maximum angle of an incline at which a block remains stationary. tan $\alpha = \mu_s$

Symbols:

- μ_s : Coefficient of static friction
- μ_k : Coefficient of kinetic friction
- N : Normal reaction force

Constraint Motion & Pulley Systems

For ideal pulleys (massless and frictionless) and inextensible strings:

Simple Pulley (Atwood Machine): $\alpha = \dfrac{(m_2 - m_1)g}{m_1 + m_2}$

$$T = \frac{2m_1 + m_2 g}{m_1 + m_2}$$

Constraint Relation: $\sum T.\upsilon = 0 \sum T.\alpha = 0$

Circular Motion & Banking

For a vehicle to turn safely without skidding:

- Centripetal Force: $F_c = \; = \dfrac{mv^2}{r} = m\omega^2 r$
- Bending of a Cyclist: $\tan\theta = \dfrac{v^2}{rg}$
- Banking of Roads (without friction): $\tan\theta = \dfrac{v^2}{rg}$
- Maximum Safe Speed on Banked Road (with friction):

$$v_{max} = \sqrt{rg\left(\frac{\mu_o + \tan\theta}{1 - \mu_s \tan\theta}\right)}$$

Symbols:

r : Radius of the circular path

ω : Angular velocity

θ : Angle of banking or bending

Pseudo Force

Used in non-inertial (accelerating) frames of reference to make Newton's Laws applicable

Pseudo Force $\left(F_p\right): F_p = -ma_o$

Symbols:

a_o : Acceleration of the observer/frame. (The force is applied in the direction opposite to the frame's acceleration).

Work, Energy, and Power

Work Done

Work is a scalar quantity representing the energy transferred by a force.

- Work by a Constant Force: $W = F.s = \cos\theta$
- Work by a Variable Force: $W = \int_{s_1}^{s_2} F.ds$
- Work Done by Gravity: $W_g = \pm\, mgh$ (Positive if moving down, negative if moving up)
- Work Done by a Spring: $W_s = \frac{1}{2}k\left(x_i^2 - x_f^2\right)$

Symbols:

- W : Work done (Joule, J)
- F : Force vector (Newton, N)
- s : Displacement vector (Meter, m)
- θ : Angle between Force and Displacement
- k : Spring constant (N/m)
- x_i, x_f : Initial and final deformation of the spring

Kinetic & Potential Energy

Energy is the capacity to do work.

- Kinetic Energy (KE): $K = \frac{1}{2}mv^2 = \frac{p^2}{2m}$
- Gravitational Potential Energy (PE): $U = mgh$
- Elastic Potential Energy (Spring): $U_s = \frac{1}{2}kx^2$
- Mechanical Energy (E): $E = K + U$

Symbols:

- m : Mass (kg)
- v : Velocity (m/s)
- p : Linear momentum ($p = mv$)
- g : Acceleration due to gravity ($\approx 9.8\ m/s^2$)
- h : Height from reference level

Work-Energy Theorem & Conservation

These principles are the most powerful tools for solving complex mechanics problems.

- Work-Energy Theorem: $W_{net} = \Delta K = K_f - K_i$ (Net work done by ALL forces equals change in Kinetic Energy)
- Law of Conservation of Mechanical Energy: $K_i + U_i = K_f + Uf$ (Applicable only when only conservative forces do work)
- Conservative Force Relation: $F = -\frac{dU}{dx}$

Power

Power is the rate at which work is done or energy is transferred.

- Average Power: $P_{avg} = \frac{W}{t} = \frac{\Delta E}{t}$
- Instantaneous Power: $P = \frac{dW}{dt} = F.v = Fv\cos\theta$
- Efficiency (η): $\eta = \left(\frac{F_{output}}{P_{input}}\right) \times 100\%$

Symbols:

- P : Power (Watt, W or J/s)
- t : Time (s)
- v : Instantaneous velocity

Collisions (One Dimension)

- Conservation of Momentum: $m_1v_1 + m_2v_2 = m_1v_2 + m_2v_2$
- Coefficient of Restitution (e): $e =$ $e = \frac{\text{Velocity os separation}}{\text{Velocity of Approach}} = \frac{v_2 - v_1}{u_1 - u_2}$
- Elastic Collision: $e = 1$ (KE is conserved)

Inelastic Collision: $0 < e < 1$ (KE is NOT conserved)

Perfectly Inelastic: $e = 0$ (Bodies stick together)

Would you like me to provide a summary of Vertical Circular Motion or some shortcut tricks for solving pulley-block systems using work-energy?

System of Particles and Rotational Motion

Center of Mass (COM)

The point where the entire mass of the system can be supposed to be concentrated. For Discrete Particles:

$$R_{cm} = \frac{\sum m_i r_i}{\sum m_i}$$

For Continuous Bodies:

$$R_{cm} = \frac{1}{M}\int r\,dm$$

Rotational Kinematics

These formulas apply when the angular acceleration (α) is constant

Linear Motion	Rotational Motion	Relationship
Displacement (s)	Angular Displacement (θ)	$s = r\theta$
Velocity (v)	Angular Velocity (ω)	$v = r\omega$
Acceleration (a)	Angular Acceleration (α)	$\alpha_t = ra$
$v = u + at$	$\omega = \omega_o + \alpha t$	—
$s = ut + \frac{1}{2}at^2$	$\theta = \omega_o t + \frac{1}{2}\alpha t^2$	—

Moment of Inertia (*I*)

The rotational equivalent of mass. It depends on the distribution of mass relative to the axis of rotation

General Formula: $I = \sum m_i r_i^2 \;\; I = \int r^2 dm$

Radius of Gyration (k): $I = Mk^2 \Rightarrow k = \sqrt{I/M}$

Important Theorems

Parallel Axis Theorem: $I = I_{cm} + Md^2$(Where d is the distance between the parallel axes)

Perpendicular Axis Theorem: $I_z = I_x + I_y$ (Only for 2D planar objects)

Torque and Angular Momentum

These describe the "turning" effect and the "quantity of rotation.

"Torque (τ):

$\tau = r \times F = rF\sin\phi$

$\tau = I\alpha$

Angular Momentum (*L*):

$L = r \times p = I\omega$

Law of Conservation of Angular Momentum: *If* $\tau_{ext} = 0$ Then *L*= Constant $I_1\omega_1 = I_2\omega_2$

Work, Power, and Energy

Rotational Kinetic Energy: $K_{rot} = \frac{1}{2}I\omega^2$

Work Done : $W = \int \tau d\theta$

Power : $P = \tau.\omega$

Total KE (Rolling without slipping):

$$K_{\text{total}} = K_{\text{trans}} + K_{\text{rot}} = \frac{1}{2}Mv_{cm}^2 + \frac{1}{2}I_{cm}\omega^2$$

$$K_{\text{total}} = \frac{1}{2}Mv^2\left(1 + \frac{k^2}{R^2}\right)$$

Symbol Meanings

m, *M* : Mass of particle/body

r : Position vector from the axis

v, ω : Linear velocity / Angular velocity

α, α : Linear acceleration / Angular acceleration

I : Moment of Inertia

T : Torque

L : Angular Momentum

k : Radius of gyration

R : Radius of the object

Gravitation

Symbol	Meaning	SI Unit

G	Universal Gravitational Constant	$N.m^2 / kg^2$
M, m	Masses of the objects	kg
r, R	Distance between masses or radius	m
g	Acceleration due to gravity	m/s^2
g'	Modified acceleration due to gravity	m/s^2
V	Gravitational Potential	J/kg
U	Gravitational Potential Energy	J
v_e	Escape Velocity	m/s
v_o	Orbital Velocity	m/s
T	Time Period of Orbit	S
ρ	Density	kg/m^3
h	Height above the surface	m
d	Depth below the surface	m
ω	Angular velocity of Earth	rad/s
λ	Latitude angle	degrees or radians

Newton's Law of Gravitation

- The gravitational force of attraction between two point masses M and m, separated by a distance r:

$$F = \frac{GMm}{r^2}$$

Vector Form (Force on m_2 due to m_1):

- $$F_{21} = -\frac{Gm_1m_2}{r^2}\hat{r}_{12}$$

where $\hat{r}_{12}$ is a unit vector pointing from m_1 to m_2.

Acceleration Due to Gravity (g)

On the Earth's Surface

- The acceleration due to gravity on the surface of a planet of mass M and radius R:

$$= \frac{GM}{R^2}$$

- If the Earth's average density is $\rho : M = \frac{4}{3}\pi R^3 \rho$

$$g = \frac{G}{R^2}\left(\frac{4}{3}\pi R^3 \rho\right) = \frac{4}{3}\pi G R \rho$$

Variation of *g*.

- Effect of Altitude (Height, *h*) At a height *h* above the Earth's surface

(R_e) is Earth's radius):

Exact Formula: $gh = \frac{GM}{(R_e + h)^2} = g\left(\frac{R_e}{R_e + h}\right)^2$

Approximate Formula (for $h << R_e$)

$$gh \approx g\left(1 - \frac{2h}{R_e}\right)$$

Note: g_h decreases with altitude.

Effect of Depth (*d*) At a depth *d* below the Earth's surface:

$$g_d = g\left(1 - \frac{d}{R_e}\right)$$

Note: g_d decreases linearly with depth and is zero at the center ($d = R_e$).

Effect of Latitude (λ) and Rotation

- Due to the Earth's rotation (angular velocity ω):
- $g' = g - R_e \omega^2 \cos^2 \lambda$
- At the poles $(\lambda = 90^\circ)$: $g' = g$ (No effect)
- At the equator: $(\lambda = 0^\circ)$: $g' = g - R_e \omega^2$ (Minimum *g*')

Gravitational Field and Potential

- Gravitational Field Intensity (*E*)

The force experienced by a unit mass (m = 1) at a point.

$$E = \frac{F}{m}$$

For a point mass *M* at distance *r*:

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

Gravitational Potential (V)

- The work done to bring a unit mass from infinity to a point in the field

$$V = -\int_{\infty}^{r} E.dr$$

For a point mass M at distance r:

- $V = -\frac{GM}{r}$

Gravitational Potential Energy (U)

- The work done to assemble two masses M and m at a distance r.

$$U = mV = -\frac{GMm}{r}$$

Note: Gravitational potential and potential energy are always negative for attractive forces.

Satellite Motion and Orbital Mechanics

- Consider a satellite of mass m orbiting a planet of mass M (typically $M >> m$) in a circular orbit of radius r.

Orbital Velocity (v_o)

- Centripetal force is provided by the gravitational force $\frac{mv_0^2}{r} = \frac{GMm}{r^2}$

$$v_o = \sqrt{\frac{GM}{r}}$$

- If the satellite is close to the planet's surface ($r \approx R$)

$$v_o \approx \sqrt{\frac{GM}{R}} = \sqrt{gR}$$

- Time Period of Orbit (T)

$$T = \frac{2\pi r}{v_o} = 2\pi\sqrt{\frac{r^3}{GM}}$$

Energy of an Orbiting Satellite

- Kinetic Energy (K):

$$K=\frac{1}{2}mv_o^2=\frac{1}{2}m\left(\frac{GM}{r}\right)=\frac{GMm}{2r}$$

Potential Energy (U):

$$U=-\frac{GMm}{r}$$

Total Energy (E):

- $E=K+U=\frac{GMm}{2r}-\frac{GMm}{r}=-\frac{GMm}{2r}$

  Note: $K=-E$ and $U=2E$

Binding Energy

- The energy required to remove the satellite from the orbit to infinity

$$E_{bininding}=-E=\frac{GMm}{2r}$$

Escape Velocity (v_e)

The minimum velocity required for a body to escape the gravitational field of a planet of mass M and radius R.

(Total Energy $=0:\frac{1}{2}mv_e^2-\frac{GMm}{R}=0$

$$v_e=\sqrt{\frac{2GM}{R}}$$

- In terms of $g:GM=gR^2$

  $v_e=\sqrt{2gR}$

- For Earth: $v_e\approx 11.2km/s$
- Relation between v_e and v_o (near the surface):

  $v_e=\sqrt{2}v_o$

Kepler's Laws of Planetary Motion

A. Law of Orbits (First Law)

- All planets move in elliptical orbits with the Sun at one of the foci.

B. Law of Areas (Second Law)

- The line joining the planet and the Sun sweeps equal areas in equal intervals of time.
- This is a consequence of the conservation of angular momentum (L = constant).

$$\frac{dA}{dt} = \frac{L}{2m} = \text{Constant}$$

Law of Periods (Third Law)

The square of the time period (T) of revolution of a planet around the Sun is directly proportional to the cube of the semi-major axis (a) of its elliptical orbit.

$$\frac{T^2}{a^3} = \frac{4\pi^2}{GM} = \text{Consatant}$$

- For circular orbits, the semi-major axis \$a\$ is replaced by the radius r.

Mechanical properties of solids

Fundamental Definitions

Deformation is quantified using Stress (internal restoring force per unit area) and Strain (fractional change in dimension).

- Stress (σ): $\sigma = \frac{F}{A}$

- Longitudinal Strain ($\in$): $\in = \frac{\Delta L}{L}$

- Volumetric Strain: $\frac{\Delta V}{V}$

- Shearing Strain (θ) $\theta = \frac{\Delta x}{L} \approx$ angle of twist (in radius)

Hooke's Law & Moduli of Elasticity

Within the elastic limit, Stress is directly proportional to Strain: Stress = E × Strain

Type of Modulus	Formula	Description
Young's Modulus (Y)	$Y = \frac{F/A}{\Delta L/L} = \frac{FL}{F\Delta L}$	For solids (wires/rods) under tension/compression.
Bulk Modulus (B or K)	$B = -\frac{P}{\Delta V/V}$	For volume changes; P is hydraulic pressure.
Shear Modulus (G or η)	$G = \frac{F_{Tengential}/A}{\theta}$	Also called Modulus of Rigidity.
Compressibility (k)	$k = \frac{1}{B}$	Reciprocal of Bulk Modulus.

Energy in Deformed Solids

When a wire is stretched, work is done against interatomic forces and stored as Elastic Potential Energy.

Work Done / Total Energy (U):

- $U = \frac{1}{2} \times Load \times Extebsion = \frac{1}{2} F \Delta L$

Energy Density (u): (Energy per unit volume)

- $u = \frac{1}{2} \times Stress \times Strain = \frac{1}{2} Y \in^2$

Poisson's Ratio (sigma σ or v)

The ratio of lateral strain (change in diameter) to longitudinal strain (change in length)

- $\sigma = \frac{\text{Lateral Strain}}{\text{Longitudinal Strain}} = -\frac{\Delta d / d}{\Delta L / L}$

Theoretical Range : $-1 < \sigma < 0.5$

Practical Range: $0 \le \sigma < 0.5$

Important Inter-relations

These are high-yield for JEE Main and NEET numericals

- $Y = 3B(1 - 2\sigma)$
- $Y = 2B(1 + \sigma)$
- $\sigma = \frac{3B - 2G}{6B + 2G}$
- $\frac{9}{Y} = \frac{3}{G} + \frac{1}{B}$

Meaning of Symbols

- F: Applied Force (or Restoring Force)
- A: Cross-sectional Area (πr^2 for a wire)
- L, ΔL: Original length and change in length
- V, ΔV: Original volume and change in volume
- P: Pressure (Hydraulic Stress)
- Y, B, G: Young's, Bulk, and Shear Moduli
- σ: Poisson's Ratio (sometimes denoted by v or μ)

Mechanical Properties of Fluids

Pressure

Formula

$$P = \frac{F}{A}$$

$P = P_o + pgh$ (Hydrostatic Pressure)

Symbols

P : Pressure

Formula

$P_1 = P_2$

Hydraulic lift : $\frac{F_1}{A_1} = \frac{F_2}{A_2}$

Symbols

F_1, F_2 : Forces

A_1, A_2 : Area of pistons

Buoyancy – Archimedes' Principle

Formula

$F_B = \rho g V$

Apparent weight = $W - F_B$

Symbols

F_B : Buoyant force

V : Volume of fluid displaced

W : Actual weight

Continuity Equation

Formula

$A_1 v_1 = A_2 v_2 = \text{Constant}$

$\rho_1 A_1 v_1 = \rho_2 A_2 v_2$ (Compressible)

Symbols

A_1, A_2 : Cross-sectional areas

F : Force

A : Area

P_0 : Atmospheric pressure

ρ : Density of fluid

g : Acceleration due to gravity

h : Height/depth

Pascal's Law

v_1, v_2 : Fluid velocities

Bernoulli's Equation

Formula

$$P + \frac{1}{2}\rho v^2 + \rho g h = \text{Constant}$$

Symbols

P : Pressure

ρ : Density

v : Speed of fluid

h : Height

Torricelli's Theorem

Formula

$v = \sqrt{2gh}$

Symbols

v : Speed of efflux

h : Height of fluid column

Viscosity

Newton's Law of Viscous Force

$$F = \eta A \frac{dv}{dy}$$

Symbols

F : Viscous force

η : Coefficient of viscosity

A : Area

$\frac{dv}{dy}$: Velocity gradient

Poiseuille's Law (Laminar flow in tube)

$$Q = \frac{\pi r^4 (P_1 - P_2)}{8\eta L}$$

Symbol

Q : Volume flow rate

r : Radius of tube

$P_1 - P_2$: Pressure difference

L : Length of tube

Terminal Velocity

Formula

For sphere falling in viscous fluid:

$$v_t = \frac{2r^2 (\rho_s - \rho_f) g}{9\eta}$$

Symbols

v_t : Terminal velocity

r : Radius

ρ_s : Density of sphere

ρ_f : Density of fluid

Surface Tension

Formula

$T = \frac{F}{2L}$ (Liquid Film)

Pressure inside a soap bubble: $\Delta P = \frac{4T}{r}$

Pressure inside a liquid drop: $\Delta P = \frac{2T}{r}$

Symbols

T : Surface tension

L : Length

ΔP : Excess pressure

r : Radius

Capillarity

Formula

$$h = \frac{2T\cos\theta}{\rho g r}$$

Symbols

h : Height rise/fall

θ : Contact angle

Pressure at Depth & Density Relation

$\Delta P = \rho g \Delta h$

Average density: $\rho = \frac{m}{V}$

Fluid Force on Walls

Horizontal plate: $F = PA$

Vertical plate: $F = \rho g A h_{cm}$

Thermal properties of matter

Temperature Scales and Thermal Expansion

These formulas describe how substances change physical dimensions when heated.

Concept	Formula	Symbols
Scale Conversion	$\frac{C}{5}=\frac{F-32}{9}=\frac{K-273.15}{5}$	C: Celsius, F: Fahrenheit, K: Kelvin
Linear Expansion	$\Delta L = L_o \alpha \Delta T$	α : Coeff. of linear expansion, L_0: Original length
Area Expansion	$\Delta A = A_o \beta \Delta T$	β : Coeff. of area expansion $(\beta = 2\alpha)$
Volume Expansion	$\Delta V + V_o \gamma \Delta T$	γ : Coeff. of volume expansion $(\gamma = 3\alpha)$
Density Variation	$\rho = \frac{\rho_1}{1+\gamma\Delta T} \approx \rho_0(1-\gamma\Delta T)$	p: New density, ρ_o : Initial density

Calorimetry

Calorimetry deals with the measurement of heat transfer during state changes or temperature shifts.

- **Specific Heat Capacity (s or c):** The heat required to raise the temperature of unit mass by 1°C.
  $Q = ms\Delta T$

- **Latent Heat (L):** The heat required to change the phase of a substance without changing its temperature.
  $Q = mL$

- Latent Heat of Fusion (L_f): For Ice ≈ 80 cal/g
- Latent Heat of Vaporization (L_v): For Water ≈ 540 cal/g
- Water Equivalent (W): $W = ms$ (expressed in grams of water).

Heat Transfer: Conduction

Conduction is the transfer of heat through solids via molecular vibrations.

Thermal Current (H): Rate of flow of heat

$$H = \frac{dQ}{dt} = \frac{KA(T_1 - T_2)}{L}$$

- K: Thermal conductivity of the material.
- A: Cross-sectional area.
- L: Length of the conductor.

Thermal Resistance (R_{th}): Analogous to electrical resistance.

$R_{th} = \frac{L}{KA}$

Series Combination: $R_{eq} = R_1 + R_2$

Parallel Combination: $\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2}$

Radiation and Newton's Law of Cooling

Radiation involves heat transfer through electromagnetic waves and does not require a medium.

Stefan-Boltzmann Law: The energy radiated per unit area per unit time (E)

$E = \sigma e A T^4$

- σ: Stefan's constant ($5.67 \times 10_{-8}$ $Wm^{-2} K^{-4}$).
- e: Emissivity ($0 \le e \le 1$)
- T: Absolute temperature in Kelvin

Wien's Displacement Law: Relates the temperature of a blackbody to the peak wavelength of emission.

$\lambda_m T = b$

b: Wien's constant $\left(\approx 2.89 \times 10^{-3} mK\right)$

Newton's Law of Cooling: The rate of loss of heat is proportional to the temperature difference between the body and surroundings

$\frac{dT}{dt} = -k\left(T - T_s\right)$

- **Average Form (for numerical)** $\frac{T_1 - T_2}{t} = K\left(\frac{T_1 + T_2}{2} - T_s\right)$

Kinetic Theory of Gases (Short Reference)

Ideal Gas Equation: $PV = nRT$

Root Mean Square Velocity: $v_{rms} = \sqrt{\frac{3RT}{M}} = \sqrt{\frac{3kT}{m}}$ f

- k: Boltzmann constant.

m: Mass of a single molecule.

Thermodynamics

Important Terminology

Internal Energy (U): For an ideal gas, it depends only on temperature.

$\Delta u = nC_v \Delta T$

Work Done by Gas (W):

- $W = \int P dV$
- $W > 0$ if the gas expands (V increases).
- $W < 0$ if the gas is compressed (V decreases).

Molar Specific Heat:

- At constant volume: $C_V = \frac{f}{2} R$
- At constant pressure: $C_p = C_v + R = \left(\frac{f}{2} + 1\right) R$
- Mayer's Formula: $C_p - C_v = R$
- Ratio of Specific Heats $(\gamma) : \gamma = \frac{C_p}{C_v} = 1 + \frac{2}{f}$ (Note: f is the degrees of the freedom:3 for monoatomic, 5 for diatomic)

Laws of Thermodynamics

First Law of Thermodynamics (FLOT)

Based on the conservation of energy: $\Delta Q = \Delta U + W$

- ΔQ: Heat supplied to the system.
- ΔU: Change in internal energy.
- W: Work done by the system.

Second Law of Thermodynamics

Kelvin-Planck Statement: No engine can convert all heat into work (Efficiency $\eta < 1$).

Clausius Statement: Heat cannot flow spontaneously from a cold body to a hot body.

Process	**Condition**	**Work Done (W)**	**First Law Form**
Isochoric	V =Constant	0	$\Delta Q = \Delta U$
Isobaric	P = Const	0	$\Delta Q = nC_p \Delta T$
Isothermal	T = Const	$nRTIn\left(\frac{V_2}{V_1}\right)$	$\Delta Q = W\left(\Delta U = 0\right)$
Adiabatic	$\Delta Q = 0$	$\frac{P_1V_1 - P_2V_2}{\gamma - 1}$	$w = \Delta U$

Heat Engines and Refrigerators

Carnot Engine

An ideal reversible engine operating between a hot reservoir (T_1) and a cold reservoir (T_2).

- Efficiency (η):

$$\eta = 1 - \frac{Q_1}{Q_2} = 1 - \frac{T_2}{T_1}$$

(Temperatures must be in Kelvin)

Refrigerator / Heat Pump

Coefficient of Performance $(\beta \;\; or \;\; \alpha)$

- Q_2: Heat extracted from the cold reservoir.
- W: Work input required.

Symbols Glossary

- P, V, T: Pressure, Volume, and Absolute Temperature.
- n: Number of moles.
- R: Universal Gas Constant (≈ 8.314 J/mol. K).
- f: Degrees of freedom.
- y: Adiabatic exponent.
- Q_1: Heat absorbed from the source.
- Q_2: Heat rejected to the sink.

Kinetic theory of Gases

Ideal Gas Laws & Pressure

The core of KTG lies in the relationship between molecular motion and the pressure exerted on a container.

- Ideal Gas Equation: $PV = nRT = Nk_BT$

- Pressure of an Ideal Gas: $P = \frac{1}{3}\rho v_{rms}^2 = \frac{1}{3}\frac{mN}{V}v_{rms}^2$

- Kinetic Interpretation of Temperature: The average translational kinetic energy is directly proportional to the absolute temperature

$$E_{avg} = \frac{3}{2}k_BT$$

Molecular Speeds

Molecules in a gas move at various speeds. We use three specific "statistical" speeds for calculations:

Speed Type	Formula	Relation
Root Mean Square (v_{rms})	$\sqrt{\frac{3RT}{M}} = \sqrt{\frac{3k_BT}{m}}$	Largest Speed
Average Speed (v_{avg})	$\sqrt{\frac{8RT}{\pi M}} = \sqrt{\frac{8k_BT}{\pi m}}$	Middle Speed
Most Probable (v_{mp})	$\sqrt{\frac{2RT}{M}} = \sqrt{\frac{2k_BT}{m}}$	Smallest Speed

Memory Trick: $v_{rms} > v_{avg} > v_{mp}$ (Remember **RAM**: RMS > Average > Most Probable).

Degrees of Freedom (f) and Equipartition

The Law of Equipartition states that energy is shared equally among all degrees of freedom (1/2 k_BT) per degree of freedom).

Gas Atomicity	Degrees of Freedom (*f*)	C_v	C_p	$\gamma = C_p/C_v$
Monoatomic (He, Ar)	3	3/2 R	5/2 R	1.67
Diatomic (O_2, N_2)	5	5/2 R	7/2 R	1.40
Polyatomic (Non-linear)	6	3 R	4 R	1.33

- Internal Energy (U): $U = \frac{1}{2}nRT$
- Relationship between γ and f: $\gamma = 1 + \frac{2}{f}$

Mean Free Path & Collision

The average distance a molecule travels between two successive collisions.

- Mean Free Path (λ):

$$\lambda = \frac{1}{\sqrt{2\pi d^2 n}}$$

- d: Diameter of the molecule.
- n: Number of molecules per unit volume (N/V).
- Collision Frequency: Number of collisions per second

Symbols Glossary

- P: Pressure (Pa)
- V: Volume (m^3)
- T: Absolute Temperature (Kelvin)
- n: Number of moles
- N: Total number of molecules
- m: Mass of one molecule
- M: Molar mass of the gas
- R: Universal Gas Constant ($\approx$ 8.314 J/mol. K)
- K_B: Boltzmann Constant ($R/N_A \approx 1.38 \times 10^{-23}$ J/K)
- p: Density of the gas (mN/V)

Oscillations

Basics of SHM

The fundamental condition for a motion to be SHM is that the acceleration (a) must be proportional to displacement (x) and directed toward the mean position.

- **Restoring Force:** $F = -kx$
- **Standard Differential Equation :** $\frac{d^2x}{dt^2} + \omega^2 x = 0$
- **Angular Frequency (** ω **) :** $\omega = \sqrt{\frac{k}{m}}$

Kinematics of SHM

These formulas define the position, speed, and acceleration of a particle at any time t.

Quantity	Formula	Remarks
Displacement	$x = A\sin(\omega t + \phi)$	A: Amplitude, ϕ: Initial phase
Velocity	$v = \omega\sqrt{A^2 - x^2}$	Max at mean $(x+0): v_{max} = A\omega$
Acceleration	$a = -\omega^2 x$	Max at extremes $(x = A): a_{max} = \omega^2 A$
Time Period	$T = \frac{2\pi}{\omega} = 2\pi\sqrt{\frac{\pi}{2}}$	Time for one complete cycle
Frequency	$f = \frac{1}{T} = \frac{\omega}{2\pi}$	Measured in Hertz (Hz)

Energy in SHM

In an ideal SHM, energy oscillates between kinetic and potential forms, but the total mechanical energy remains constant.

- **Kinetic Energy** $(K): K = \frac{1}{2}m\omega^2(A^2 - x^2) = \frac{1}{2}k(A^2 - x^2)$
- **Potential Energy** $(U): U = \frac{1}{2}kx^2 = \frac{1}{2}m\omega^2 x^2$
- **Total Energy** $(E): E = K + U = \frac{1}{2}kA^2 = \frac{1}{2}m\omega^2 A^2$

Note: E is independent of both time (t) and displacement (x).

Common Oscillating Systems

- Series Combination: $\frac{1}{k_{eq}} = \frac{1}{k_1} + \frac{1}{k_2}$
- Parallel Combination: $k_{eq} = k_1 + k_2$
- Cut Spring: If a spring is cut into n equal pieces, each piece has a spring constant *nk*.

Pendulums:

- Spring-Mass System $T = 2\pi\sqrt{\frac{L}{g}}$ (L: length, *g:* gravity*)*
- Physical (Compound) Pendulum: $T = 2\pi\sqrt{\frac{L}{mgd}}$
- *I*: Moment of inertia about the hinge.
- *d*: Distance from hinge to Center of Mass
- Torsional Pendulum: $T = 2\pi\sqrt{\frac{I}{C}}$ (C : Torsional Constans)

Damped and Forced Oscillations (JEE Specific)

- Damped SHM Displacement: $x(t) = Ae^{-bt/2m}\cos(\omega' t + \phi)$
- *b*: Damping constant
- $\omega' = \sqrt{\frac{k}{m} - \frac{b^2}{4m^2}}$
- Resonance: Occurs when the driving frequency matches the natural frequency $(\omega_\alpha = \omega_o)$, leading to maximum amplitude.

Symbols Glossary

A : Amplitude (maximum displacement from mean).

ω : Angular frequency (*rad/s*).

ϕ : Phase constant (initial state of motion).

k : Spring constant or force constant (*N/m*).

T : Time period (*s*).

x : Instantaneous displacement (*m*).

m : Mass of the oscillating body (*kg*)

Waves

Basic Definitions

Wavelength (λ): Distance between two consecutive crests/troughs.

Time Period (T): Time taken for one oscillation.

Frequency (f): Number of oscillations per second → $f = \frac{1}{T}$

Wave Speed

General Formula: $v = \lambda f$

Speed of Wave on Stretched String: $v = \sqrt{\frac{T_s}{\mu}}$

where Ts = tension in string, and μ = linear mass density.

Speed of Sound in Gas: $v = \sqrt{\gamma \frac{P}{\rho}}$

Alternate form using temperature (in °C): $v \approx 331 + 0.6T$

Wave Equation

Standard form of a progressive harmonic wave:

Travelling in +x direction: $y(x,t) = A\sin(kx - \omega t + \phi)$

Travelling in −x direction: $y(x,t) = A\sin(kx + \omega t + \phi)$

Where:

$$k = \frac{2\pi}{\lambda}, \omega = 2\pi f$$

Superposition & Interference

Resultant amplitude (for coherent waves): $A = \sqrt{A_1^2 + A_2^2 + 2A_1 \cos\phi}$

Intensity formula: $I \propto A^2$

Beats

Beat frequency: $f_{beats} = |f_1 - f_2|$

Standing Waves

General condition: $L = n\frac{\lambda}{2}$

(for a string fixed at both ends or air column closed at both ends)

For closed organ pipe (one end closed): $L = (2n-1)\frac{\lambda}{4}$

For open organ pipe (both ends open): $L = n\frac{\lambda}{2}$

Harmonic Frequencies:

System	Frequency
Open Organ Pipe	$f_n = n\frac{v}{2L}$
Closed Organ Pipe	$f_n = (2n-1)\frac{v}{4L}$
Stretched String	$f_n = n\frac{v}{2L}$

Doppler Effect

General Formula: $f_n = f\left(\frac{v \pm v_o}{v \pm v_s}\right)$

Signs:

Observer moving toward source → use + in numerator

Source moving toward observer → use − in denominator

(Sound waves only; medium speed = v)

Energy in Waves

Intensity of progressive wave: $I = \frac{1}{2}\mu A^2\omega^2 v$

Symbols and Meanings

Symbol	Meaning
A	Amplitude
λ	Wavelength
f	Frequency
T	Time period
v	Wave speed
k	Wave number = $2\pi/\lambda$
ω	Angular frequency = $2\pi f$
φ	Phase constant
μ	Linear mass density (kg/m)
Ts	Tension in string
γ	Ratio of specific heats
ρ	Density of medium
P	Pressure of gas
Vo	Velocity of observer
Vs	Velocity of source
I	Intensity of wave
n	Harmonic number (1,2,3...)