CLASS 11 PHYSICS — FORMULA SHEET

Chapter 1 : Units and Measurements (NCERT)

1.1 SI Base (Fundamental) Units

Physical Quantity	SI Unit	Symbol
Length	metre	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Temperature	kelvin	K
Amount of substance	mole	mol
Luminous intensity	candela	cd
Supplementary: plane angle	radian	rad
Supplementary: solid angle	steradian	sr

1.2 Measurement of Length, Mass & Time

Concept	Detail / Value
Parallax method	Distance $D = b \div \theta$ (b = basis/baseline, θ = parallax angle in radian)
Angular size relation	$d = D \times \alpha$ (α = angular diameter in radian)
1 light year	$= 9.46 \times 10^{15}$ m (distance light travels in 1 year)
1 astronomical unit (AU)	$= 1.496 \times 10^{11}$ m (mean Earth–Sun distance)
1 parsec	$= 3.08 \times 10^{16}$ m = 3.26 light years
1 angstrom (Å)	$= 10^{-10}$ m
1 fermi	$= 10^{-15}$ m
1 atomic mass unit (u)	$= 1.66 \times 10^{-27}$ kg

1.3 Significant Figures — Rules

Rule	Example
All non-zero digits are significant	23.45 → 4 s.f.
Zeros between non-zero digits are significant	1005 → 4 s.f.
Leading zeros are NOT significant	0.0023 → 2 s.f.
Trailing zeros after decimal ARE significant	2.300 → 4 s.f.
Trailing zeros (no decimal) ambiguous	use scientific notation to be clear
Addition / Subtraction	Answer keeps least DECIMAL PLACES
Multiplication / Division	Answer keeps least SIGNIFICANT FIGURES
Rounding off	If digit > 5 round up; < 5 round down; = 5 → make preceding digit even

1.4 Errors in Measurement

Type of Error	Formula
Mean / true value	$a_{mean} = (a_1 + a_2 + \ldots + a_n) \div n$
Absolute error	$\Delta a_i = \lvert a_{mean} - a_i \rvert$
Mean absolute error	$\Delta a_{mean} = (\lvert\Delta a_1\rvert + \ldots + \lvert\Delta a_n\rvert) \div n$
Relative (fractional) error	$= \Delta a_{mean} \div a_{mean}$
Percentage error	$= (\Delta a_{mean} \div a_{mean}) \times 100\%$

1.5 Combination (Propagation) of Errors

Operation	Resultant Error
Sum: $Z = A + B$	$\Delta Z = \Delta A + \Delta B$ (absolute errors ADD)
Difference: $Z = A - B$	$\Delta Z = \Delta A + \Delta B$ (absolute errors still ADD)
Product: $Z = A \times B$	$\Delta Z/Z = \Delta A/A + \Delta B/B$ (relative errors add)
Quotient: $Z = A \div B$	$\Delta Z/Z = \Delta A/A + \Delta B/B$ (relative errors add)
Power: $Z = A^p B^q / C^r$	$\Delta Z/Z = p(\Delta A/A) + q(\Delta B/B) + r(\Delta C/C)$
Key idea	In ±, absolute errors add; in ×÷ and powers, relative/percentage errors add

1.6 Dimensional Analysis

Quantity	Dimensional Formula
Area	$[L^2]$
Volume	$[L^3]$
Velocity / Speed	$[M^0L^1T^{-1}]$
Acceleration	$[M^0L^1T^{-2}]$
Force	$[M^1L^1T^{-2}]$
Work / Energy / Torque	$[M^1L^2T^{-2}]$
Power	$[M^1L^2T^{-3}]$
Pressure / Stress	$[M^1L^{-1}T^{-2}]$
Momentum / Impulse	$[M^1L^1T^{-1}]$
Density	$[M^1L^{-3}T^0]$
Frequency	$[M^0L^0T^{-1}]$
Gravitational constant G	$[M^{-1}L^3T^{-2}]$
Planck's constant h	$[M^1L^2T^{-1}]$

1.7 Uses & Limitations of Dimensional Analysis

Point	Detail
Principle of homogeneity	Every term in a valid physical equation has the SAME dimensions
Use 1: Check correctness	An equation is dimensionally correct if LHS dimensions = RHS dimensions
Use 2: Convert units	$n_1u_1 = n_2u_2$ (numeric value × unit size is constant)
Use 3: Derive relations	Deduce form of a formula by equating dimensions
Limitation 1	Cannot find dimensionless constants (like ½, 2π)
Limitation 2	Cannot derive equations with +, −, trig, exp, or log terms
Limitation 3	Fails if a quantity depends on more than 3 quantities

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7 SI base units	'metre, kg, second, ampere, kelvin, mole, candela' — Length, Mass, Time, Current, Temp, Amount, Light.
Error rule	± → absolute errors ADD ; ×÷ and powers → relative (%) errors ADD.
Power error	For $Z = A^pB^q/C^r$, multiply each relative error by its power (p, q, r).
Homogeneity	Both sides of any real equation must have identical dimensions.
Sig-fig zeros	Leading zeros never count; trailing zeros count only after a decimal.
Length ladder	fermi 10^{-15} < Å 10^{-10} < AU 10^{11} < light-year 10^{15} < parsec 10^{16} (in metres).
Energy = Work = Torque	All share dimension $[ML^2T^{-2}]$ — handy for quick checks.
Unit conversion	$n_1u_1 = n_2u_2$: bigger unit → smaller number.

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Chapter 2 : Motion in a Straight Line (NCERT)

2.1 Basic Terms — Distance, Displacement, Speed, Velocity

Quantity	Definition / Formula
Distance (path length)	Total length of path travelled; scalar; always ≥ 0
Displacement (Δx)	$\Delta x = x_2 - x_1$; shortest straight-line change in position; vector
Average speed	= Total distance ÷ Total time (scalar, always ≥ 0)
Average velocity	$v_{avg} = \Delta x \div \Delta t = (x_2 - x_1) \div (t_2 - t_1)$ (vector)
Instantaneous velocity	$v = dx/dt$ (slope of x–t graph at a point)
Instantaneous speed	Magnitude of instantaneous velocity
|Displacement| ≤ Distance	Equal only when motion is along a straight line without reversing

2.2 Acceleration

Quantity	Formula
Average acceleration	$a_{avg} = \Delta v \div \Delta t = (v_2 - v_1) \div (t_2 - t_1)$
Instantaneous acceleration	$a = dv/dt = d^2x/dt^2$
a in terms of position	$a = v\,(dv/dx)$
Uniform motion	$a = 0$, velocity constant (x–t graph is a straight line)
Uniformly accelerated motion	a = constant (v–t graph is a straight line)
Retardation	Negative acceleration (a opposite to v)

2.3 Equations of Motion (Uniform Acceleration)

Equation	Use / Note
$v = u + at$	Velocity after time t (no displacement needed)
$s = ut + \frac{1}{2}at^2$	Displacement in time t
$v^2 = u^2 + 2as$	Relates velocity & displacement (no time)
$s = \frac{1}{2}(u + v)t$	Displacement from average velocity
$s_{nth} = u + (a/2)(2n - 1)$	Displacement in the n-th second only
Sign convention	Take one direction +ve; u, v, a, s carry signs accordingly

2.4 Motion Under Gravity (Free Fall, a = g)

Situation	Equation (taking $g = 9.8\ m/s^2$, downward +ve)
Dropped from rest ($u = 0$)	$v = gt$; $h = \frac{1}{2}gt^2$; $v^2 = 2gh$
Thrown down (initial speed u)	$v = u + gt$; $h = ut + \frac{1}{2}gt^2$
Thrown up (u, taking up +ve, $a = -g$)	$v = u - gt$; $h = ut - \frac{1}{2}gt^2$

Situation	Equation (taking $g = 9.8\ m/s^2$, downward +ve)
Max height (thrown up)	$H = u^2 \div (2g)$
Time of ascent = time of descent	$t = u \div g$ (each); total time of flight $= 2u \div g$
Velocity on return to start	Equal in magnitude to u (opposite direction)

2.5 Graphs in Motion

Graph	What its Slope / Area Gives
Position–time (x–t)	Slope = velocity ; straight line = uniform velocity
Velocity–time (v–t): slope	Slope = acceleration
Velocity–time (v–t): area	Area under curve = displacement
Acceleration–time (a–t): area	Area under curve = change in velocity
x–t for uniform acceleration	Parabola (curved)
v–t for uniform acceleration	Straight inclined line

2.6 Relative Velocity (1-D)

Concept	Formula
Velocity of A relative to B	$v_{AB} = v_A - v_B$
Velocity of B relative to A	$v_{BA} = v_B - v_A = -v_{AB}$
Same direction	Relative speed $= \lvert v_A - v_B \rvert$
Opposite directions	Relative speed $= \lvert v_A + v_B \rvert$
Time to meet (separation d)	$t = d \div v_{relative}$

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3 main equations	'$v = u + at$, $s = ut + ½at^2$, $v^2 = u^2 + 2as$' — memorise these three first.
When to use which	No s → use $v = u + at$; no t → use $v^2 = u^2 + 2as$; need s → $s = ut + ½at^2$.
s in n-th second	$s_n = u + (a/2)(2n - 1)$ — note it's a DISTANCE in 1 s, not total displacement.
Up-throw symmetry	Time up = time down ; speed at launch = speed on return.
Max height	$H = u^2/2g$; total flight time $= 2u/g$ (thrown straight up).
Graph slopes	x–t slope = velocity ; v–t slope = acceleration ; v–t area = displacement.
Sign convention	Fix +ve direction FIRST, then give u, v, a, s their correct signs.
Relative velocity	Same way → subtract speeds ; opposite ways → add speeds.

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Chapter 3 : Motion in a Plane (NCERT)

3.1 Scalars and Vectors

Concept	Detail
Scalar	Has magnitude only (mass, speed, distance, time, energy, temperature)
Vector	Has magnitude AND direction (displacement, velocity, force, acceleration)
Unit vector	$\hat{A} = A / \lvert A \rvert$; magnitude 1, gives direction only
Standard unit vectors	$\hat{i}, \hat{j}, \hat{k}$ along x, y, z axes (mutually perpendicular)
Equal vectors	Same magnitude AND direction
Negative vector	Same magnitude, opposite direction ($-A$)
Null (zero) vector	Zero magnitude, arbitrary direction
Collinear / parallel	Act along the same or parallel lines

3.2 Vector Addition & Resolution

Concept	Formula
Component form	$A = A_x\hat{i} + A_y\hat{j}$; $A_x = A \cos\theta$, $A_y = A \sin\theta$
Magnitude	$\lvert A \rvert = \sqrt{(A_x^2 + A_y^2)}$
Direction	$\tan\theta = A_y \div A_x$
Triangle / parallelogram law	Resultant $R = A + B$ (placed head-to-tail / on adjacent sides)
Resultant magnitude	$R = \sqrt{(A^2 + B^2 + 2AB \cos\theta)}$ (θ = angle between A and B)
Direction of resultant	$\tan\alpha = (B \sin\theta) \div (A + B \cos\theta)$
Max & min resultant	$R_{max} = A + B$ ($\theta = 0°$) ; $R_{min} = \lvert A - B \rvert$ ($\theta = 180°$)
Perpendicular vectors (θ = 90°)	$R = \sqrt{(A^2 + B^2)}$

3.3 Product of Vectors

Product	Formula / Property
Scalar (dot) product	$A \cdot B = AB \cos\theta$ (gives a scalar)
Dot in components	$A \cdot B = A_xB_x + A_yB_y + A_zB_z$
Dot properties	$\hat{i}\cdot\hat{i} = \hat{j}\cdot\hat{j} = \hat{k}\cdot\hat{k} = 1$; $\hat{i}\cdot\hat{j} = \hat{j}\cdot\hat{k} = \hat{k}\cdot\hat{i} = 0$; commutative
Vector (cross) product	$A \times B = AB \sin\theta\ \hat{n}$ (gives a vector ⊥ to both)
Cross magnitude	$\lvert A \times B \rvert = AB \sin\theta$ = area of parallelogram
Cross properties	$\hat{i}\times\hat{j} = \hat{k}$, $\hat{j}\times\hat{k} = \hat{i}$, $\hat{k}\times\hat{i} = \hat{j}$; $A\times B = -(B\times A)$; $A\times A = 0$
Angle between vectors	$\cos\theta = (A \cdot B) \div (\lvert A \rvert \lvert B \rvert)$

3.4 Motion in a Plane (2-D Kinematics)

Quantity	Formula
Position vector	$r = x\,\hat{\imath} + y\,\hat{\jmath}$
Velocity	$v = dr/dt = v_x\hat{\imath} + v_y\hat{\jmath}$
Acceleration	$a = dv/dt = a_x\hat{\imath} + a_y\hat{\jmath}$
Equations (vector form)	$v = u + a\,t$; $r = u\,t + ½\,a\,t^2$
Independence of motions	x and y motions are independent (treated separately)

3.5 Projectile Motion

Quantity	Formula (launch speed u, angle θ)
Horizontal velocity	$u_x = u\cos\theta$ (constant throughout)
Vertical velocity	$u_y = u\sin\theta$ (changes due to g)
Equation of path	$y = x\tan\theta - (g\,x^2) \div (2u^2\cos^2\theta)$ → parabola
Time of flight	$T = (2u\sin\theta) \div g$
Maximum height	$H = (u^2\sin^2\theta) \div (2g)$
Horizontal range	$R = (u^2\sin 2\theta) \div g$
Maximum range	$R_{max} = u^2 \div g$ at $\theta = 45°$
Range equal for	θ and (90° − θ) give the same range
Velocity at time t	$v = \sqrt{u_x^2 + (u_y - gt)^2}$

3.6 Uniform Circular Motion

Quantity	Formula
Angular displacement	θ (radian) ; $s = r\,\theta$
Angular velocity	$\omega = \theta/t = 2\pi/T = 2\pi f$
Linear–angular relation	$v = r\,\omega$
Time period	$T = 2\pi/\omega = 2\pi r/v$
Frequency	$f = 1/T = \omega/2\pi$
Centripetal acceleration	$a_c = v^2/r = \omega^2 r = 4\pi^2 f^2 r$ (directed toward centre)
Centripetal force	$F_c = mv^2/r = m\omega^2 r$
Angular acceleration (non-uniform)	$\alpha = d\omega/dt$; tangential accel $a_t = r\alpha$

3.7 Relative Velocity in a Plane

Concept	Formula
Relative velocity	$v_{AB} = v_A - v_B$ (vector subtraction)
River–boat (cross straight)	Point boat upstream at angle θ where $\sin\theta = v_{river} \div v_{boat}$
Resultant speed across river	$v = \sqrt{v_{boat}^2 - v_{river}^2}$ (for shortest path)
Rain–man problem	$v_{rain,man} = v_{rain} - v_{man}$; tilt umbrella along this resultant

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Resultant formula	$R = \sqrt{A^2 + B^2 + 2AB\cos\theta}$. Max at $\theta=0$ ($A+B$), min at $\theta=180°$ ($\|A-B\|$).
Dot vs Cross	Dot → scalar ($AB\cos\theta$) ; Cross → vector ($AB\sin\theta$, perpendicular).
$\hat{i}\ \hat{j}\ \hat{k}$ cross cycle	$\hat{i}\times\hat{j}=\hat{k}$, $\hat{j}\times\hat{k}=\hat{i}$, $\hat{k}\times\hat{i}=\hat{j}$ (cyclic +) ; reverse order gives minus.
Projectile splits	Horizontal: constant velocity. Vertical: free fall under g. Solve separately.
Range max at 45°	$R = u^2\sin 2\theta/g$; maximum when $2\theta = 90°$, i.e. $\theta = 45°$.
Complementary angles	θ and $(90°-\theta)$ give the SAME range (e.g. 30° and 60°).
H : R relation	At $\theta = 45°$, $R = 4H$. Useful quick check.
Centripetal a	$a_c = v^2/r = \omega^2 r$, always pointing toward the centre.

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Chapter 4 : Laws of Motion (NCERT)

4.1 Newton's Three Laws of Motion

Law	Statement / Formula
First law (inertia)	A body stays at rest or in uniform motion unless acted on by a net external force. Defines inertia & force.
Inertia	Tendency to resist change in state of rest/motion; measured by mass
Second law	F = dp/dt = ma (net force = rate of change of momentum)
Linear momentum	p = mv (vector; unit kg m/s)
Third law	Every action has an equal and opposite reaction ($F_{AB} = -F_{BA}$)
Action-reaction note	Act on DIFFERENT bodies, so they never cancel each other

4.2 Force, Momentum & Impulse

Quantity	Formula
Net force	F_{net} = ma (vector sum of all forces)
Impulse	J = F × Δt = Δp = m(v − u)
Impulse–momentum theorem	Impulse = change in momentum
Impulsive force	Large force acting for a very short time (e.g. bat hitting ball)
Area under F–t graph	= Impulse
Conservation of momentum	If $F_{ext} = 0$, total momentum p = constant
Recoil of gun	$m_{gun}v_{gun} = -m_{bullet}v_{bullet}$; $v_{gun} = -(m_b v_b)/m_g$

4.3 Equilibrium & Common Forces

Concept	Detail / Formula
Equilibrium of particle	Net force = 0 → $\Sigma F_x = 0$ and $\Sigma F_y = 0$
Weight	W = mg (acts vertically downward)
Normal reaction (N)	Perpendicular contact force from a surface
Tension (T)	Pull along a string; same throughout a massless string
Spring force (Hooke's law)	F = −kx (k = spring constant, x = extension/compression)
Apparent weight in lift (up, accel a)	N = m(g + a)
Apparent weight in lift (down, accel a)	N = m(g − a)
Free fall in lift (a = g)	N = 0 (weightlessness)

4.4 Friction

Type	Formula / Detail
Static friction	$f_s \le \mu_s N$ (self-adjusting up to a maximum)
Limiting friction	$f_{s,max} = \mu_s N$ (just before motion begins)
Kinetic friction	$f_k = \mu_k N$ (during motion; $\mu_k < \mu_s$)
Coefficient of friction	$\mu = f \div N$ (dimensionless)
Angle of friction (λ)	$\tan\lambda = \mu_s$
Angle of repose (α)	$\tan\alpha = \mu_s$ (angle at which body just slides on incline) $\rightarrow \alpha = \lambda$
Body on incline (no friction)	$a = g \sin\theta$ (down the slope)
Body on incline (with friction)	$a = g(\sin\theta - \mu\cos\theta)$ when sliding down

4.5 Connected Bodies & Pulleys

System	Formula
Two masses on smooth table (pull F)	$a = F \div (m_1 + m_2)$; tension $T = m_2 a$
Atwood machine ($m_1 > m_2$)	$a = (m_1 - m_2)g \div (m_1 + m_2)$
Atwood tension	$T = 2m_1 m_2 g \div (m_1 + m_2)$
Mass on table + hanging mass	$a = m_2 g \div (m_1 + m_2)$; $T = m_1 m_2 g \div (m_1 + m_2)$
General method	Draw free-body diagram for each mass; apply F = ma along motion

4.6 Circular Motion Dynamics

Situation	Formula
Centripetal force	$F_c = mv^2/r = m\omega^2 r$ (directed toward centre)
Level circular road (max speed)	$v_{max} = \sqrt{(\mu_s r g)}$
Banked road (no friction)	$\tan\theta = v^2 \div (r g) \rightarrow v = \sqrt{(r g \tan\theta)}$
Banked road (with friction, v_{max})	$v_{max} = \sqrt{[r g (\mu + \tan\theta) \div (1 - \mu\tan\theta)]}$
Conical pendulum	$\tan\theta = v^2 \div (r g)$; $T_{period} = 2\pi\sqrt{(L\cos\theta \div g)}$
Vertical circle (top)	$v_{top} \ge \sqrt{(gr)}$ for the string to stay taut
Vertical circle (bottom)	$v_{bottom} \ge \sqrt{(5gr)}$ to complete the loop

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Newton's 2nd law	F = ma is the master equation — always start with a free-body diagram.
Action–reaction	Equal & opposite but on DIFFERENT bodies → they never cancel.
Impulse = Δp	J = FΔt = change in momentum = area under F–t graph.
Lift trick	Going up (or accelerating up): N = m(g+a). Down: N = m(g−a). Free fall: N = 0.
Friction order	$\mu_s > \mu_k$; static friction is self-adjusting up to $\mu_s N$.
Angle of repose	$\tan\alpha = \mu_s$; equals the angle of friction λ.
Banking (no friction)	$\tan\theta = v^2/rg$ — independent of mass.

Vertical circle speeds	Top ≥ $\sqrt{gr}$; Bottom ≥ $\sqrt{5gr}$ to complete the loop.

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Chapter 5 : Work, Energy and Power (NCERT)

5.1 Work

Concept	Formula / Detail
Work (constant force)	$W = F\cdot d = Fd\cos\theta$ (θ = angle between force & displacement)
Unit & nature	Joule (J) ; scalar quantity ; 1 J = 1 N·m
Positive work	$\theta < 90°$ (force has component along motion)
Negative work	$\theta > 90°$ (e.g. friction, retarding force)
Zero work	$\theta = 90°$ OR $d = 0$ OR $F = 0$ (e.g. centripetal force)
Work by variable force	$W = \int F\,dx$ = area under F–x graph
Work by spring	$W = \frac{1}{2}kx^2$ (to stretch/compress by x) ; restoring $W = -\frac{1}{2}kx^2$

5.2 Kinetic Energy & Work–Energy Theorem

Concept	Formula
Kinetic energy	$KE = \frac{1}{2}mv^2$
KE in terms of momentum	$KE = p^2 \div (2m)$; $p = \sqrt{2m\cdot KE}$
Work–energy theorem	$W_{net} = \Delta KE = \frac{1}{2}mv^2 - \frac{1}{2}mu^2$
Relation p and KE	If p doubles, KE becomes 4× ; if KE doubles, p increases by $\sqrt{2}$

5.3 Potential Energy

Type	Formula
Gravitational PE (near Earth)	$U = mgh$
Elastic (spring) PE	$U = \frac{1}{2}kx^2$
Force from PE	$F = -dU/dx$ (force points toward decreasing PE)
Conservative force	Work done depends only on end points, not path (gravity, spring)
Non-conservative force	Work depends on path (friction, air resistance)

5.4 Conservation of Mechanical Energy

Concept	Formula / Detail
Total mechanical energy	E = KE + PE = constant (only conservative forces act)
Conservation statement	$\frac{1}{2}mu^2 + mgh_1 = \frac{1}{2}mv^2 + mgh_2$
Free fall from height h	$v = \sqrt{2gh}$ at the bottom
Simple pendulum / swing	Max KE at lowest point, max PE at extreme positions
With friction (non-conservative)	Energy lost = $W_{friction}$; $E_{final} = E_{initial} - \lvert W_{friction}\rvert$

5.5 Power

Concept	Formula
Average power	$P_{avg} = W \div t$
Instantaneous power	$P = dW/dt = F \cdot v = Fv \cos\theta$
Unit	Watt (W) ; 1 W = 1 J/s ; 1 horsepower (hp) = 746 W
Commercial unit of energy	1 kWh = 3.6×10^6 J (1 unit of electricity)

5.6 Collisions

Type	Conserved / Formula
Momentum (all collisions)	$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$ (always conserved)
Elastic collision	Both momentum AND kinetic energy conserved
Inelastic collision	Momentum conserved, KE NOT conserved
Perfectly inelastic	Bodies stick together: $v = (m_1u_1 + m_2u_2) \div (m_1 + m_2)$
Coefficient of restitution (e)	$e = (v_2 - v_1) \div (u_1 - u_2)$; elastic e = 1, perfectly inelastic e = 0
1-D elastic: final v_1	$v_1 = [(m_1-m_2)u_1 + 2m_2u_2] \div (m_1+m_2)$
1-D elastic: final v_2	$v_2 = [(m_2-m_1)u_2 + 2m_1u_1] \div (m_1+m_2)$
Equal masses (elastic)	Velocities are exchanged ($v_1 = u_2$, $v_2 = u_1$)

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Work sign	$\theta < 90° \rightarrow +W$; $\theta = 90° \rightarrow$ zero work ; $\theta > 90° \rightarrow -W$ (friction).
Work–energy theorem	Net work = change in KE. Fastest way to find final speed.
KE & momentum link	$KE = p^2/2m$. Double p → 4× KE ; double KE → p × $\sqrt{2}$.
Force from PE	$F = -dU/dx$. Force always points 'downhill' on the PE curve.
Energy conservation	KE + PE = constant (smooth). With friction, subtract heat lost.
Power forms	$P = W/t = F \cdot v$. Use $F \cdot v$ when force and speed are known.
Collisions	Momentum ALWAYS conserved ; KE conserved ONLY if elastic.
Equal-mass elastic	Velocities just swap. Perfectly inelastic → they move together.

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Chapter 6 : System of Particles and Rotational Motion (NCERT)

6.1 Centre of Mass (CoM)

Concept	Formula
CoM of two particles	$x_{cm} = (m_1x_1 + m_2x_2) \div (m_1 + m_2)$
CoM of n particles	$x_{cm} = \Sigma m_ix_i \div \Sigma m_i$ (similarly y_{cm}, z_{cm})
CoM (continuous body)	$x_{cm} = (1/M) \int x\, dm$
Velocity of CoM	$v_{cm} = \Sigma m_iv_i \div M$
Acceleration of CoM	$a_{cm} = F_{ext} \div M$
Motion of CoM	CoM moves as if total mass & external force act there
CoM of symmetric bodies	At geometric centre (sphere, ring, disc, rod)

6.2 Linear Momentum of a System

Concept	Formula
Total momentum	$P = M\, v_{cm} = \Sigma m_iv_i$
Newton's 2nd law (system)	$F_{ext} = dP/dt = M\, a_{cm}$
Conservation	If $F_{ext} = 0 \rightarrow P$ = constant, v_{cm} = constant
Internal forces	Cancel in pairs (Newton's 3rd law); don't affect CoM motion

6.3 Vector (Cross) Product & Torque

Concept	Formula
Cross product magnitude	$\|A \times B\| = AB \sin\theta$
Torque (moment of force)	$\tau = r \times F$; $\|\tau\| = rF \sin\theta = F \times$ (perpendicular distance)
Torque & angular accel	$\tau = I\, \alpha$ (rotational analogue of $F = ma$)
Angular momentum (particle)	$L = r \times p$; $\|L\| = rp \sin\theta = mvr \sin\theta$
Angular momentum (rigid body)	$L = I\, \omega$
Relation τ and L	$\tau = dL/dt$ (rotational form of Newton's 2nd law)

6.4 Equilibrium of a Rigid Body

Condition	Detail
Translational equilibrium	$\Sigma F = 0$ (net force zero)
Rotational equilibrium	$\Sigma \tau = 0$ (net torque zero)
Couple	Two equal, opposite, parallel forces → pure rotation; $\tau = F \times d$
Principle of moments (lever)	Load × load arm = Effort × effort arm
Mechanical advantage	MA = Load ÷ Effort = effort arm ÷ load arm

Condition	Detail
Centre of gravity (CG)	Point where total weight acts; coincides with CoM in uniform gravity

6.5 Moment of Inertia (I)

Concept	Formula
Moment of inertia	$I = \Sigma m_i r_i^2 = \int r^2\, dm$ (rotational analogue of mass)
Radius of gyration	$K = \sqrt{(I/M)} \rightarrow I = MK^2$
Parallel axis theorem	$I = I_{cm} + Md^2$ (d = distance between axes)
Perpendicular axis theorem	$I_z = I_x + I_y$ (planar bodies only)
Rotational KE	$KE_{rot} = ½I\omega^2$
Work done by torque	$W = \tau\theta$; Power $P = \tau\omega$

6.6 Moment of Inertia of Standard Bodies

Body (axis)	Moment of Inertia
Ring (through centre, ⊥ plane)	$I = MR^2$
Ring (diameter)	$I = ½MR^2$
Disc (through centre, ⊥ plane)	$I = ½MR^2$
Disc (diameter)	$I = ¼MR^2$
Solid sphere (diameter)	$I = (2/5)MR^2$
Hollow sphere (diameter)	$I = (2/3)MR^2$
Solid cylinder (axis)	$I = ½MR^2$
Thin rod (centre, ⊥ length)	$I = (1/12)ML^2$
Thin rod (one end, ⊥ length)	$I = (1/3)ML^2$

6.7 Rotational Kinematics & Rolling Motion

Concept	Formula
Rotational equations	$\omega = \omega_0 + \alpha t$; $\theta = \omega_0 t + ½\alpha t^2$; $\omega^2 = \omega_0^2 + 2\alpha\theta$
Linear–angular link	$v = r\omega$; $a = r\alpha$; $s = r\theta$
Conservation of L	If $\tau_{ext} = 0 \rightarrow L = I\omega$ = constant ($I_1\omega_1 = I_2\omega_2$)
Rolling condition	$v_{cm} = R\omega$ (rolling without slipping)
Total KE (rolling)	$KE = ½Mv^2 + ½I\omega^2 = ½Mv^2(1 + K^2/R^2)$
Rolling down incline (accel)	$a = g \sin\theta \div (1 + K^2/R^2)$
Velocity at bottom of incline	$v = \sqrt{[2gh \div (1 + K^2/R^2)]}$

6.8 Translational ↔ Rotational Analogues

Linear Quantity	Rotational Analogue
Mass (m)	Moment of inertia (I)
Force (F)	Torque ($\tau = I\alpha$)
Linear momentum (p = mv)	Angular momentum ($L = I\omega$)
F = ma	$\tau = I\alpha$
KE = ½mv^2	KE = ½$I\omega^2$
Work W = Fs	Work $W = \tau\theta$
Power P = Fv	Power $P = \tau\omega$

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CoM master formula	$x_{cm} = \Sigma mx/\Sigma m$. CoM moves as if all mass & external force act there.
Torque = r × F	$\tau = rF \sin\theta$. Maximum when force is perpendicular ($\theta = 90°$).
Two theorems	Parallel: $I = I_{cm} + Md^2$. Perpendicular: $I_z = I_x + I_y$ (flat bodies only).
MI quick recall	Ring MR^2, Disc/Cylinder ½MR^2, Solid sphere ⅖MR^2, Hollow sphere ⅔MR^2.
Rod MI	Centre (1/12)ML^2 ; End (1/3)ML^2 — end value is 4× the centre.
Rolling KE	KE = ½$Mv^2(1 + K^2/R^2)$. Hollow bodies roll slower (bigger K^2/R^2).
Incline race	Solid sphere fastest, then disc, then ring (smallest K^2/R^2 wins).
L conservation	$I\omega$ = constant. Skater pulls arms in → I down, ω up.

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Chapter 7 : Gravitation (NCERT)

7.1 Newton's Law of Gravitation

Concept	Formula / Detail
Universal law	$F = G\, m_1 m_2 \div r^2$ (attractive force along the line joining masses)
Gravitational constant	$G = 6.67 \times 10^{-11}$ N m^2 kg^{-2} ; dimension $[M^{-1}L^3T^{-2}]$
Vector form	Force is along the line joining the two masses; always attractive
Nature	Central force, conservative, weakest of the four fundamental forces
Principle of superposition	Net force = vector sum of forces due to each mass

7.2 Acceleration due to Gravity (g)

Concept	Formula
g at Earth's surface	$g = GM \div R^2 \approx 9.8$ m/s^2
Relation g and G	$g = GM/R^2$; also $M = gR^2/G$
At height h above surface	$g_h = g\,(R \div (R+h))^2 \approx g(1 - 2h/R)$ for $h << R$
At depth d below surface	$g_d = g\,(1 - d/R)$
At centre of Earth	$g = 0$ $(d = R)$
Effect of rotation (latitude λ)	$g_\lambda = g - \omega^2 R \cos^2\lambda$
At poles vs equator	g is MAXIMUM at poles, MINIMUM at equator

7.3 Gravitational Field, Potential & PE

Quantity	Formula
Gravitational field intensity	$E = F/m = GM \div r^2$ (force per unit mass)
Gravitational potential	$V = -GM \div r$ (work done per unit mass to bring from infinity)
Gravitational PE (two masses)	$U = -G\, m_1 m_2 \div r$
PE near Earth's surface	$U = mgh$ (for small heights)
Relation E and V	$E = -dV/dr$
Potential at infinity	$V = 0, U = 0$ (reference point)

7.4 Orbital & Escape Velocity

Concept	Formula
Orbital velocity (radius r)	$v_o = \sqrt{(GM \div r)}$; near surface $v_o = \sqrt{(gR)} \approx 7.9$ km/s
Orbital velocity at height h	$v_o = \sqrt{(GM \div (R+h))}$
Escape velocity	$v_e = \sqrt{(2GM \div R)} = \sqrt{(2gR)} \approx 11.2$ km/s
Relation escape & orbital	$v_e = \sqrt{2} \times v_o$ (escape velocity is $\sqrt{2}$ times orbital)

Concept	Formula
Independence	Escape velocity is independent of mass & direction of projection

7.5 Satellite Motion & Energy

Quantity	Formula
Time period of satellite	$T = 2\pi \sqrt{(R+h)^3 \div GM}$
Kinetic energy	$KE = \frac{1}{2} GMm \div r = \frac{1}{2} \lvert U \rvert$
Potential energy	$PE = -GMm \div r$
Total energy	$E = -GMm \div (2r)$ (negative → bound orbit)
Relation of energies	$KE = -E$; $PE = 2E$; $E = -KE$
Binding energy of satellite	$BE = +GMm \div (2r)$ (energy to escape orbit)

7.6 Geostationary & Polar Satellites

Type	Detail
Geostationary satellite	Period = 24 h ; height ≈ 36,000 km ; orbits over equator, west → east
Use of geostationary	Communication, TV broadcasting, weather
Polar satellite	Low altitude (500-800 km), passes over poles; used for mapping & spying
Weightlessness in orbit	Satellite & astronaut both in free fall → apparent weight = 0

7.7 Kepler's Laws of Planetary Motion

Law	Statement
First law (orbit / ellipse)	Each planet moves in an ellipse with the Sun at one focus
Second law (areal velocity)	Line joining planet & Sun sweeps equal areas in equal times → dA/dt = constant (L conserved)
Third law (period)	$T^2 \propto a^3$ (a = semi-major axis) → T^2/a^3 = constant
Consequence of 2nd law	Planet moves faster when nearer the Sun (perihelion), slower when farther (aphelion)

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g formula	$g = GM/R^2$. Decreases with both height AND depth; zero at Earth's centre.
Height vs depth	Height: $g(1 - 2h/R)$; Depth: $g(1 - d/R)$. Height falls TWICE as fast.
g at poles/equator	Maximum at poles (no rotation effect), minimum at equator.
Escape = √2 × orbital	$v_e = \sqrt{2}\, v_o$. Surface escape ≈ 11.2 km/s, orbital ≈ 7.9 km/s.
Satellite energy	$E = -GMm/2r$. $KE = -E$ (positive), $PE = 2E$ (negative), Total = $-KE$.
Potential sign	$V = -GM/r$ (always negative) ; zero only at infinity.
Kepler's 3rd	$T^2 \propto a^3$ — bigger orbit means much longer year.

Geostationary	Period exactly 24 h, about 36,000 km up, sits over the equator.

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Chapter 8 : Mechanical Properties of Solids (NCERT)

8.1 Stress and Strain

Quantity	Formula / Detail
Stress	Stress = Force ÷ Area = F/A ; SI unit N/m^2 (Pa); dimension $[M^1L^{-1}T^{-2}]$
Longitudinal (normal) stress	Force perpendicular to area; tensile (stretch) or compressive
Tangential (shear) stress	Force parallel to the surface
Hydraulic stress	Force applied uniformly from all sides (by a fluid)
Strain	Strain = change in dimension ÷ original dimension; dimensionless, no unit
Longitudinal strain	$\Delta L \div L$ (change in length per unit length)
Shear strain	$= \tan\theta \approx \theta$ (angular deformation, in radian)
Volume strain	$\Delta V \div V$ (change in volume per unit volume)

8.2 Hooke's Law & Stress–Strain Curve

Concept	Detail
Hooke's law	Within elastic limit: Stress ∝ Strain → Stress = E × Strain (E = modulus of elasticity)
Proportional limit	Up to here stress ∝ strain (Hooke's law obeyed)
Elastic limit / yield point	Beyond it, body does not regain original shape (permanent set)
Plastic region	Permanent deformation occurs
Ultimate tensile strength	Maximum stress a material can withstand
Fracture / breaking point	Material breaks
Elastomers	Stretch a lot, no linear region (e.g. rubber); large elastic range

8.3 Moduli of Elasticity

Modulus	Formula
Young's modulus (Y)	Y = Longitudinal stress ÷ Longitudinal strain = $(F\cdot L) \div (A\cdot\Delta L)$
Young's modulus (wire)	$Y = (F\cdot L) \div (\pi r^2\cdot\Delta L)$
Bulk modulus (B / K)	B = −Hydraulic stress ÷ Volume strain = $-P\cdot V \div \Delta V$
Compressibility	$k = 1 \div B$
Shear / Rigidity modulus (G / η)	G = Shear stress ÷ Shear strain = $F \div (A\cdot\theta)$
Units of all moduli	N/m^2 (Pa) — same as stress (strain is dimensionless)

8.4 Poisson's Ratio & Elastic Energy

Concept	Formula
Lateral strain	$= \Delta d \div d$ (change in diameter per unit diameter)

Concept	Formula
Poisson's ratio (σ)	σ = Lateral strain ÷ Longitudinal strain = $-(\Delta d/d) \div (\Delta L/L)$
Range of σ	Theoretically −1 to 0.5 ; practically 0 to 0.5
Elastic potential energy	U = ½ × Stress × Strain × Volume
Energy density	u = U/Volume = ½ × Stress × Strain = ½ × Y × $(\text{strain})^2$
Energy in stretched wire	$U = \frac{1}{2} \times F \times \Delta L = \frac{1}{2} \times (Y A \Delta L^2) \div L$

8.5 Applications & Important Facts

Concept	Detail
Elongation under own weight	$\Delta L = (Mg\, L) \div (2AY) = (\rho\, g\, L^2) \div (2Y)$
Thermal stress (rod fixed)	Stress = $Y\, \alpha\, \Delta T$ (α = coeff. of linear expansion)
Why hollow beams / I-shape	Greater rigidity per unit mass; resist bending better
Depression of a beam (loaded centre)	$\delta = (W\, L^3) \div (4\, b\, d^3\, Y)$ (rectangular beam)
Elastic after-effect	Delay in regaining original shape after stress removed
Elastic fatigue	Loss of strength due to repeated stress cycles

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Stress vs strain	Stress = F/A (has units, Pa) ; Strain = change/original (no units).
Three moduli	Young's → length change ; Bulk → volume change ; Shear → shape change.
Hooke's law	Stress = E × Strain (only within the elastic limit).
Young's modulus wire	$Y = FL/(A\Delta L)$. Thicker/longer setups change ΔL — keep units consistent.
Poisson's ratio	σ = lateral/longitudinal strain ; practical range 0 to 0.5.
Energy density	u = ½ × stress × strain = ½ Y $(\text{strain})^2$. Area under stress–strain graph.
Bulk & compressibility	$k = 1/B$. Gases most compressible, solids least.
Thermal stress	= $Y\, \alpha\, \Delta T$ (independent of length, for a rigidly fixed rod).

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Chapter 9 : Mechanical Properties of Fluids (NCERT)

9.1 Pressure in Fluids

Concept	Formula / Detail
Pressure	$P = F \div A$ (force per unit area; scalar) ; SI unit Pa (N/m^2)
Density	ρ = mass ÷ volume (kg/m^3)
Relative density	= density of substance ÷ density of water (no unit)
Pressure due to liquid column	$P = \rho g h$ (gauge pressure at depth h)
Absolute pressure	$P = P_0 + \rho gh$ (P_0 = atmospheric pressure)
Gauge pressure	$P_{gauge} = P - P_0 = \rho gh$
Atmospheric pressure	1 atm = 1.013×10^5 Pa = 76 cm of Hg
Pascal's law	Pressure applied to an enclosed fluid is transmitted equally in all directions

9.2 Applications of Pascal's Law & Buoyancy

Concept	Formula
Hydraulic lift / press	$F_2 = F_1 \times (A_2 \div A_1)$ (force multiplied by area ratio)
Hydraulic principle	$P_1 = P_2 \rightarrow F_1/A_1 = F_2/A_2$
Archimedes' principle	Buoyant force = weight of fluid displaced = $\rho_{fluid} V_{submerged} g$
Apparent weight (submerged)	$W_{app} = W - F_{buoyant} = V g (\rho_{body} - \rho_{fluid})$
Law of floatation	Floats if $\rho_{body} \leq \rho_{fluid}$; weight = buoyant force
Fraction submerged (floating)	$V_{submerged} \div V_{total} = \rho_{body} \div \rho_{fluid}$

9.3 Fluid Flow & Bernoulli's Principle

Concept	Formula
Equation of continuity	$A_1v_1 = A_2v_2$ = constant (Av = volume flow rate)
Consequence	Narrow pipe → higher velocity (smaller area, faster flow)
Bernoulli's equation	$P + \frac{1}{2}\rho v^2 + \rho gh$ = constant (along a streamline)
Bernoulli (per unit volume)	Pressure energy + KE + PE per unit volume = constant
Speed of efflux (Torricelli)	$v = \sqrt{(2gh)}$ (liquid out of a hole at depth h)
Venturimeter	$v = \sqrt{[2(P_1 - P_2) \div \rho]}$; measures flow speed
Dynamic lift / aerofoil	Faster air on top → lower pressure → upward lift

9.4 Viscosity

Concept	Formula
Viscous force (Newton)	$F = -\eta A (dv/dx)$; η = coefficient of viscosity

Concept	Formula
SI unit of η	Pa·s (or poiseuille) ; CGS: poise (1 Pa·s = 10 poise)
Stokes' law (sphere in fluid)	$F = 6\pi\eta rv$ (drag on a small sphere of radius r)
Terminal velocity	$v_t = [2r^2(\rho - \sigma)g] \div (9\eta)$ (ρ = sphere, σ = fluid density)
Reynolds number	$Re = (\rho\, v\, D) \div \eta$ (dimensionless)
Flow type by Re	$Re < 1000$ laminar ; 1000-2000 unstable ; > 2000 turbulent
Poiseuille's equation	$Q = (\pi\, P\, r^4) \div (8\, \eta\, L)$ (volume flow rate through a pipe)

9.5 Surface Tension

Concept	Formula
Surface tension (T)	T = Force ÷ length = F/L ; SI unit N/m
Surface energy	= T × increase in surface area
Excess pressure (liquid drop)	$P = 2T \div R$
Excess pressure (soap bubble)	$P = 4T \div R$ (two surfaces)
Excess pressure (air bubble in liquid)	$P = 2T \div R$
Capillary rise (Jurin's law)	$h = (2T\cos\theta) \div (\rho\, g\, r)$ (θ = angle of contact)
Angle of contact	$\theta < 90°$ wetting (water-glass) ; $\theta > 90°$ non-wetting (mercury-glass)

9.6 Effect of Temperature & Key Facts

Concept	Detail
Viscosity vs temperature	Liquids: viscosity DECREASES with temperature ; Gases: INCREASES
Surface tension vs temperature	Decreases with rise in temperature; zero at critical temperature
Effect of impurities on T	Soluble impurities (salt) increase T ; soap/detergent decreases T
Why drops are spherical	Surface tension minimises surface area → sphere (least area per volume)
Streamline vs turbulent	Streamline: orderly layers ; Turbulent: irregular, eddies

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Pressure with depth	$P = P_0 + \rho gh$. Depends on depth, NOT on shape or area of container.
Pascal → hydraulic lift	$F_2 = F_1(A_2/A_1)$. Small force on small piston lifts big load.
Continuity	Av = constant → pinch a hose, water shoots faster.
Bernoulli	$P + \frac{1}{2}\rho v^2 + \rho gh$ = constant. High speed → low pressure.
Torricelli	Efflux speed $v = \sqrt{2gh}$ — same as a freely falling body.
Terminal velocity	$v_t \propto r^2$. Bigger sphere falls faster in a viscous fluid.
Drop vs bubble	Drop/air-bubble: 2T/R ; Soap bubble: 4T/R (two surfaces).
Capillary rise	$h = 2T\cos\theta/\rho gr$. Narrower tube → higher rise.

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Chapter 10 : Thermal Properties of Matter (NCERT)

10.1 Temperature & Thermal Expansion

Concept	Formula
Celsius–Fahrenheit	$(F - 32)/9 = C/5$; also $C/100 = (F-32)/180$
Celsius–Kelvin	$K = C + 273.15$
Linear expansion	$\Delta L = \alpha L \Delta T$; $L = L_0(1 + \alpha \Delta T)$
Area (superficial) expansion	$\Delta A = \beta A \Delta T$; $\beta = 2\alpha$
Volume (cubical) expansion	$\Delta V = \gamma V \Delta T$; $\gamma = 3\alpha$
Relation	$\alpha : \beta : \gamma = 1 : 2 : 3$
Thermal stress (rod fixed)	Stress = $Y \alpha \Delta T$

10.2 Specific Heat & Calorimetry

Concept	Formula
Heat absorbed/released	$Q = m c \Delta T$ (c = specific heat capacity)
Molar specific heat	$Q = n C \Delta T$
Specific heat of water	$c = 4186\ J\ kg^{-1}\ K^{-1} = 1\ cal\ g^{-1}\ °C^{-1}$
Principle of calorimetry	Heat lost by hot body = heat gained by cold body
Water equivalent	$W = m c \div c_{water}$ (mass of water needing same heat)
1 calorie	= 4.186 J

10.3 Latent Heat & Change of State

Concept	Formula / Value
Latent heat	$Q = m L$ (heat for phase change at constant T)
Latent heat of fusion (ice)	$L_f = 3.34 \times 10^5$ J/kg = 80 cal/g
Latent heat of vaporisation (water)	$L_v = 22.6 \times 10^5$ J/kg = 540 cal/g
Melting	Solid → liquid (absorbs heat, T constant)
Vaporisation	Liquid → gas (absorbs heat, T constant)
Sublimation	Solid → gas directly
Effect of pressure	↑ pressure → m.p. of ice falls, b.p. of water rises

10.4 Heat Transfer — Conduction

Concept	Formula
Rate of heat flow (conduction)	$Q/t = K A (T_1 - T_2) \div L$
Thermal conductivity	K (unit: $W\ m^{-1}\ K^{-1}$)

Concept	Formula
Thermal resistance	$R = L \div (KA)$
Temperature gradient	$= (T_1 - T_2) \div L$
Series combination	$R_{eq} = R_1 + R_2$ (resistances add)
Parallel combination	$1/R_{eq} = 1/R_1 + 1/R_2$

10.5 Convection, Radiation & Laws

Concept	Formula / Statement
Convection	Heat transfer by actual movement of fluid (no formula required)
Stefan–Boltzmann law	$E = \sigma T^4$; $\sigma = 5.67 \times 10^{-8}$ W m^{-2} K^{-4}
Power radiated by a body	$P = e \sigma A T^4$ (e = emissivity)
Net radiated power	$P = e \sigma A (T^4 - T_0^4)$
Wien's displacement law	$\lambda_m T = b$; $b = 2.9 \times 10^{-3}$ m·K
Newton's law of cooling	Rate of cooling $\propto (T - T_0)$ (small temperature difference)
Cooling expression	$dT/dt = -k(T - T_0)$
Kirchhoff's law (radiation)	Good absorbers are good emitters (a = e)

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Expansion ratio	$\alpha : \beta : \gamma = 1 : 2 : 3$. $\beta = 2\alpha$ (area), $\gamma = 3\alpha$ (volume).
Temperature scales	K = C + 273.15 ; C/5 = (F−32)/9.
Calorimetry	Heat lost = heat gained. Mix problems balance the two sides.
Latent heat	Q = mL. Ice: 80 cal/g (fusion) ; Water: 540 cal/g (vaporisation).
Conduction	$Q/t = KA\Delta T/L$. Like Ohm's law: heat current = ΔT / thermal resistance.
Stefan's law	$E \propto T^4$ — doubling temperature raises radiated power 16×.
Wien's law	λ_m T = constant. Hotter body → shorter peak wavelength (bluer).
Newton's cooling	Rate ∝ temperature difference (valid for small ΔT only).

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Chapter 11 : Thermodynamics (NCERT)

11.1 Basic Terms & Zeroth Law

Concept	Detail
Thermodynamic system	A definite quantity of matter under study
State variables	P, V, T, internal energy U (describe the state)
Thermal equilibrium	No net heat flow between systems (same temperature)
Zeroth law	If A is in equilibrium with C, and B with C, then A and B are in equilibrium → defines temperature
Internal energy (U)	Total KE + PE of molecules ; a state function
For ideal gas	U depends only on temperature

11.2 First Law of Thermodynamics

Concept	Formula
First law	$\Delta Q = \Delta U + \Delta W$ (heat = internal energy change + work done)
Sign convention	Q +ve if absorbed ; W +ve if done BY the gas
Work done by gas	$\Delta W = P\,\Delta V$; $W = \int P\,dV$ (area under P–V curve)
Change in internal energy	$\Delta U = n\,C_v\,\Delta T$ (depends only on temperature)
State vs path	U is a state function ; Q and W are path functions

11.3 Thermodynamic Processes

Process	Condition & Key Results
Isothermal	T constant ; $\Delta U = 0$; $Q = W = nRT \ln(V_2/V_1)$
Adiabatic	$Q = 0$; $\Delta U = -W$; PV^{γ} = constant
Adiabatic relations	$TV^{(\gamma-1)}$ = const ; $P^{(1-\gamma)}T^{\gamma}$ = const
Isobaric (P constant)	$W = P\,\Delta V = nR\,\Delta T$; $Q = n\,C_p\,\Delta T$
Isochoric (V constant)	$W = 0$; $Q = \Delta U = n\,C_v\,\Delta T$
Cyclic process	$\Delta U = 0$; Q = W (net) ; area of P–V loop = work

11.4 Specific Heats of Gas

Concept	Formula
Molar heat (constant V)	$C_v = (f/2)R$ (f = degrees of freedom)
Molar heat (constant P)	$C_p = C_v + R$ (Mayer's relation)
Ratio of specific heats	$\gamma = C_p/C_v = 1 + 2/f$
Monatomic gas	$C_v = (3/2)R$, $C_p = (5/2)R$, $\gamma = 1.67$

Concept	Formula
Diatomic gas	$C_v = (5/2)R$, $C_p = (7/2)R$, $\gamma = 1.40$
Polyatomic gas	$C_v = 3R$, $C_p = 4R$, $\gamma = 1.33$

11.5 Second Law & Heat Engines

Concept	Formula / Statement
Second law (Kelvin–Planck)	No engine can convert all heat into work (some is rejected)
Second law (Clausius)	Heat cannot flow from cold to hot body on its own
Heat engine efficiency	$\eta = W \div Q_1 = 1 - Q_2/Q_1$
Carnot efficiency	$\eta = 1 - T_2/T_1$ (T in kelvin)
Carnot is the maximum	No engine between two temperatures can beat Carnot
Refrigerator COP	$\beta = Q_2 \div W = Q_2 \div (Q_1 - Q_2)$
Carnot refrigerator COP	$\beta = T_2 \div (T_1 - T_2)$
Relation	$\eta + \beta$(for same engine reversed) ; $\beta = (1-\eta)/\eta$

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First law	$\Delta Q = \Delta U + \Delta W$. Heat in = internal energy rise + work by gas.
Process map	Isothermal: $\Delta U=0$; Adiabatic: $Q=0$; Isochoric: $W=0$; Isobaric: $Q=nC_p\Delta T$.
Adiabatic	PV^γ = constant. No heat exchange — fast compression/expansion.
Cp − Cv = R	Mayer's relation (per mole). Cp always greater than Cv.
Gamma values	Monatomic 1.67, diatomic 1.40, polyatomic 1.33. $\gamma = 1 + 2/f$.
Carnot efficiency	$\eta = 1 - T_2/T_1$ (kelvin). Higher source temperature → better efficiency.
No 100% engine	Second law forbids converting all heat into work.
Fridge COP	$\beta = T_2/(T_1-T_2)$. Smaller temperature gap → better cooling efficiency.

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Chapter 12 : Kinetic Theory (NCERT)

12.1 Ideal Gas Laws

Law	Formula
Boyle's law	PV = constant (T constant)
Charles's law	V/T = constant (P constant)
Gay-Lussac's law	P/T = constant (V constant)
Avogadro's law	Equal volumes have equal molecules (same T, P)
Ideal gas equation	PV = nRT = NkT
Gas constant	$R = 8.314\ J\ mol^{-1}\ K^{-1}$
Boltzmann constant	$k = R \div N_A = 1.38 \times 10^{-23}$ J/K
Avogadro number	$N_A = 6.022 \times 10^{23}$ per mole

12.2 Kinetic Theory — Pressure & Energy

Concept	Formula
Pressure of gas	$P = (1/3)(mN/V)\ \bar{v}^2 = (1/3)\rho\ \bar{v}^2$
Pressure & KE	P = (2/3)(E/V) ; E = average KE per unit volume
Average KE per molecule	$(1/2)m\ \bar{v}^2 = (3/2)kT$
Average KE per mole	(3/2)RT
Internal energy (ideal gas)	U = (3/2)nRT (monatomic)
KE depends only on	Temperature (not on mass or type of gas)

12.3 Molecular Speeds

Speed	Formula
RMS speed	$v_{rms} = \sqrt{(3RT/M)} = \sqrt{(3kT/m)} = \sqrt{(3P/\rho)}$
Average speed	$v_{avg} = \sqrt{(8RT/\pi M)} = \sqrt{(8kT/\pi m)}$
Most probable speed	$v_{mp} = \sqrt{(2RT/M)} = \sqrt{(2kT/m)}$
Ratio of speeds	$v_{rms} : v_{avg} : v_{mp} = \sqrt{3} : \sqrt{(8/\pi)} : \sqrt{2} = 1.73 : 1.60 : 1.41$
Order	$v_{rms} > v_{avg} > v_{mp}$
Speed vs temperature	$v \propto \sqrt{T}$ (all speeds increase with $\sqrt{T}$)

12.4 Degrees of Freedom & Equipartition

Concept	Detail
Degrees of freedom (f)	Monatomic: 3 ; Diatomic: 5 ; Polyatomic (non-linear): 6
Equipartition theorem	Each degree of freedom has energy (1/2)kT per molecule

Concept	Detail
Energy per mole	$U = (f/2)RT$
Specific heats	$C_v = (f/2)R$; $C_p = (f/2 + 1)R$
Adiabatic exponent	$\gamma = C_p/C_v = 1 + 2/f$
Monatomic γ	$\gamma = 1.67$ ($f = 3$)
Diatomic γ	$\gamma = 1.40$ ($f = 5$)

12.5 Mean Free Path

Concept	Formula
Mean free path	$\lambda = 1 \div (\sqrt{2}\ \pi\ d^2\ n)$
In terms of P, T	$\lambda = kT \div (\sqrt{2}\ \pi\ d^2\ P)$
d = molecular diameter	n = number density (molecules per volume)
Mean free path vs P	$\lambda \propto 1/P$ (lower pressure → longer free path)
Mean free path vs T	$\lambda \propto T$ (at constant P)

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Ideal gas	$PV = nRT = NkT$. Use n (moles) with R, or N (molecules) with k.
Pressure formula	$P = (1/3)\rho\bar{v}^2$. Pressure comes from molecular collisions.
KE & temperature	Average KE = $(3/2)kT$ — depends ONLY on temperature.
Speed order	v_rms > v_avg > v_mp (1.73 : 1.60 : 1.41). All $\propto \sqrt{T}$.
RMS speed	v_rms = $\sqrt{3RT/M}$. Lighter gas → faster molecules.
Degrees of freedom	Mono 3, di 5, polyatomic 6. Energy = $(f/2)kT$ per molecule.
Cv from f	$C_v = (f/2)R$, $C_p = C_v + R$, $\gamma = 1 + 2/f$.
Mean free path	$\lambda = kT/(\sqrt{2}\ \pi d^2 P)$. Lower pressure → longer free path.

CLASS 11 PHYSICS — FORMULA SHEET

Chapter 13 : Oscillations (NCERT)

13.1 Periodic & Simple Harmonic Motion

Concept	Formula
Time period	T = time for one oscillation ; unit second
Frequency	$f = 1/T$; unit hertz (Hz)
Angular frequency	$\omega = 2\pi/T = 2\pi f$
SHM condition	Restoring force $F = -kx$ ($\propto$ displacement, opposite direction)
Acceleration in SHM	$a = -\omega^2 x$
Displacement	$x = A \sin(\omega t + \varphi)$ (A = amplitude, φ = phase constant)

13.2 Velocity, Acceleration & Energy in SHM

Quantity	Formula
Velocity	$v = \omega \sqrt{(A^2 - x^2)}$; $v_{max} = \omega A$ (at mean position)
Acceleration	$a = -\omega^2 x$; $a_{max} = \omega^2 A$ (at extreme position)
Kinetic energy	$KE = \frac{1}{2} m \omega^2 (A^2 - x^2)$
Potential energy	$PE = \frac{1}{2} m \omega^2 x^2$
Total energy	$E = \frac{1}{2} m \omega^2 A^2$ (constant)
KE at mean position	Maximum (= total energy) ; PE = 0
PE at extreme position	Maximum (= total energy) ; KE = 0

13.3 Phase & Special Positions

Position	Displacement, Velocity, Acceleration
Mean position ($x = 0$)	v = max ; $a = 0$; KE = max ; PE = 0
Extreme position ($x = A$)	$v = 0$; a = max ; KE = 0 ; PE = max
Phase difference (v from x)	Velocity leads displacement by $\pi/2$
Phase difference (a from x)	Acceleration is opposite to displacement (π)
KE & PE frequency	Both vary at TWICE the frequency of displacement

13.4 Spring & Pendulum Systems

System	Time Period
Spring–mass	$T = 2\pi \sqrt{(m/k)}$
Springs in series	$1/k_{eq} = 1/k_1 + 1/k_2$ (softer, longer T)
Springs in parallel	$k_{eq} = k_1 + k_2$ (stiffer, shorter T)
Simple pendulum	$T = 2\pi \sqrt{(L/g)}$

System	Time Period
Pendulum (condition)	Valid for small angle (θ less than about 10°)
Seconds pendulum	$T = 2$ s → $L \approx 1$ m
Pendulum in lift (up)	$T = 2\pi \sqrt{L/(g+a)}$; shorter period
Pendulum in lift (down)	$T = 2\pi \sqrt{L/(g-a)}$; longer period

13.5 Damped & Forced Oscillations

Concept	Detail / Formula
Damped oscillation	Amplitude decreases over time due to friction/resistance
Damped amplitude	$A = A_0 e^{(-bt/2m)}$ (b = damping constant)
Damped angular frequency	$\omega' = \sqrt{\omega_0^2 - (b/2m)^2}$
Free oscillation	Oscillates at its natural frequency ω_0
Forced oscillation	Driven by an external periodic force
Resonance	Driving frequency = natural frequency → amplitude is maximum

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SHM core	$a = -\omega^2 x$. Acceleration always points back toward the mean position.
Velocity & accel max	$v_{max} = \omega A$ (at mean) ; $a_{max} = \omega^2 A$ (at extreme).
Energy	Total $E = \frac{1}{2} m\omega^2 A^2$ (constant). KE max at centre, PE max at ends.
Energy frequency	KE and PE oscillate at TWICE the displacement frequency.
Spring period	$T = 2\pi\sqrt{m/k}$. Heavier mass or softer spring → longer period.
Springs combine	Series → softer (add reciprocals). Parallel → stiffer (add k).
Pendulum	$T = 2\pi\sqrt{L/g}$. Independent of mass and (small) amplitude.
Resonance	Max amplitude when driving frequency matches natural frequency.

CLASS 11 PHYSICS — FORMULA SHEET

Chapter 14 : Waves (NCERT)

14.1 Wave Basics

Concept	Formula
Wave speed	$v = f\lambda = \lambda/T$
Angular frequency	$\omega = 2\pi f = 2\pi/T$
Wave number	$k = 2\pi/\lambda$
Wave speed (k, ω)	$v = \omega/k$
Transverse wave	Particle motion ⊥ to wave direction (e.g. string, light)
Longitudinal wave	Particle motion parallel to wave (e.g. sound)
Progressive wave equation	$y = A \sin(\omega t - kx)$ (moving in +x direction)

14.2 Speed of Waves

Medium / Wave	Formula
Wave on a string	$v = \sqrt{T/\mu}$; μ = mass per unit length
Sound in solid	$v = \sqrt{Y/\rho}$ (Y = Young's modulus)
Sound in liquid/gas	$v = \sqrt{B/\rho}$ (B = bulk modulus)
Newton's formula (sound in air)	$v = \sqrt{P/\rho}$ (isothermal — gives wrong value)
Laplace correction	$v = \sqrt{\gamma P/\rho}$ (adiabatic — correct value about 332 m/s)
Sound speed & temperature	$v \propto \sqrt{T}$; increases 0.61 m/s per °C

14.3 Principle of Superposition & Interference

Concept	Formula
Superposition	$y = y_1 + y_2$ (resultant displacement)
Constructive interference	Phase diff = $2n\pi$; path diff = $n\lambda$
Destructive interference	Phase diff = $(2n-1)\pi$; path diff = $(2n-1)\lambda/2$
Resultant amplitude	$A = \sqrt{A_1^2 + A_2^2 + 2A_1A_2 \cos \varphi}$
Max amplitude	$A_1 + A_2$ (in phase)
Min amplitude	$\lvert A_1 - A_2 \rvert$ (out of phase)

14.4 Standing (Stationary) Waves

System	Formula
Standing wave equation	$y = 2A \sin(kx) \cos(\omega t)$
Nodes	Points of zero amplitude (fixed)
Antinodes	Points of maximum amplitude

System	Formula
Distance node to node	$\lambda/2$; node to antinode = $\lambda/4$
String fixed both ends	$f_n = (n/2L)\sqrt{(T/\mu)}$; n = 1, 2, 3 …
Fundamental (string)	$f_1 = (1/2L)\sqrt{(T/\mu)}$
Harmonics (string)	All harmonics present (f_1, $2f_1$, $3f_1$ …)
Open pipe	$f_n = nv/(2L)$; all harmonics
Closed pipe	$f_n = (2n-1)v/(4L)$; only ODD harmonics

14.5 Beats & Doppler Effect

Concept	Formula
Beat frequency	$f_{beat} = \lvert f_1 - f_2 \rvert$
Beats condition	Two waves of slightly different frequencies
Doppler (general)	$f' = f\,(v \pm v_o) \div (v \mp v_s)$
Source approaching	$f' = f \times v \div (v - v_s)$ (frequency increases)
Source receding	$f' = f \times v \div (v + v_s)$ (frequency decreases)
Observer approaching	$f' = f \times (v + v_o) \div v$
Observer receding	$f' = f \times (v - v_o) \div v$
Sign rule	Top signs for approach (toward), bottom for recede (away)

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Wave relation	$v = f\lambda$. Speed is set by the MEDIUM, frequency by the SOURCE.
String speed	$v = \sqrt{(T/\mu)}$. Tighter string or lighter string → faster wave.
Laplace correction	Sound in air uses adiabatic: $v = \sqrt{(\gamma P/\rho)}$, not Newton's $\sqrt{(P/\rho)}$.
Sound & temperature	$v \propto \sqrt{T}$; rises about 0.61 m/s for every 1°C.
Node spacing	Node to node = $\lambda/2$; node to antinode = $\lambda/4$.
Open vs closed pipe	Open: all harmonics. Closed: only ODD harmonics (fundamental halved).
Beats	$f\_beat = \lvert f_1 - f_2 \rvert$. Used to tune instruments.
Doppler sign	'Toward' raises pitch, 'away' lowers it. Choose signs accordingly.