

NEET (UG) · JEE MAIN & ADVANCED · CLASS 11 & 12

Mind Mapping Physics Formulas

Every NCERT physics chapter as one mind map:
formulas, special cases, tables and exam traps

28 Chapters

NCERT Sequence

Free E-book



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How to use this book

1. Mind Map first. The dark pill is the chapter; each card is one branch. Cover the formula with your finger and say it before you look.

2. Flow strips. Purple strips show a method in order (how to solve a type of problem). Follow the same steps in the exam.

3. Tables. Tables collect special cases (moments of inertia, fields of standard shapes, combinations) so you can compare them at a glance.

4. Red box. Traps where students lose marks: sign conventions, units, exceptions. Revise it on the last day before the exam.

Mind Mapping Physics Formulas for NEET (UG), JEE Main and Advanced, Class 11 & 12

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Every formula has been checked against the current NCERT Physics textbooks for Class 11 and 12, and numerical constants have been computer-checked. Chapter numbering follows the rationalised NCERT syllabus.

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Constants, Prefixes and Conversions

Keep this page open while you revise; NEET and JEE give some of these, but not always.

Physical constants (NCERT values)

Constant	Symbol	Value
Speed of light in vacuum	c	$3.00 \times 10^8 \text{ m s}^{-1}$
Gravitational constant	G	$6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$
Acceleration due to gravity (surface)	g	9.8 m s^{-2}
Planck's constant	h	$6.63 \times 10^{-34} \text{ J s}$
Elementary charge	e	$1.6 \times 10^{-19} \text{ C}$
Electron mass	m_e	$9.1 \times 10^{-31} \text{ kg}$
Proton mass	m_p	$1.673 \times 10^{-27} \text{ kg}$
Permittivity of free space	ϵ_0	$8.85 \times 10^{-12} \text{ C}^2 \text{ N}^{-1} \text{ m}^{-2}$; $1/(4\pi\epsilon_0) = 9 \times 10^9 \text{ N m}^2 \text{ C}^{-2}$
Permeability of free space	μ_0	$4\pi \times 10^{-7} \text{ T m A}^{-1}$
Boltzmann constant	k_B	$1.38 \times 10^{-23} \text{ J K}^{-1}$
Avogadro number	N_A	$6.023 \times 10^{23} \text{ mol}^{-1}$
Universal gas constant	R	$8.314 \text{ J mol}^{-1} \text{ K}^{-1}$
Stefan-Boltzmann constant	σ	$5.67 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4}$
Wien's constant	b	$2.9 \times 10^{-3} \text{ m K}$
Atomic mass unit	1 u	$1.66 \times 10^{-27} \text{ kg} \equiv 931.5 \text{ MeV}$
Bohr radius / ground-state energy (H)	a_0, E_1	$0.53 \text{ \AA} (5.3 \times 10^{-11} \text{ m}); -13.6 \text{ eV}$
Rydberg constant	R	$1.097 \times 10^7 \text{ m}^{-1}$
hc (handy for photons)	hc	$\approx 1240 \text{ eV nm}$

Prefixes and conversions

Prefix	Factor	Conversion	Value
giga (G)	10^9	1 eV	$1.6 \times 10^{-19} \text{ J}$
mega (M)	10^6	1 Å	10^{-10} m
kilo (k)	10^3	1 atm	$1.013 \times 10^5 \text{ Pa}$
milli (m)	10^{-3}	1 km h ⁻¹	$5/18 \text{ m s}^{-1}$
micro (μ)	10^{-6}	1 calorie	4.186 J
nano (n)	10^{-9}	1 kWh	$3.6 \times 10^6 \text{ J}$
pico (p)	10^{-12}	1 horsepower	746 W
femto (f)	10^{-15}	1 light year	$9.46 \times 10^{15} \text{ m}$

Trigonometric values you use every day

θ	0°	30°	37°	45°	53°	60°	90°
$\sin \theta$	0	$1/2$	$3/5$	$1/\sqrt{2}$	$4/5$	$\sqrt{3}/2$	1
$\cos \theta$	1	$\sqrt{3}/2$	$4/5$	$1/\sqrt{2}$	$3/5$	$1/2$	0
$\tan \theta$	0	$1/\sqrt{3}$	$3/4$	1	$4/3$	$\sqrt{3}$	∞

Notes

- 37° and 53° values are approximations (3-4-5 triangle) used in problems; exact $\sin 37^\circ = 0.6018$.
- Small angle: $\sin \theta \approx \tan \theta \approx \theta$ (in radians), $\cos \theta \approx 1 - \theta^2/2$.
- Binomial: $(1 + x)^n \approx 1 + nx$ when $x \ll 1$.
- $1 \text{ rad} = 57.3^\circ$; $\pi \text{ rad} = 180^\circ$.



PART A

Class 11

Chapters in NCERT sequence

Units and Measurements

SI units, significant figures, errors and dimensional analysis.

MIND MAP · Units and Measurements

Units and Measurements

SI base units (7)

- **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:** radian (plane angle), steradian (solid angle)

Significant figures

- All non-zero digits are significant
- Zeros between non-zero digits are significant
- Leading zeros (0.00ab) are not significant
- Trailing zeros after decimal point are significant (2.300 has 4)
- **x or ÷:** result has as many s.f. as the least precise number
- **+ or −:** result has as many decimal places as the least precise number

Errors

- **Absolute error:** $\Delta a_i = a_{\text{mean}} - a_i$
- **Mean absolute error:** $\Delta a_{\text{mean}} = (\sum |\Delta a_i|)/n$
- **Relative error:** $\Delta a_{\text{mean}} / a_{\text{mean}}$; percentage error = $(\Delta a/a) \times 100\%$
- **Sum or difference $Z = A \pm B$:** $\Delta Z = \Delta A + \Delta B$ (absolute errors add)
- **Product or quotient $Z = AB$ or A/B :** $\Delta Z/Z = \Delta A/A + \Delta B/B$
- **Power $Z = A^p B^q / C^r$:** $\Delta Z/Z = p\Delta A/A + q\Delta B/B + r\Delta C/C$

Dimensional analysis

- **Check correctness:** both sides must have same dimensions (principle of homogeneity)
- **Derive relations:** only if the quantity is a product of powers
- **Limits:** cannot find dimensionless constants (2π , $\frac{1}{2}$) or handle sums / trig / log / exp
- Arguments of sin, log, e^x must be dimensionless

Dimensional formulas to know

Quantity	Formula	Dimensions
Force	ma	$[M L T^{-2}]$
Work, energy, torque	Fs	$[M L^2 T^{-2}]$
Power	W/t	$[M L^2 T^{-3}]$
Pressure, stress, modulus	F/A	$[M L^{-1} T^{-2}]$
Momentum, impulse	mv	$[M L T^{-1}]$
Angular momentum, Planck's constant h	$mvr, E/v$	$[M L^2 T^{-1}]$
Gravitational constant G	Fr^2/m^2	$[M^{-1} L^3 T^{-2}]$
Coefficient of viscosity η	$F/(A dv/dx)$	$[M L^{-1} T^{-1}]$
Surface tension, spring constant	F/l	$[M T^{-2}]$
Moment of inertia	mr^2	$[M L^2]$
Charge	It	$[A T]$
Potential difference	W/q	$[M L^2 T^{-3} A^{-1}]$
Resistance	V/I	$[M L^2 T^{-3} A^{-2}]$
Capacitance	q/V	$[M^{-1} L^{-2} T^4 A^2]$
Magnetic field B	$F/(qv)$	$[M T^{-2} A^{-1}]$
Inductance	Φ/I	$[M L^2 T^{-2} A^{-2}]$
ϵ_0	$q^2/(4\pi Fr^2)$	$[M^{-1} L^{-3} T^4 A^2]$

NEET / JEE Traps & Quick Recall

- Strain, angle, refractive index, relative density are dimensionless (but angle has a unit: radian).
- $1/\sqrt{\mu_0 \epsilon_0}$ has dimensions of speed; RC and L/R have dimensions of time.
- Same dimensions: work and torque; pressure and energy density; impulse and momentum.
- Percentage error in a quantity with power p is multiplied by p : error in r^2 is $2 \times$ error in r .
- Rounding: $2.745 \rightarrow 2.74$ (preceding digit even, unchanged); $2.735 \rightarrow 2.74$ (odd, raised by 1).

Motion in a Straight Line

Displacement, velocity, acceleration, the kinematic equations and graphs.

MIND MAP · Motion in a Straight Line

Motion in a Straight Line

Basic quantities

- Distance: scalar, path length, never negative
- Displacement: vector, final – initial position;
|displacement| ≤ distance
- Average velocity = $\Delta x / \Delta t$; average speed = total path / total time
- Instantaneous velocity: $v = dx/dt$
- Acceleration: $a = dv/dt = d^2x/dt^2 = v dv/dx$

Equations (constant a)

- $v = u + at$
- $s = ut + \frac{1}{2}at^2$
- $v^2 = u^2 + 2as$
- $s = (u + v)t/2$
- Distance in n-th second: $s_n = u + a(2n - 1)/2$

Free fall (a = g downward)

- Dropped from height h: $t = \sqrt{2h/g}$, $v = \sqrt{2gh}$
- Thrown up with u: $H_{\max} = u^2/2g$, time to top = u/g , total time = $2u/g$
- Galileo's law of odd numbers: distances in successive equal intervals are 1 : 3 : 5 : 7 ...

Graphs

- x-t slope = velocity
- v-t slope = acceleration; area under v-t = displacement
- a-t area = change in velocity
- Straight x-t line = uniform velocity; parabola = uniform acceleration

Relative velocity

- $v_{AB} = v_A - v_B$
- Same direction: relative speed = $v_A - v_B$
- Opposite direction: relative speed = $v_A + v_B$

Stopping distance

- $d_s = u^2/2a$ (proportional to square of initial speed)
- Reaction time: distance covered before brakes = $u \times t_r$

How to solve a 1-D kinematics problem

- Choose origin and positive direction → Write u, a, t, s with signs →
- Pick the equation without the unknown you do not need →
- Check: is a constant? If not, use $v = dx/dt$, $a = dv/dt$ and integrate

NEET / JEE Traps & Quick Recall

- Velocity can be zero while acceleration is not (top of vertical throw, $a = g$).
- A body thrown up and returning has zero displacement but non-zero distance.
- For a ball dropped, ratio of distances in 1st, 2nd, 3rd second = 1 : 3 : 5.
- Speedometer reads instantaneous speed; odometer reads distance.
- If $x \propto t^2$, acceleration is constant; if $x \propto t^3$, acceleration $\propto t$.

Motion in a Plane

Vectors, projectile motion, uniform circular motion and relative motion in 2-D.

MIND MAP · Motion in a Plane

Motion in a Plane

Vectors

- **Resultant:** $R = \sqrt{A^2 + B^2 + 2AB \cos \theta}$
- **Direction:** $\tan \alpha = B \sin \theta / (A + B \cos \theta)$
- $|A - B| \leq R \leq A + B$
- **Subtraction:** $|A - B| = \sqrt{A^2 + B^2 - 2AB \cos \theta}$
- **Components:** $A_x = A \cos \theta$, $A_y = A \sin \theta$
- **Unit vector:** $\hat{A} = A/|A|$

Products

- **Dot:** $A \cdot B = AB \cos \theta = A_x B_x + A_y B_y + A_z B_z$
- **Cross:** $|A \times B| = AB \sin \theta$; direction by right-hand rule
- $A \times B = -(B \times A)$; $\hat{i} \times \hat{j} = \hat{k}$
- $\text{Work} = F \cdot s$ (dot); $\text{torque} = r \times F$ (cross)

Projectile (from ground)

- **Time of flight:** $T = 2u \sin \theta / g$
- **Max height:** $H = u^2 \sin^2 \theta / 2g$
- **Range:** $R = u^2 \sin 2\theta / g$; maximum at 45° : $R_{\max} = u^2/g$
- **Trajectory:** $y = x \tan \theta - gx^2 / (2u^2 \cos^2 \theta)$
- Same range for θ and $(90^\circ - \theta)$
- Horizontal velocity $u \cos \theta$ stays constant; at top speed $= u \cos \theta$

Horizontal projection from height h

- **Time:** $t = \sqrt{2h/g}$
- **Range:** $R = u\sqrt{2h/g}$
- **Speed at ground:** $\sqrt{u^2 + 2gh}$

Uniform circular motion

- $\omega = 2\pi/T = 2\pi v/r$; $v = \omega r$
- **Centripetal acceleration:** $a_c = v^2/r = \omega^2 r$, towards centre
- Speed constant but velocity changes (direction)

Relative motion

- $v_{AB} = v_A - v_B$ (vector subtraction)
- **Rain-man:** hold umbrella along $v_{\text{rain}} - v_{\text{man}}$; $\tan \theta = v_{\text{man}}/v_{\text{rain}}$
- **River crossing, shortest time:** swim $\perp$ to bank, $t = d/v_{\text{swim}}$
- **Shortest path:** head upstream at $\sin \alpha = v_{\text{river}}/v_{\text{swim}}$

NEET / JEE Traps & Quick Recall

- At the highest point of a projectile, velocity and acceleration are perpendicular.
- $R = 4H \cot \theta$; when $R = 4H$, $\theta = 45^\circ$.
- Maximum height is reached when vertical velocity is zero, not total velocity.
- Two complementary angles give the same range but different times and heights: $T_1 T_2 = 2R/g$.
- In uniform circular motion, work done by centripetal force is zero.

Laws of Motion

Newton's laws, momentum, friction, equilibrium and circular dynamics.

MIND MAP · Laws of Motion

Laws of Motion

Newton's laws

- **First:** a body stays at rest or uniform motion unless an external force acts (inertia)
- **Second:** $F = dp/dt = ma$ (for constant mass)
- **Third:** every action has an equal and opposite reaction, on different bodies

Momentum and impulse

- $p = mv$
- Impulse $J = F\Delta t = \Delta p$ (area under $F-t$ graph)
- **Conservation:** if $\Sigma F_{\text{ext}} = 0$, total p is constant
- **Gun recoil:** $m_{\text{bullet}}v_{\text{bullet}} = M_{\text{gun}}V_{\text{gun}}$

Equilibrium

- **Concurrent forces:** $\Sigma F = 0$
- **Lami's theorem:** $F_1/\sin \alpha = F_2/\sin \beta = F_3/\sin \gamma$

Friction

- **Static:** $f_s \leq \mu_s N$; limiting $f_{s,\text{max}} = \mu_s N$
- **Kinetic:** $f_k = \mu_k N$; $\mu_k < \mu_s$
- **Angle of repose:** $\tan \theta = \mu_s$
- Rolling friction much smaller than sliding friction

Connected bodies

- **Atwood machine:** $a = (m_1 - m_2)g/(m_1 + m_2)$
- **Tension:** $T = 2m_1m_2g/(m_1 + m_2)$
- **Block on smooth incline:** $a = g \sin \theta$
- **Rough incline (sliding down):** $a = g(\sin \theta - \mu \cos \theta)$

Apparent weight in a lift

- **Accelerating up:** $R = m(g + a)$
- **Accelerating down:** $R = m(g - a)$
- **Free fall ($a = g$):** $R = 0$, weightlessness

Circular dynamics

- **Level road:** $v_{\text{max}} = \sqrt{(\mu_s rg)}$
- **Banked road (no friction):** $\tan \theta = v^2/(rg)$
- **Banked with friction:** $v_{\text{max}} = \sqrt{[rg(\mu_s + \tan \theta)/(1 - \mu_s \tan \theta)]}$

NEET / JEE Traps & Quick Recall

- Action and reaction act on different bodies, so they never cancel each other.
- A man in a lift cannot tell uniform motion from rest ($R = mg$ in both).
- Friction opposes relative motion, not motion; it helps us walk.
- Pseudo force $-ma$ acts only in an accelerated (non-inertial) frame.
- Spring balance in a freely falling lift reads zero.

Work, Energy and Power

Work-energy theorem, conservative forces, potential energy, power and collisions.

MIND MAP · Work, Energy and Power

Work, Energy and Power

Work

- Constant force: $W = F \cdot d = Fd \cos \theta$
- Variable force: $W = \int F dx$ (area under F - x graph)
- Positive ($\theta < 90^\circ$), zero ($\theta = 90^\circ$), negative ($\theta > 90^\circ$)

Kinetic energy

- $K = \frac{1}{2}mv^2 = p^2/2m$
- Work-energy theorem: $W_{\text{net}} = \Delta K$

Potential energy

- Gravity near earth: $U = mgh$
- Spring: $U = \frac{1}{2}kx^2$; spring force $F = -kx$
- Conservative force: $F = -dU/dx$; work independent of path

Conservation of mechanical energy

- $K + U = \text{constant}$ (only conservative forces)
- Vertical circle (string): u_{min} at bottom = $\sqrt{5gl}$; at top $v_{\text{min}} = \sqrt{gl}$
- Tension difference bottom - top = $6mg$

Power

- $P = dW/dt = F \cdot v$
- 1 hp = 746 W; 1 kWh = 3.6×10^6 J

Collisions

- Momentum always conserved
- Elastic: KE also conserved
- Inelastic: KE not conserved; perfectly inelastic: bodies stick
- Coefficient of restitution: $e = (v_2 - v_1)/(u_1 - u_2)$; $e = 1$ elastic, $e = 0$ perfectly inelastic

1-D elastic collision (m_1 moving with u_1 hits m_2 at rest)

Case	v_1	v_2
General	$(m_1 - m_2)u_1/(m_1 + m_2)$	$2m_1u_1/(m_1 + m_2)$
$m_1 = m_2$	0	u_1 (velocities exchange)
$m_1 \gg m_2$	$\approx u_1$	$\approx 2u_1$
$m_1 \ll m_2$	$\approx -u_1$ (bounces back)	≈ 0
Perfectly inelastic	$v = m_1u_1/(m_1 + m_2)$ (common)	KE lost = $m_1m_2u_1^2/[2(m_1 + m_2)]$

NEET / JEE Traps & Quick Recall

- Work done by friction can be negative or positive (on a block placed on an accelerating truck it is positive).
- If momentum doubles, KE becomes four times; if KE doubles, momentum becomes $\sqrt{2}$ times.
- For same KE, the heavier body has larger momentum ($p = \sqrt{2mK}$).
- Work done by centripetal force and by normal reaction perpendicular to motion is zero.
- Spring cut in half: each half has spring constant $2k$.

System of Particles and Rotational Motion

Centre of mass, torque, angular momentum, moment of inertia and rolling.

MIND MAP · Rotational Motion

System of Particles and Rotation

Centre of mass

- $x_{cm} = \sum m_i x_i / \sum m_i$
- Two particles:** from m_1 , distance = $m_2 d / (m_1 + m_2)$
- $M a_{cm} = F_{ext}$; internal forces do not move the CM

Rotational kinematics (constant α)

- $\omega = \omega_0 + \alpha t$
- $\theta = \omega_0 t + \frac{1}{2} \alpha t^2$
- $\omega^2 = \omega_0^2 + 2 \alpha \theta$
- $v = r \omega$; $a_t = r \alpha$

Torque and angular momentum

- $\tau = r \times F$; $|\tau| = r F \sin \theta$
- $L = r \times p$; for a rigid body $L = I \omega$
- $\tau = dL/dt = I \alpha$
- Conservation:** if $\tau_{ext} = 0$, $L = \text{constant}$ (diver, ice skater)

Moment of inertia

- $I = \sum m r^2$
- Parallel axes:** $I = I_{cm} + M d^2$
- Perpendicular axes (lamina):** $I_z = I_x + I_y$
- Radius of gyration:** $I = M K^2$

Rotational energy and work

- $K_{rot} = \frac{1}{2} I \omega^2$
- Work:** $W = \tau \theta$; power $P = \tau \omega$

Rolling without slipping

- $v_{cm} = R \omega$
- $K = \frac{1}{2} M v^2 (1 + K^2/R^2)$
- Acceleration down incline:** $a = g \sin \theta / (1 + K^2/R^2)$
- Top point speed $2v_{cm}$; contact point speed 0

Equilibrium of rigid body

- $\Sigma F = 0$ (translational) and $\Sigma \tau = 0$ (rotational)
- Principle of moments:** $F_1 d_1 = F_2 d_2$ (lever)

Moments of inertia (axis through centre unless stated)

Body	Axis	I	K^2/R^2 (rolling)
Ring	$\perp$ to plane	MR^2	1
Ring	Diameter	$MR^2/2$	—
Disc	$\perp$ to plane	$MR^2/2$	1/2
Disc	Diameter	$MR^2/4$	—
Hollow cylinder	Own axis	MR^2	1
Solid cylinder	Own axis	$MR^2/2$	1/2
Solid sphere	Diameter	$2MR^2/5$	2/5
Hollow sphere	Diameter	$2MR^2/3$	2/3
Thin rod (length L)	$\perp$ through centre	$ML^2/12$	—
Thin rod	$\perp$ through end	$ML^2/3$	—

NEET / JEE Traps & Quick Recall

- Rolling race down an incline: solid sphere first, then disc/solid cylinder, then hollow sphere, ring last.
- Moment of inertia depends on mass distribution and axis, not on angular speed.
- When a skater pulls arms in, I decreases, ω increases; rotational KE increases (work done by muscles).
- CM of a system may lie where there is no mass (ring, L-shaped rod).
- Fraction of KE that is rotational in rolling = $(K^2/R^2)/(1 + K^2/R^2)$; disc: $1/3$, sphere: $2/7$.

Gravitation

Newton's law, g and its variation, potential, escape and orbital speed, Kepler's laws.

MIND MAP · Gravitation

Gravitation

Newton's law

- $F = Gm_1m_2/r^2$; $G = 6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$
- Always attractive; central; conservative; independent of medium

Acceleration due to gravity

- $g = GM/R^2 = (4/3)\pi G\rho R$
- **Height $h \ll R$:** $g_h = g(1 - 2h/R)$; general: $g_h = g R^2/(R + h)^2$
- **Depth d :** $g_d = g(1 - d/R)$; zero at centre
- **Latitude λ :** $g' = g - \omega^2 R \cos^2 \lambda$ (least at equator)

Field and potential

- **Field:** $I = GM/r^2$ (outside a sphere)
- **Potential:** $V = -GM/r$
- **Potential energy:** $U = -GMm/r$
- **Inside a solid sphere:** field = GMr/R^3 ($\propto r$)
- **Inside a hollow shell:** field = 0, potential = $-GM/R$ (constant)

Satellites

- **Orbital speed:** $v_o = \sqrt{GM/r}$; near surface $\sqrt{gR} \approx 7.9 \text{ km/s}$
- **Period:** $T = 2\pi\sqrt{r^3/GM}$
- $KE = GMm/2r$; $PE = -GMm/r$; total $E = -GMm/2r$
- Binding energy = $GMm/2r$
- **Geostationary:** $T = 24 \text{ h}$, height $\approx 36,000 \text{ km}$, equatorial plane, west to east

Escape speed

- $v_e = \sqrt{2GM/R} = \sqrt{2gR} \approx 11.2 \text{ km/s}$ (earth)
- $v_e = \sqrt{2} \times v_o$ (near surface)
- Independent of mass of body and direction of projection

Kepler's laws

- 1. Orbits are ellipses with sun at one focus
- **2. Equal areas in equal times:** $dA/dt = L/2m = \text{constant}$ (conservation of L)
- 3. $T^2 \propto a^3$ (a = semi-major axis)

NEET / JEE Traps & Quick Recall

- Weight is zero at the centre of earth, but mass is unchanged.
- Astronauts feel weightless because they and the spacecraft fall freely together.
- g decreases faster with height than with depth ($2h/R$ vs d/R) for small values.
- If earth stopped rotating, g at equator would increase; at poles unchanged.
- Escape speed from the moon is about 2.3 km/s , so the moon has no atmosphere.

Mechanical Properties of Solids

Stress, strain, Hooke's law, elastic moduli and elastic energy.

MIND MAP · Mechanical Properties of Solids

Elasticity

Stress and strain

- Stress = F/A ($N\ m^{-2} = Pa$)
- Longitudinal strain = $\Delta L/L$
- Volume strain = $\Delta V/V$
- Shearing strain = $\Delta x/L = \tan \theta \approx \theta$

Hooke's law

- Stress $\propto$ strain within elastic limit
- Modulus of elasticity = stress/strain

Moduli

- Young's modulus:** $Y = (F/A)/(\Delta L/L) = FL/(A\Delta L)$
- Bulk modulus:** $B = -p/(\Delta V/V)$; compressibility $k = 1/B$
- Shear (rigidity) modulus:** $G = (F/A)/\theta$
- Poisson's ratio:** lateral strain / longitudinal strain (dimensionless)

Stress-strain curve

- Proportional limit $\rightarrow$ yield point $\rightarrow$ ultimate tensile strength $\rightarrow$ fracture
- Ductile:** large plastic region (copper); brittle: fracture soon after elastic limit (glass)
- Elastomers (rubber, aorta):** no linear region, very large strain

Elastic potential energy

- Energy stored = $\frac{1}{2} \times \text{stress} \times \text{strain} \times \text{volume}$
- $U = \frac{1}{2} F \Delta L$
- Energy density = $\frac{1}{2} \times \text{stress} \times \text{strain} = (\text{stress})^2/2Y$

Elastic moduli at a glance

Modulus	Defined for	Relation	Applies to
Young's (Y)	Change in length	$Y = FL/(A\Delta L)$	Solids only
Bulk (B)	Change in volume	$B = -pV/\Delta V$	Solids, liquids, gases
Shear (G)	Change in shape	$G = F/(A\theta)$	Solids only
Typical order	—	$G \approx Y/3$ for metals	—

NEET / JEE Traps & Quick Recall

- Steel is more elastic than rubber: $Y_{\text{steel}} > Y_{\text{rubber}}$ (smaller strain for same stress).
- Y depends only on material, not on length or area of the wire.
- Extension of a wire under its own weight = $MgL/(2AY)$ (half that of the same load at the end).
- Liquids and gases have no shear modulus.
- Bulk modulus of gas: isothermal $B = p$; adiabatic $B = \gamma p$.

Mechanical Properties of Fluids

Pressure, Pascal's law, Bernoulli, viscosity, Stokes' law and surface tension.

MIND MAP · Mechanical Properties of Fluids

Fluids

Pressure

- $p = F/A$
- **At depth h:** $p = p_a + \rho gh$
- Gauge pressure = $p - p_a = \rho gh$
- **Pascal's law:** pressure applied to enclosed fluid is transmitted equally (hydraulic lift: $F_1/A_1 = F_2/A_2$)

Buoyancy

- **Archimedes:** upthrust = weight of fluid displaced = $V\rho_{\text{fluid}}g$
- **Floating:** fraction submerged = $\rho_{\text{body}}/\rho_{\text{fluid}}$

Fluid flow

- **Equation of continuity:** $A_1v_1 = A_2v_2$ ($Av = \text{constant}$)
- **Bernoulli:** $p + \frac{1}{2}\rho v^2 + \rho gh = \text{constant}$ (along a streamline)
- **Torricelli:** speed of efflux $v = \sqrt{2gh}$
- **Venturimeter, atomiser, lift on an aeroplane wing:** all use Bernoulli

Viscosity

- $F = -\eta A dv/dx$; unit poise (1 Pa s = 10 poise)
- **Stokes' law:** $F = 6\pi\eta rv$
- **Terminal velocity:** $v_t = 2r^2(\rho - \sigma)g / 9\eta$
- **Reynolds number:** $R_e = \rho vd/\eta$; < 1000 streamline, > 2000 turbulent

Surface tension

- $S = F/l = \text{surface energy per unit area}$
- **Excess pressure:** drop $2S/r$; soap bubble $4S/r$ (two surfaces); air bubble in liquid $2S/r$
- **Capillary rise:** $h = 2S \cos \theta / (r\rho g)$
- **Angle of contact $\theta < 90^\circ$:** liquid rises and wets (water-glass); $\theta > 90^\circ$: falls (mercury-glass)
- Detergents lower surface tension

NEET / JEE Traps & Quick Recall

- Viscosity of liquids decreases with temperature; of gases increases.
- Surface tension decreases with rise in temperature.
- Terminal velocity $\propto r^2$: a drop of radius $2r$ falls 4 times faster.
- Hydraulic machines multiply force, not energy.
- When n small drops merge into one big drop, energy is released (surface area decreases).

Thermal Properties of Matter

Temperature scales, expansion, calorimetry, latent heat and heat transfer.

MIND MAP · Thermal Properties of Matter

Thermal Properties

Temperature scales

- $t_F = (9/5)t_C + 32$
- $T = t_C + 273.15$
- $(X - LFP)/(UFP - LFP)$ is same on all scales
- $-40^\circ\text{C} = -40^\circ\text{F}$

Thermal expansion

- **Linear:** $\Delta L = \alpha L \Delta T$
- **Area:** $\Delta A = \beta A \Delta T$, $\beta = 2\alpha$
- **Volume:** $\Delta V = \gamma V \Delta T$, $\gamma = 3\alpha$
- **Ideal gas at constant p:** $\gamma = 1/T$
- **Anomalous expansion of water:** maximum density at 4°C
- Thermal stress (rod fixed at ends) = $Y\alpha\Delta T$

Calorimetry

- $Q = mc\Delta T$; heat capacity $S = mc$
- **Molar specific heat:** $C_p - C_v = R$ (ideal gas)
- **Principle:** heat lost = heat gained

Latent heat

- $Q = mL$
- **Water:** $L_f = 3.33 \times 10^5 \text{ J/kg}$; $L_v = 22.6 \times 10^5 \text{ J/kg}$
- Temperature stays constant during change of state

Conduction

- $H = KA(T_C - T_D)/L$
- Thermal resistance $R = L/(KA)$
- **Series:** $R = R_1 + R_2$; parallel: $1/R = 1/R_1 + 1/R_2$

Radiation and cooling

- **Stefan-Boltzmann:** $H = e\sigma AT^4$; net loss = $e\sigma A(T^4 - T_s^4)$
- **Wien's law:** $\lambda_m T = b = 2.9 \times 10^{-3} \text{ m K}$
- **Newton's law of cooling:** $dT/dt = -k(T - T_s)$
- **Convection:** natural (density difference) or forced

NEET / JEE Traps & Quick Recall

- A hole in a metal plate expands on heating, as if it were made of the metal.
- Good absorbers are good emitters (black body: $e = 1$).
- Sea breeze (day) and land breeze (night) are convection currents.
- Steam at 100°C burns more than water at 100°C (extra latent heat).
- Hotter body glows from red to white: λ_m shifts to shorter wavelength.

MIND MAP · Thermodynamics

Thermodynamics

Laws

- Zeroth:** if A and B are each in equilibrium with C, A and B are in equilibrium (defines temperature)
- First:** $\Delta Q = \Delta U + \Delta W$ (energy conservation)
- Second (Kelvin-Planck):** no engine converts all heat into work
- Second (Clausius):** heat cannot flow from cold to hot by itself

Internal energy and work

- U depends only on state (ideal gas: only on T)**
- $W = \int p \, dV$ (area under p-V curve)
- Cyclic process:** $\Delta U = 0$, so $Q = W$

Processes

- Isothermal (T const):** $pV = \text{const}$; $W = nRT \ln(V_2/V_1)$; $\Delta U = 0$
- Adiabatic (Q = 0):** $pV^\gamma = \text{const}$; $W = (p_1V_1 - p_2V_2)/(\gamma - 1) = nR(T_1 - T_2)/(\gamma - 1)$
- Isochoric (V const):** $W = 0$; $Q = \Delta U = nC_V\Delta T$
- Isobaric (p const):** $W = p\Delta V$; $Q = nC_p\Delta T$
- Slope of adiabatic on p-V = $\gamma \times$ slope of isothermal

Heat engine

- Efficiency:** $\eta = W/Q_1 = 1 - Q_2/Q_1$
- Carnot:** $\eta = 1 - T_2/T_1$ (temperatures in kelvin)
- Carnot cycle:** isothermal expansion $\rightarrow$ adiabatic expansion $\rightarrow$ isothermal compression $\rightarrow$ adiabatic compression

Refrigerator / heat pump

- Coefficient of performance:** $\alpha = Q_2/W$
- Carnot refrigerator:** $\alpha = T_2/(T_1 - T_2)$
- Relation:** $\alpha = (1 - \eta)/\eta$

Specific heats of ideal gases

Gas	Degrees of freedom f	C_V	C_p	$\gamma = C_p/C_V$
Monatomic	3	$3R/2$	$5R/2$	$5/3 \approx 1.67$
Diatomic (rigid)	5	$5R/2$	$7R/2$	$7/5 = 1.4$
Diatomic with vibration	7	$7R/2$	$9R/2$	$9/7 \approx 1.29$
Triatomic non-linear (rigid)	6	$3R$	$4R$	$4/3 \approx 1.33$
General	f	$fR/2$	$(f/2 + 1)R$	$1 + 2/f$

NEET / JEE Traps & Quick Recall

- Sign convention (NCERT): Q positive when heat is supplied to the system; W positive when work is done by the system.
- No engine working between two temperatures can be more efficient than a Carnot engine.
- Free expansion of an ideal gas: $Q = 0$, $W = 0$, so $\Delta U = 0$ and T is unchanged.
- In a p-V cycle, clockwise = net work by the gas (engine); anticlockwise = work on the gas.
- Efficiency 100% would need $T_2 = 0$ K, which is impossible.

Kinetic Theory

Ideal gas law, pressure from molecular motion, kinetic energy, equipartition and mean free path.

MIND MAP · Kinetic Theory

Kinetic Theory of Gases

Ideal gas equation

- $pV = nRT = Nk_B T$
- **Boyle:** $pV = \text{const}$ (T const); Charles: $V/T = \text{const}$ (p const)
- **Dalton:** $p = p_1 + p_2 + \dots$ (mixture of non-reacting gases)

Pressure from kinetic theory

- $p = \frac{1}{3} n m \bar{v}^2$ (n = number density)
- $p = \frac{1}{3} \rho v_{\text{rms}}^2$
- $p = \frac{2}{3} \times (\text{KE per unit volume})$

Kinetic energy and temperature

- Average KE per molecule (translational) = $(3/2)k_B T$
- Total translational KE of 1 mole = $(3/2)RT$
- KE depends only on T , not on the nature of the gas

Molecular speeds

- $v_{\text{rms}} = \sqrt{(3RT/M)} = \sqrt{(3k_B T/m)}$
- $v_{\text{avg}} = \sqrt{(8RT/\pi M)}$
- $v_{\text{mp}} = \sqrt{(2RT/M)}$
- $v_{\text{rms}} > v_{\text{avg}} > v_{\text{mp}}$ (ratio $\approx 1.22 : 1.13 : 1$ relative to v_{mp})

Equipartition of energy

- Each degree of freedom gets $\frac{1}{2}k_B T$ per molecule
- U for 1 mole = $(f/2)RT$
- **Specific heat of solids:** $C = 3R$ (Dulong–Petit)

Mean free path

- $\lambda = 1/(\sqrt{2} n \pi d^2)$
- Increases when density falls (higher altitude)

NEET / JEE Traps & Quick Recall

- $v_{\text{rms}} \propto \sqrt{(T/M)}$: doubling T (kelvin) raises v_{rms} by $\sqrt{2}$.
- Hydrogen and oxygen at the same temperature have the same average KE, but $v_{\text{rms}}(\text{H}_2) = 4 v_{\text{rms}}(\text{O}_2)$.
- Real gases behave ideally at low pressure and high temperature.
- At absolute zero, KE of an ideal-gas molecule would be zero.
- Number of molecules in 22.4 L of an ideal gas at STP = Avogadro number.

MIND MAP · Oscillations

Simple Harmonic Motion

Defining equations

- $F = -kx$ (restoring force $\propto$ displacement)
- $a = -\omega^2 x$
- $x = A \cos(\omega t + \phi)$
- $\omega = 2\pi/T = 2\pi\nu$

Velocity and acceleration

- $v = \omega\sqrt{A^2 - x^2}$; $v_{\max} = A\omega$ (at mean position)
- $a_{\max} = \omega^2 A$ (at extreme position)
- Velocity leads displacement by $\pi/2$; acceleration leads by π

Energy

- $KE = \frac{1}{2}k(A^2 - x^2)$
- $PE = \frac{1}{2}kx^2$
- Total $E = \frac{1}{2}kA^2 = \frac{1}{2}m\omega^2 A^2$ (constant)
- $KE = PE$ at $x = A/\sqrt{2}$
- KE and PE oscillate with frequency 2ν

Spring-mass system

- $T = 2\pi\sqrt{m/k}$
- **Series:** $1/k = 1/k_1 + 1/k_2$
- **Parallel:** $k = k_1 + k_2$
- **Vertical spring:** same T ; static extension = mg/k

Simple pendulum

- $T = 2\pi\sqrt{L/g}$ (small angles)
- **Seconds pendulum:** $T = 2$ s, $L \approx 1$ m
- **In a lift accelerating up:** $T = 2\pi\sqrt{L/(g + a)}$; in free fall $T \rightarrow \infty$
- Independent of mass of bob and of amplitude (small)

Where are things maximum?

Quantity	At mean position ($x = 0$)	At extreme position ($x = \pm A$)
Speed	Maximum ($A\omega$)	Zero
Acceleration	Zero	Maximum ($\omega^2 A$)
Restoring force	Zero	Maximum (kA)
Kinetic energy	Maximum ($\frac{1}{2}kA^2$)	Zero
Potential energy	Zero	Maximum ($\frac{1}{2}kA^2$)

NEET / JEE Traps & Quick Recall

- All SHMs are periodic, but all periodic motions are not SHM (e.g. uniform circular motion is periodic, its projection is SHM).
- Pendulum clock in summer (longer L) loses time; on the moon T increases by $\sqrt{6}$.
- Period of a spring is the same on earth and on the moon.
- $x = A \sin \omega t + B \cos \omega t$ is SHM with amplitude $\sqrt{A^2 + B^2}$.
- Cutting a spring into n equal parts makes each part's constant nk .

MIND MAP · Waves

Waves

Basics

- $y(x, t) = a \sin(kx - \omega t + \phi)$; wave moves along +x
- $k = 2\pi/\lambda$; $\omega = 2\pi\nu$; $v = v\lambda = \omega/k$
- Phase difference = $(2\pi/\lambda) \times \text{path difference}$

Speed of waves

- **String**: $v = \sqrt{T/\mu}$ (μ = mass per unit length)
- **Sound in a solid rod**: $v = \sqrt{Y/\rho}$
- **Sound in fluid**: $v = \sqrt{B/\rho}$
- **Gas (Laplace)**: $v = \sqrt{\gamma p/\rho}$; Newton's $\sqrt{p/\rho}$ gave 280 m/s, too low
- $v \propto \sqrt{T}$ for a gas; independent of pressure at constant T

Superposition and reflection

- Resultant $y = y_1 + y_2$
- **Rigid boundary**: reflected wave has phase change π
- **Open boundary**: no phase change

Standing waves on a string (both ends fixed)

- $v_n = nv/2L$, $n = 1, 2, 3, \dots$
- Nodes at $x = 0, \lambda/2, \lambda, \dots$; distance node–node = $\lambda/2$
- All harmonics present

Air columns

- **Closed at one end**: $v = (2n - 1)v/4L$; only odd harmonics
- **Open at both ends**: $v = nv/2L$; all harmonics

Beats

- Beat frequency = $|v_1 - v_2|$
- Used to tune instruments

Doppler effect (sound; v = speed of sound)

Situation	Observed frequency
Source moving towards stationary observer	$v' = v/(v - v_s)$
Source moving away	$v' = v/(v + v_s)$
Observer moving towards stationary source	$v' = v(v + v_o)/v$
Observer moving away	$v' = v(v - v_o)/v$
Both moving towards each other	$v' = v(v + v_o)/(v - v_s)$

NEET / JEE Traps & Quick Recall

- Sound cannot travel in vacuum; light can.
- Speed of sound in air rises about 0.6 m/s per °C rise in temperature.
- Humidity increases speed of sound (moist air is less dense).
- Closed pipe of length L and open pipe of length 2L have the same fundamental frequency.
- Transverse waves cannot travel through gases or inside liquids (no shear).



PART B

Class 12

Chapters in NCERT sequence

Electric Charges and Fields

Coulomb's law, electric field, dipole, flux and Gauss's law with standard fields.

MIND MAP · Electric Charges and Fields

Electric Charges and Fields

Charge

- **Quantised:** $q = ne$, $e = 1.6 \times 10^{-19} \text{ C}$
- Conserved and additive (scalar)
- Charging by conduction, induction, friction

Coulomb's law

- $F = (1/4\pi\epsilon_0) q_1 q_2 / r^2$; $1/4\pi\epsilon_0 = 9 \times 10^9 \text{ N m}^2 \text{ C}^{-2}$
- **In medium:** $F_m = F_{\text{vacuum}} / K$ (K = dielectric constant = ϵ/ϵ_0)
- **Superposition:** net force is vector sum

Electric field

- $E = F/q_0$ (N C^{-1} or V m^{-1})
- **Point charge:** $E = kq/r^2$
- Field lines start on +, end on -; never cross; no closed loops; $\perp$ to conductor surface

Electric dipole

- Dipole moment $p = q \times 2a$, from $-q$ to $+q$
- **Axial field:** $E = 2kp/r^3$
- **Equatorial field:** $E = kp/r^3$ (opposite to p)
- **Torque in uniform field:** $\tau = p \times E$, $|\tau| = pE \sin \theta$
- Net force in uniform field = 0
- **PE:** $U = -pE \cos \theta$; stable at $\theta = 0$, unstable at $\theta = 180^\circ$

Flux and Gauss's law

- $\Phi = E \cdot A = EA \cos \theta$; $\Phi = \oint E \cdot dA$
- **Gauss's law:** $\Phi = q_{\text{enclosed}}/\epsilon_0$
- Charge outside the surface gives zero net flux
- **Charge at centre of cube:** flux through each face = $q/6\epsilon_0$

Fields of standard charge distributions (from Gauss's law)

Distribution	Field E	Direction / note
Infinite line, charge density λ	$\lambda/(2\pi\epsilon_0 r)$	Radial, $\propto 1/r$
Infinite plane sheet, density σ	$\sigma/(2\epsilon_0)$	Uniform, independent of distance
Charged conductor surface	σ/ϵ_0	Just outside; zero inside
Two parallel sheets ($+\sigma, -\sigma$)	σ/ϵ_0 between, 0 outside	Basis of capacitor
Thin spherical shell (R, q)	kq/r^2 outside; 0 inside	Acts as point charge outside
Uniformly charged solid sphere	kqr/R^3 inside; kq/r^2 outside	Maximum at surface

NEET / JEE Traps & Quick Recall

- Electrostatic field inside a conductor is zero; excess charge lives on the outer surface.
- Mass of a body increases slightly when it gains electrons (negatively charged).
- A dipole in a non-uniform field feels a net force as well as a torque.
- Gauss's law is true for any closed surface, but useful only with symmetry.
- Dipole field falls as $1/r^3$; point-charge field as $1/r^2$.

Electrostatic Potential and Capacitance

Potential, potential energy, equipotential surfaces, capacitors, dielectrics and energy stored.

MIND MAP · Potential and Capacitance

Potential and Capacitance

Potential

- $V = W/q_0$ (work per unit charge from infinity)
- **Point charge:** $V = kq/r$
- **Dipole:** $V = kp \cos \theta / r^2$; zero on equatorial line
- $E = -dV/dr$ (field points towards decreasing potential)
- **Uniform field:** $E = V/d$

Potential energy

- **Two charges:** $U = kq_1q_2/r$
- **System:** sum over every pair
- **Work to move charge q:** $W = q(V_B - V_A)$

Equipotential surfaces

- Field is $\perp$ to them; no work along them
- **Point charge:** concentric spheres; uniform field: parallel planes
- Conductor surface is an equipotential

Capacitance

- $C = Q/V$ (farad)
- **Parallel plate:** $C = \epsilon_0 A/d$
- **With dielectric filling:** $C = K\epsilon_0 A/d$
- **Partly filled (slab t):** $C = \epsilon_0 A/[d - t(1 - 1/K)]$
- **Isolated sphere:** $C = 4\pi\epsilon_0 R$

Combinations

- **Series:** $1/C = 1/C_1 + 1/C_2 + \dots$; same Q
- **Parallel:** $C = C_1 + C_2 + \dots$; same V

Energy stored

- $U = \frac{1}{2}CV^2 = Q^2/2C = \frac{1}{2}QV$
- **Energy density:** $u = \frac{1}{2}\epsilon_0 E^2$
- Sharing charge between two capacitors always loses energy

Dielectrics

- **Polarisation reduces field:** $E = E_0/K$
- **Battery connected:** V fixed, Q and U increase K times
- **Battery removed:** Q fixed, V and U decrease K times

Capacitor with a dielectric slab: decide first what stays constant

Is the battery still connected? → Yes: V constant; $C \times K$, $Q \times K$, $U \times K$ → No: Q constant; $C \times K$, $V \div K$, $U \div K$

NEET / JEE Traps & Quick Recall

- Potential can be zero where field is not (midpoint of a dipole), and field can be zero where potential is not (inside a charged shell).
- A charge moved along an equipotential surface: work done = 0.
- $1 \mu\text{F}$ of a parallel-plate capacitor in air needs a huge plate area; real capacitors use dielectrics.
- Potential inside a charged hollow sphere = potential on its surface.
- Electron volt: $1 \text{ eV} = 1.6 \times 10^{-19} \text{ J}$.

Current Electricity

Current, drift velocity, Ohm's law, resistivity, cells, Kirchhoff's rules and Wheatstone bridge.

MIND MAP · Current Electricity

Current Electricity

Current and drift

- $I = dq/dt$
- $I = neAv_d$ (drift velocity $v_d \approx 10^{-4}$ m/s)
- $v_d = eE\tau/m$; mobility $\mu = v_d/E = e\tau/m$
- Current density $j = I/A = \sigma E$

Ohm's law

- $V = IR$
- $R = \rho l/A$; $\rho = m/(ne^2\tau)$
- Conductivity $\sigma = 1/\rho$
- **Temperature:** $\rho_T = \rho_0[1 + \alpha(T - T_0)]$
- **Stretching a wire n times (same volume):** R becomes n^2R

Combinations

- **Series:** $R = R_1 + R_2 + \dots$; same current
- **Parallel:** $1/R = 1/R_1 + 1/R_2 + \dots$; same voltage
- **Two in parallel:** $R = R_1R_2/(R_1 + R_2)$

Cells

- **Terminal voltage (discharging):** $V = \epsilon - Ir$
- $I = \epsilon/(R + r)$
- **Series cells:** $\epsilon_{eq} = \epsilon_1 + \epsilon_2$, $r_{eq} = r_1 + r_2$
- **Parallel cells:** $\epsilon_{eq} = (\epsilon_1r_2 + \epsilon_2r_1)/(r_1 + r_2)$, $1/r_{eq} = 1/r_1 + 1/r_2$
- Internal resistance $r = R(\epsilon/V - 1)$

Power and energy

- $P = VI = I^2R = V^2/R$
- Energy $H = I^2Rt$ (Joule heating)
- Maximum power to load when $R = r$

Kirchhoff's rules

- **Junction rule:** $\Sigma I = 0$ (charge conservation)
- **Loop rule:** $\Sigma \Delta V = 0$ (energy conservation)

Wheatstone bridge

- Balanced when $P/Q = R/S$; no current through galvanometer
- **Metre bridge:** $R/S = l/(100 - l)$

Colour code of carbon resistors

Colour	Digit	Multiplier	Mnemonic
Black	0	10^0	B
Brown	1	10^1	B
Red	2	10^2	R
Orange	3	10^3	O
Yellow	4	10^4	Y
Green	5	10^5	G
Blue	6	10^6	B
Violet	7	10^7	V
Grey	8	10^8	G
White	9	10^9	W
Tolerance	Gold 5%, silver 10%, none 20%		—

NEET / JEE Traps & Quick Recall

- Resistivity of metals rises with temperature; of semiconductors falls.
- Manganin and constantan (small α) are used for standard resistors.
- Drift velocity is tiny, yet a bulb lights instantly because the field is set up at nearly the speed of light.
- Fuse wire: high resistivity, low melting point; connected in series.
- In a balanced bridge, the galvanometer and the battery can be interchanged.

Moving Charges and Magnetism

Lorentz force, motion in a magnetic field, Biot–Savart, Ampere's law, forces on wires and the galvanometer.

MIND MAP · Moving Charges and Magnetism

Moving Charges and Magnetism

Lorentz force

- $F = q[E + v \times B]$
- **Magnetic part:** $F = qvB \sin \theta$; does no work
- **Charge in $B \perp v$:** circle of radius $r = mv/qB$
- Period $T = 2\pi m/qB$ (independent of speed); cyclotron frequency $\nu = qB/2\pi m$
- **Velocity at an angle:** helix; pitch = $2\pi m v \cos \theta / qB$
- **Velocity selector:** $v = E/B$

Biot–Savart law

- $dB = (\mu_0/4\pi) I dl \sin \theta / r^2$
- **Centre of a circular loop:** $B = \mu_0 I / 2R$ (N turns: $\mu_0 NI / 2R$)
- **Axis of a loop:** $B = \mu_0 I R^2 / [2(x^2 + R^2)^{3/2}]$
- **Long straight wire:** $B = \mu_0 I / 2\pi r$

Ampere's circuital law

- $\oint B \cdot dl = \mu_0 I_{\text{enclosed}}$
- **Solenoid inside:** $B = \mu_0 n I$ (n = turns per unit length)
- **Toroid inside:** $B = \mu_0 NI / 2\pi r$; zero outside

Force on conductors

- $F = I l \times B$; $F = BIl \sin \theta$
- **Two parallel wires:** $F/l = \mu_0 I_1 I_2 / 2\pi d$
- Like currents attract; unlike repel
- 1 ampere defined from this force (2×10^{-7} N/m at 1 m)

Torque on a current loop

- $\tau = m \times B$; $|\tau| = NIAB \sin \theta$
- Magnetic moment $m = NIA$

Moving coil galvanometer

- $NIAB = k\phi$; current sensitivity $\phi/I = NAB/k$
- Voltage sensitivity $\phi/V = NAB/(kR_G)$
- **To ammeter:** small shunt $S = I_g G / (I - I_g)$ in parallel
- **To voltmeter:** large $R = V/I_g - G$ in series

NEET / JEE Traps & Quick Recall

- Magnetic force does no work; speed (and KE) of a charge in pure B never changes.
- A charge moving parallel to B feels no magnetic force.
- Increasing current sensitivity by increasing N does not always increase voltage sensitivity (R also rises).
- Ideal ammeter: zero resistance; ideal voltmeter: infinite resistance.
- Field inside a long straight current-carrying hollow pipe is zero.

Magnetism and Matter

Bar magnet as an equivalent solenoid, earth's magnetism and magnetic materials.

MIND MAP · Magnetism and Matter

Magnetism and Matter

Bar magnet

- Behaves like a solenoid; m = pole strength $\times$ length
- Axial field:** $B = \mu_0 2m / (4\pi r^3)$
- Equatorial field:** $B = \mu_0 m / (4\pi r^3)$
- Torque in field:** $\tau = m \times B$; PE $U = -m \cdot B$
- Period of oscillation:** $T = 2\pi \sqrt{I/mB}$

Gauss's law for magnetism

- $\oint \mathbf{B} \cdot d\mathbf{A} = 0$ (no isolated magnetic poles)
- Field lines form closed loops

Earth's magnetism (dropped from rationalised NCERT; revise if your board asks)

- Magnetic declination:** angle between geographic and magnetic meridian
- Inclination (dip) I :** angle of B_E with horizontal
- $H_E = B_E \cos I$; $Z_E = B_E \sin I$; $\tan I = Z_E / H_E$
- Dip is 0° at magnetic equator, 90° at magnetic poles

Magnetic quantities

- Magnetisation $M = m_{\text{net}} / V$
- $H = B / \mu_0 - M$
- $M = \chi H$ (χ = susceptibility)
- $B = \mu_0 (1 + \chi) H = \mu_0 \mu_r H$; $\mu_r = 1 + \chi$

Materials

- Diamagnetic:** χ small, negative (Bi, Cu, water, superconductors)
- Paramagnetic:** χ small, positive (Al, Na, O_2)
- Ferromagnetic:** χ very large, positive (Fe, Co, Ni, gadolinium)
- Curie law:** $\chi = C/T$ (paramagnets)
- Above Curie temperature, ferromagnet becomes paramagnet

Comparing magnetic materials

Property	Diamagnetic	Paramagnetic	Ferromagnetic
Susceptibility χ	Small, negative	Small, positive	Very large, positive
Relative permeability μ_r	Slightly < 1	Slightly > 1	$\gg 1$
In non-uniform field	Moves to weaker field	Moves to stronger field	Strongly to stronger field
Effect of temperature	Nearly none	$\chi \propto 1/T$	Becomes paramagnetic above T_c
Examples	Bi, Cu, Pb, Si, N_2 , water	Al, Na, Ca, O_2 , $CuCl_2$	Fe, Ni, Co, Gd

NEET / JEE Traps & Quick Recall

- Superconductors are perfect diamagnets ($\chi = -1$): Meissner effect.
- Soft iron (low retentivity, low coercivity) is used for electromagnets and transformer cores; steel for permanent magnets.
- A freely suspended magnet at a magnetic pole stands vertical (dip 90°).
- Diamagnetism is present in all materials but is masked in para- and ferromagnets.
- Magnetic field lines of a bar magnet run S to N inside the magnet.

Electromagnetic Induction

Faraday's and Lenz's laws, motional emf, eddy currents, self and mutual inductance, AC generator.

MIND MAP · Electromagnetic Induction

Electromagnetic Induction

Magnetic flux

$$\Phi = \mathbf{B} \cdot \mathbf{A} = BA \cos \theta \text{ (weber)}$$

Faraday's law

$$\begin{aligned} \varepsilon &= -N \frac{d\Phi}{dt} \\ \text{Induced charge } q &= N\Delta\Phi/R \text{ (independent of time taken)} \end{aligned}$$

Lenz's law

- Induced current opposes the change that produces it
- Follows from conservation of energy

Motional emf

- Rod of length l moving with $\mathbf{v} \perp \mathbf{B}$:** $\varepsilon = Blv$
- Rod rotating about one end:** $\varepsilon = \frac{1}{2}B\omega l^2$
- Force needed to keep rod moving:** $F = B^2 l^2 v / R$

Eddy currents

- Loops of current in bulk metal from changing flux
- Uses:** magnetic braking in trains, electromagnetic damping, induction furnace, energy meters
- Reduced by laminating cores

Inductance

- Self:** $\Phi = LI$; $\varepsilon = -L \frac{dI}{dt}$
- Solenoid:** $L = \mu_0 n^2 A l = \mu_0 N^2 A / l$
- Mutual:** $\Phi_2 = M I_1$; $\varepsilon_2 = -M \frac{dI_1}{dt}$
- Coaxial solenoids:** $M = \mu_0 n_1 n_2 \pi r_1^2 l$
- Energy stored:** $U = \frac{1}{2} L I^2$

AC generator

- $\varepsilon = NBA\omega \sin \omega t$
- Peak emf $\varepsilon_0 = NBA\omega$

NEET / JEE Traps & Quick Recall

- Inductance is the electrical analogue of mass (inertia); it opposes change in current, not the current.
- Bringing the N-pole of a magnet towards a coil makes the near face of the coil an N-pole (repels).
- Induced emf exists even in an open circuit; induced current needs a closed circuit.
- Rate of change of flux decides emf, not the flux itself.
- Energy density of a magnetic field = $B^2/2\mu_0$.

Alternating Current

rms values, AC through R, L, C, LCR circuits, resonance, power factor and transformers.

MIND MAP · Alternating Current

Alternating Current

AC basics

- $v = v_m \sin \omega t$; $i = i_m \sin(\omega t + \phi)$
- rms:** $I = i_m/\sqrt{2} \approx 0.707 i_m$; $V = v_m/\sqrt{2}$
- Average over a full cycle = 0
- Household 220 V is rms; peak ≈ 311 V

Single elements

- Resistor:** v and i in phase
- Inductor:** $X_L = \omega L$; current lags voltage by $\pi/2$
- Capacitor:** $X_C = 1/\omega C$; current leads voltage by $\pi/2$
- Ideal L or C:** average power = 0 (wattless)

Series LCR

- Impedance:** $Z = \sqrt{R^2 + (X_C - X_L)^2}$
- Phase:** $\tan \phi = (X_C - X_L)/R$
- Resonance:** $X_L = X_C$; $\omega_0 = 1/\sqrt{LC}$; $Z = R$, current maximum
- Quality factor:** $Q = \omega_0 L/R = 1/(\omega_0 CR)$; sharper resonance for larger Q

Power

- $P = VI \cos \phi$
- Power factor $\cos \phi = R/Z$
- Pure R:** $\cos \phi = 1$; pure L or C: $\cos \phi = 0$

LC oscillations

- Energy shuttles between capacitor (electric) and inductor (magnetic)
- $\omega_0 = 1/\sqrt{LC}$

Transformer

- $V_s/V_p = N_s/N_p = I_p/I_s$ (ideal)
- Step-up:** $N_s > N_p$; step-down: $N_s < N_p$
- Losses:** flux leakage, copper (I^2R), eddy currents (laminated core), hysteresis
- Power transmitted at high voltage, low current to cut I^2R losses

Phase between voltage and current

Circuit	Impedance	Phase	Power factor
Pure R	R	In phase ($\phi = 0$)	1
Pure L	ωL	Current lags by 90°	0
Pure C	$1/\omega C$	Current leads by 90°	0
RL	$\sqrt{R^2 + \omega^2 L^2}$	Current lags	R/Z
RC	$\sqrt{R^2 + 1/\omega^2 C^2}$	Current leads	R/Z
LCR at resonance	R	In phase	1

NEET / JEE Traps & Quick Recall

- A capacitor blocks DC ($\omega = 0$, $X_C = \infty$); an inductor passes DC freely.
- AC ammeters and voltmeters read rms values.
- At resonance, voltages across L and C can each be much larger than the source voltage.
- A transformer does not work on DC.
- Below resonance an LCR circuit is capacitive; above resonance it is inductive.

Electromagnetic Waves

Displacement current, properties of EM waves and the electromagnetic spectrum.

MIND MAP · Electromagnetic Waves

Electromagnetic Waves

Displacement current

- $i_d = \epsilon_0 d\Phi_E/dt$ (Maxwell)
- Ampere–Maxwell law:** $\oint \mathbf{B} \cdot d\mathbf{l} = \mu_0(i_c + i_d)$
- Makes current continuous through a charging capacitor

Source

- Accelerated charges radiate EM waves
- Oscillating charge with frequency ν gives waves of frequency ν

Properties

- E and B oscillate $\perp$ to each other and to the direction of travel (transverse)
- $c = 1/\sqrt{(\mu_0\epsilon_0)} = 3 \times 10^8$ m/s in vacuum
- $E_0/B_0 = c$
- In a medium:** $v = 1/\sqrt{(\mu\epsilon)}$
- Need no medium

Energy and momentum

- Carry energy and momentum; exert radiation pressure
- Momentum delivered (full absorption):** $p = U/c$
- Average energy density:** equal shares of electric and magnetic

Electromagnetic spectrum (increasing frequency)

Wave	Wavelength range	Produced by	Use
Radio	> 0.1 m	Accelerated charges in aerials	Radio, TV, mobile communication
Microwaves	0.1 m to 1 mm	Klystron, magnetron, Gunn diode	Radar, microwave ovens
Infrared	1 mm to 700 nm	Hot bodies, molecules	Remote controls, physiotherapy, greenhouse effect
Visible	700 nm to 400 nm	Electrons in atoms	Vision
Ultraviolet	400 nm to 1 nm	Very hot bodies (sun), special lamps	Sterilisation (water purifiers), LASIK; ozone absorbs it
X-rays	1 nm to 10^{-3} nm	X-ray tubes (high-energy electrons hitting metal)	Medical diagnosis, cancer treatment
Gamma rays	< 10^{-3} nm	Radioactive nuclei	Cancer treatment, nuclear reactions

NEET / JEE Traps & Quick Recall

- All EM waves travel at the same speed c in vacuum; they differ in frequency and wavelength.
- Order by wavelength (long to short): radio > micro > IR > visible > UV > X > γ .
- Infrared is called heat waves; UV is absorbed by the ozone layer.
- Welders wear special goggles to protect eyes from UV.
- Sound waves are not EM waves.

Ray Optics and Optical Instruments

Reflection, refraction, total internal reflection, lenses, prism and optical instruments.

MIND MAP · Ray Optics

Ray Optics

Mirrors

- $f = R/2$
- **Mirror equation:** $1/v + 1/u = 1/f$
- **Magnification:** $m = -v/u = h'/h$
- **Cartesian sign convention:** distances measured from pole; along incident light positive

Refraction

- **Snell:** $n_1 \sin i = n_2 \sin r$
- $n_{21} = v_1/v_2$
- Apparent depth = real depth / n
- **Lateral shift in a glass slab:** $d = t \sin(i - r)/\cos r$

Total internal reflection

- Denser to rarer, $i > \text{critical angle}$
- $\sin i_c = 1/n$ (rarer medium air)
- **Examples:** mirage, diamond sparkle, optical fibres, prisms in binoculars

Spherical refracting surface and lenses

- **Single surface:** $n_2/v - n_1/u = (n_2 - n_1)/R$
- **Lens maker:** $1/f = (n - 1)(1/R_1 - 1/R_2)$
- **Thin lens:** $1/v - 1/u = 1/f$; $m = v/u$
- **Power:** $P = 1/f$ (f in metre, unit dioptre)
- **Lenses in contact:** $1/f = 1/f_1 + 1/f_2$; $P = P_1 + P_2$

Prism

- $A + \delta = i + e$; $r_1 + r_2 = A$
- **Minimum deviation:** $n = \sin[(A + \delta_m)/2] / \sin(A/2)$
- **Thin prism:** $\delta = (n - 1)A$

Optical instruments

- **Simple microscope:** $m = 1 + D/f$ (image at $D = 25$ cm); $m = D/f$ (image at infinity)
- **Compound microscope:** $m = (L/f_o)(D/f_e)$ (normal adjustment)
- **Telescope (normal adjustment):** $m = f_o/f_e$; length = $f_o + f_e$
- Resolving power improves with larger objective aperture

Image formation by a concave mirror

Object position	Image position	Nature and size
At infinity	At F	Real, inverted, highly diminished
Beyond C	Between F and C	Real, inverted, diminished
At C	At C	Real, inverted, same size
Between C and F	Beyond C	Real, inverted, magnified
At F	At infinity	Real, inverted, highly magnified
Between F and P	Behind mirror	Virtual, erect, magnified

NEET / JEE Traps & Quick Recall

- A convex mirror always gives a virtual, erect, diminished image (used as rear-view mirror).
- A convex lens in a denser medium than its glass behaves like a diverging lens.
- Focal length of a mirror does not change in water; a lens's does.
- Critical angle for glass ($n = 1.5$) is about 42° ; for diamond (2.42) about 24° .
- In a compound microscope both objective and eyepiece have short focal lengths; in a telescope the objective has a long focal length.

MIND MAP · Wave Optics

Wave Optics

Huygens principle

- Each point of a wavefront is a source of secondary wavelets
- Explains reflection and refraction; in denser medium light is slower:** $v = c/n$
- Frequency unchanged in refraction; wavelength becomes λ/n

Interference

- Needs coherent sources (constant phase difference)
- Constructive:** path difference = $n\lambda$; $I = I_1 + I_2 + 2\sqrt{I_1 I_2}$
- Destructive:** path difference = $(n + \frac{1}{2})\lambda$; $I = I_1 + I_2 - 2\sqrt{I_1 I_2}$
- Equal intensities:** $I = 4I_0 \cos^2(\phi/2)$

Young's double slit

- Fringe width:** $\beta = \lambda D/d$
- Bright fringe at $y = n\lambda D/d$; dark at $y = (n + \frac{1}{2})\lambda D/d$
- In a medium:** $\beta' = \beta/n$
- White light:** central fringe white, others coloured

Diffraction (single slit, width a)

- Minima at $a \sin \theta = n\lambda$
- Central maximum width = $2\lambda D/a$ (twice others)
- Noticeable when a is comparable with λ

Polarisation

- Shows light is transverse
- Malus law:** $I = I_0 \cos^2 \theta$
- Unpolarised light through a polaroid:** $I_0/2$
- Brewster:** $\tan i_B = n$; reflected and refracted rays $\perp$ ($i_B + r = 90^\circ$)

Interference vs diffraction

Feature	Interference (YDSE)	Diffraction (single slit)
Cause	Two coherent sources	Secondary wavelets from one slit
Fringe width	All equal	Central twice the others
Intensity	All bright fringes equal	Falls off quickly from centre
Dark fringes	Completely dark	Not perfectly dark

NEET / JEE Traps & Quick Recall

- Two independent bulbs never give an interference pattern (not coherent).
- Putting the YDSE apparatus in water reduces fringe width by n .
- If one slit is covered, interference disappears and a single-slit diffraction pattern remains.
- Polaroids are used in sunglasses, 3-D movie glasses and LCDs.
- Ratio of maximum to minimum intensity: $I_{\max}/I_{\min} = (\sqrt{I_1} + \sqrt{I_2})^2/(\sqrt{I_1} - \sqrt{I_2})^2$.

Dual Nature of Radiation and Matter

Photoelectric effect, Einstein's equation, photon and de Broglie wavelength.

MIND MAP · Dual Nature of Radiation and Matter

Dual Nature

Electron emission

- **Work function ϕ_0** : minimum energy to free an electron (eV)
- Thermionic, field emission and photoelectric emission

Photoelectric effect

- Instantaneous emission ($< 10^{-9}$ s)
- Photocurrent $\propto$ intensity (for $\nu > \nu_0$)
- Stopping potential V_0 and $K_{\max}$ depend on ν , not on intensity
- No emission below threshold frequency ν_0 , however intense the light

Einstein's equation

- $K_{\max} = h\nu - \phi_0 = eV_0$
- $\phi_0 = h\nu_0$
- **Graph V_0 vs ν** : straight line, slope h/e , intercept ν_0

Photon

- $E = h\nu = hc/\lambda$; $E(\text{eV}) = 1240/\lambda(\text{nm})$
- Momentum $p = h/\lambda = E/c$
- Rest mass zero; speed c
- Number of photons per second = $P/(h\nu)$

de Broglie waves

- $\lambda = h/p = h/mv$
- **In terms of KE**: $\lambda = h/\sqrt{2mK}$
- **Electron accelerated through V volts**: $\lambda = 1.227/\sqrt{V}$ nm
- Davisson–Germer experiment confirmed electron diffraction

NEET / JEE Traps & Quick Recall

- Doubling intensity doubles photocurrent but leaves stopping potential unchanged.
- Increasing frequency raises $K_{\max}$ but not the number of electrons (at fixed intensity, fewer photons).
- For the same λ , photon and electron have the same momentum but different energy.
- Wave nature of macroscopic objects is undetectable because λ is extremely small.
- Saturation current depends on intensity; stopping potential depends on frequency and metal.

MIND MAP · Atoms

Atoms

Rutherford model

- **α -particle scattering (Geiger–Marsden):** most pass through, a few deflected back
- Nucleus is tiny ($\sim 10^{-15}$ m) and holds almost all mass
- **Distance of closest approach:** $r_0 = 2kZe^2/K$
- Impact parameter $b \propto \cot(\theta/2)$
- **Failed:** could not explain stability or line spectra

Bohr postulates

- **Stationary orbits:** no radiation
- **Angular momentum quantised:** $mvr = nh/2\pi$
- **Transition:** $h\nu = E_i - E_f$

Hydrogen atom results

- **Radius:** $r_n = 0.53 n^2 \text{ \AA} (\propto n^2/Z)$
- **Speed:** $v_n \propto Z/n$ ($v_1 \approx c/137$)
- **Energy:** $E_n = -13.6 Z^2/n^2 \text{ eV}$
- $KE = -E$; $PE = 2E$
- Ionisation energy of H = 13.6 eV

Spectrum

- $1/\lambda = RZ^2(1/n_1^2 - 1/n_2^2)$; $R = 1.097 \times 10^7 \text{ m}^{-1}$
- **Lines from level n :** $n(n-1)/2$
- **de Broglie:** $2\pi r_n = n\lambda$ (standing wave in the orbit)

Spectral series of hydrogen

Series	Final level n_1	n_2	Region
Lyman	1	2, 3, 4 ...	Ultraviolet
Balmer	2	3, 4, 5 ...	Visible
Paschen	3	4, 5, 6 ...	Infrared
Brackett	4	5, 6, 7 ...	Infrared
Pfund	5	6, 7, 8 ...	Infrared

NEET / JEE Traps & Quick Recall

- Energy levels get closer as n increases.
- First excitation energy of H = 10.2 eV ($n = 1 \rightarrow 2$).
- Shortest wavelength of a series: $n_2 = \infty$ (series limit).
- Bohr model works only for one-electron systems (H, He^+ , Li^{2+}).
- Total energy is negative: the electron is bound.

MIND MAP · Nuclei

Nuclei

Composition and size

- ${}^A_ZX$: Z protons, A – Z neutrons
- **Radius**: $R = R_0 A^{1/3}$, $R_0 = 1.2$ fm
- Nuclear density $\approx 2.3 \times 10^{17}$ kg m⁻³, same for all nuclei
- Isotopes (same Z), isobars (same A), isotones (same N)

Mass-energy

- $E = mc^2$; 1 u = 931.5 MeV/c²
- **Mass defect**: $\Delta M = [Zm_p + (A - Z)m_n] - M$
- **Binding energy**: $E_b = \Delta M c^2$

Binding energy per nucleon

- Nearly constant (~8 MeV) for $30 < A < 170$
- Peak ≈ 8.75 MeV at A = 56 (iron)
- Lower for light ($A < 30$) and heavy ($A > 170$) nuclei

Nuclear force

- Strongest force; short range (a few fm)
- Charge-independent (p–p, n–n, n–p alike)
- Attractive > 0.8 fm; repulsive < 0.8 fm

Fission

- Heavy nucleus splits into two medium ones; energy ~200 MeV per fission of U-235
- ${}^{235}\text{U} + n \rightarrow {}^{141}\text{Ba} + {}^{92}\text{Kr} + 3n + \text{energy}$
- Chain reaction; nuclear reactor (moderator, control rods)

Fusion

- Light nuclei join; needs very high temperature (thermonuclear)
- Source of energy of the sun and stars (proton–proton cycle)

NEET / JEE Traps & Quick Recall

- Energy is released in fission and fusion because BE per nucleon increases.
- Nuclear density does not depend on mass number.
- Mass of a nucleus is always less than the sum of masses of its nucleons.
- Neutrons are used to start fission because they are uncharged (no Coulomb repulsion).
- Fusion needs very high temperature to overcome Coulomb repulsion.

MIND MAP · Semiconductor Electronics

Semiconductors

Energy bands

- **Conductors:** bands overlap
- **Insulators:** large gap ($E_g > 3 \text{ eV}$)
- **Semiconductors:** small gap (Si 1.1 eV, Ge 0.71 eV)

Intrinsic

- Pure Si or Ge; $n_e = n_h = n_i$
- Conductivity rises with temperature

Extrinsic

- **n-type:** doped with pentavalent (As, Sb, P); electrons majority; donor
- **p-type:** doped with trivalent (In, B, Al); holes majority; acceptor
- $n_e \times n_h = n_i^2$
- Crystal remains electrically neutral

p-n junction

- Diffusion of majority carriers and drift of minority carriers
- Depletion layer with barrier potential ($\sim 0.7 \text{ V}$ Si, $\sim 0.3 \text{ V}$ Ge)
- **Forward bias:** barrier lowers, depletion layer narrows, current in mA
- **Reverse bias:** barrier rises, layer widens, tiny current (μA) until breakdown

Diode as rectifier

- **Half-wave:** output for one half-cycle; ripple frequency = input frequency
- **Full-wave (centre-tap or bridge):** both half-cycles; ripple frequency = $2 \times$ input
- Capacitor filter smooths the output

n-type vs p-type

Feature	n-type	p-type
Dopant	Pentavalent (P, As, Sb)	Trivalent (B, Al, In, Ga)
Majority carrier	Electrons	Holes
Impurity called	Donor	Acceptor
Extra level	Donor level just below conduction band	Acceptor level just above valence band
Charge of crystal	Neutral	Neutral

NEET / JEE Traps & Quick Recall

- A hole is not a real particle; it is the absence of an electron that behaves like + charge.
- In reverse bias, the small current is due to minority carriers and is nearly independent of voltage.
- Full-wave rectifier: centre-tap type uses two diodes; bridge type uses four.
- Resistance of a semiconductor decreases with temperature (negative temperature coefficient).
- A doped crystal is neutral; doping does not charge it.

All the best for NEET and JEE!

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