[M]	Mass
[T]	Time
$[L^{-1}]$	Optical power, wave no, rydberg constant, spatial frequency
$[M^{-1}]$	
$[T^{-1}]$	Frequency, velocity gradient, angular velocity
$[ML^{2}]$	Moment of inertia
$[MT^{-1}]$	Speed, velocity
$[MT^{-2}]$	Surface tension, spring constant, stiffness
$[MT^{-3}]$	Intensity of sound, heat, flux density, irradiance
$[MLT^{-1}]$	Momentum, impluse
$[MLT^{-2}]$	Force
$[M L^{-1} T^{-1}]$	Viscosity
$[M L^{-1} T^{-2}]$	Stress, pressure, young modulus
$[ML^{2}T^{-1}]$	Angular momentum, plank constant
$[ML^{2}T^{-2}]$	Energy, work, torque
$[ML^{2}T^{-2}K^{-1}]$	Heat capacity, entropy, boltzmann constant, gas constant

Beam Balance: Having rod and 2 pans used in home.

Physical Balance: Used in school science lab to take small mass.

Lever Balance: Compare two mass.

Electronic Balance: Computerized digital used in stores.

Mechanical Stopwatch: LC = 0.1 sec

Digital Stopwatch: LC = 0.01 sec

Vernier Calipers: Used to take measurements up to 10^{th} part of 1mm.

- Main scale has cm sclae and vernier scale has 10 lines.
- **Least Account**: LC = 0.01 cm
- **Zero Error**: Error in measurement.
- **Zero Correction**: Correct the error in measurement. ZC = 0.01 x line
- ZE(+) → ${}^{ms}_{0}I\ I^{vs}_{0}$ ZE(-) → ${}^{vs}_{0}I\ I^{ms}_{0}$

Screw Gauge: Used to take measurements up to 100^{th} part of 1mm.

- Main scale has mm scale and circular scale has 100 lines.
- **Least Account**: LC = 0.01 mm
- ZE(+) → 1^{st} lines meet ZE(-) → Last lines meet

MEASUREMENT

Measurement: Comparison of unknown things with a standard.
Unit: The standard with which things are compared.
Magnitude: Numerical value with a proper unit.
Physical Quantities: Observed and measureable quantities. (Base + Derived)
SI System: 1960 international committee decided 3 types of units.

- **Base**:mass(kg), length(m), time(s), temperature(K), electric current(A), light intensity(cd) & amount of substance(mol).
- **Derived**: Obtain from division or multiplication of base units.
- **Supplemenary**: The units which are base or derived not decided.
- **CGS System**: cm, gm, sec.
- **FPS System**: ft, pound, sec. (british engineering system)
- **MKS System**: m, kg, sec.

Plane Angle: $\theta = s/r$ (Radian is the unit of plane angle for 2D)

- Total plane angle in a circle is: 2π radians = 6.28 rad = 1 revolution
- 1 radian = 57.3 degree → angle at the center of circle by an arc = r.
- Degree is the unit of plane angle in sexagesimal system. 1° = 1rev/360

Solid Angle: $\Omega = A/r^2$ (Steradian is the unit of solid angle for 3D)

- Total solid angle in a sphere: 4π steradian = 12.56 sr.
- Solid angle is independent of the shape and radius of the object.
- Steradian → angle at the center of sphere by an area = r^2.

Unit Convection: Full name of a unit is written in small letters. newton

- 1^{st} letter is used as a symbol. newton → N
- Prefix + units is written without space. 10^3cm
- Two units is written with space. N m
- Power applies to all combined units. $(10^3\text{cm})^2$

Resolution: Minimum reading which an instrument can read.
Accuracy: Measure of correctness of measurement. It is closeness to actual value.

- Accuracy = 1/fractional error $\quad A \propto 1/\%E \quad A \propto L.C$

Precision: Magnitude of error in the measurement. It depend on instrument.

- Precision = 1/absolute uncertainty. $\quad P \propto 1/L.C$
- Accuracy and precision are inversely related.

Error: Difference b/w actual and measured values. $\quad E = |x_m - x_a|$

- **Personal Error/Incorrect Reading/Parallax Error**:
  Error due to carelessness, negligence, inexperience of a person.
- **Systematic Error**:
  Error due to use of faulty apparatus, poor calibration and zero error.
- **Statistical Error/Random Error/Accidental Error**:

Error due to external environmental factor.

Uncertainty: Estimate about an error in any measurement.

- personal error + systematic error + random error
- Uncertainty in the reading at one end = L.C/2
- **Total/Absolute Uncertainty** = least count → presion
- **Fractional Error/Relative Uncertainty** = error/measured value = $L.C/R_o$
- **Percentage Uncertainty** = Relative Uncertainty x 100 = $(L.C/R_o)100$
- In addition & subtraction, absolute uncertainties (LC) of all measurement are added.
- In division & multiplication, % uncertainties of all measurements are added.
- In power of quantity, % uncertainty in measurement is multiplied with power of given quantity.
- In average values of many measurements, uncertainty is the average value of the deviated values from mean values. Uncertainty = A.M = $\Sigma|x-\bar{x}|/n$
- Uncertainty in time period in timing experiment = LC/no of vibrations

Significant Figures: Accurately known digits and 1st doutful digit.

- In standard form, figures except power of ten are significant.
- All non zero digits are significants.
- The zero b/w two significant digits is also significant.
- Zero to left side of integer is not significant. (decimal/whole integer)
- Zero to right side of decimal fraction is significant.
- In an whole integer, if LC is not given then all zeros at the right side are not significant.
- No of significant figures in a whole integer = Given-No/L.C
- Greater the significant figures in measurement, more accurate it.

Scientific Notation/Standard Form: Integers written in power of ten. 6.02×10^{23}

- If point is moved from left to right then power will be negative. o → -ve
- If point is moved from right to left then power will be positive. ← o +ve

Prefixes: Special name for powers of tens.

- a(10^{-18}) f(10^{-15}) p(10^{-12}) n(10^{-9}) u(10^{-6}) m(10^{-3}) c(10^{-2}) d(10^{-1}) da(10^{1}) k(10^{3}) M(10^{6}) G(10^{9}) A(10^{10}) T(10^{12}) P(10^{15}) E(10^{18}).

Round of Numbers: x < 5 → same   x > 5 → +1   x = 5 → even

Dimension: Power to which any physical quantity be raised.

- Introduced by Josif Corier.
- Length [L], mass [M], time [T]

Dimensionless	π, all integirs, refractive index, strain, magnification, solid angle, plane angle, reynolds number, coefficient of friction, N_A
[L]	Distance, displcement

[M]	Mass
[T]	Time
$[L^{-1}]$	Optical power, wave no, rydberg constant, spatial frequency
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VECTORS

Scalar: Having dimension, phase, magnitude, unit & no direction. Arithmetic rules are applicable. Division is possible. Speed.

Vector: Having dimension, phase, magnitude, unit & direction. Vector algebra is applicable. Division is not possible. Velocity.

- Vector symbolic representation: Bold (**V**) $\vec{V}$ $\underline{V}$
- **Modulus**: Magnitude of vector. $|\vec{V}| = V$

Proper Vector: We can assume any direction. F, v, a, P.

Axial Vector: We can't assume any direction but directed according to RHR. τ

Equal Vectors: Having same magnitude & direction. A = B & $\theta=0^\circ$

Opposite Vector: Same magnitude but opposite direction. (A=-B) & $\theta=180^\circ$

Parallel Vectors: Having same direction. A = nB ($n\geq1$) & $\theta=0^\circ$

- If A & B are two non-zero vectors & if A= $\sqrt{2}$B then vectors are parallel.

Antiparallel Vectors: Having opposite direction. A = -nB & $\theta=180^\circ$

Collinear Vectors: Vectors which are parallel/anti-parallel to each other. $\theta=0^\circ$

Null/Zero Vector: $\vec{O}$ Sum of opposite vectors of same mag. If A=-B then A+B=0.

- It is vector identity for addition. Zero cannot be added to null.
- Magnitude of null vector is zero and direction is undefined/arbitrary.
- Mini no of equal and opposite vectors in same plane to result into null is 2.
- Mini no of unequal vectors in same plan to result into null is 3.
- Mini no of non-coplanar vectors to result into null is 4.

Coplanar Vectors: Vectors lie in the same plane.

Coinitial Vector: Same starting point and help in finding angle b/w vectors.

- Angle b/w vectors is always smaller the angle b/w their tails. ($0^\circ\leq\theta\leq180^\circ$)

Polar Vector: Which has a starting point or a point of application. Velocity

Concurrent Vectors: Whose line of action passes through common point.

Resultant Vector: Combination of two or more single vector.

Equilibrant Vector: A force vector which brings a body into equilibrium.

Free Vectors: Whose tail is not bonded to the origin. Displacement

Fixed Vectors: Whose tail is bonded to the origin. Position vector

Position Vector: Which describe position of a point wrt origin. $\vec{r} = x\hat{i} + y\hat{j} + z\hat{k}$

Unit Vector: Vector whose magnitude is one. $\hat{V} = \vec{V}/|V|$

Basic Unit Vector: $\hat{i}$ $\hat{j}$ $\hat{k}$

Normal Unit Vector: Always perpendicular to plane containing vectors.

Cartesian/Rectangular Coordinate System: A set of two mutually perpendicular lines having point of intersection is called origin.

- Abscissa: Value on x-axis, Ordinate: Value on y-axis.

- Vector Polar Form: $\vec{r} = (r,\theta)$
- Vector Cartesian Form: $\vec{r} = x\hat{i} + y\hat{j} + z\hat{k}$

Direction Cosines: $\cos\alpha$, $\cos\beta$, $\cos\gamma$, of a vector in xyz plane.

- Position vector makes 3 angle in xyz plane. α with x-axis, β with y-axis, γ with z-axis.
- $\cos^2\alpha + \cos^2\beta + \cos^2\gamma = 1$

Spherical Polar Coordinates: Coordinates (ρ,θ,Φ) of a point in polar plane.

- $\rho \rightarrow$ Magnitude of vector, $\theta \rightarrow$ angle b/w x-axis & vector, $\Phi \rightarrow$ angle b/w z-axis & vector.
- **Polar Plane**: xy-axis are along the plane and z-axis is normal to plane.
- $x = \rho\cos\theta\sin\Phi$, $y = \rho\sin\theta\sin\Phi$, $z = \rho\cos\Phi$

Head to Tail Rule: Graphical method to add vectors.

- $\vec{R} = \vec{A}+\vec{B}$ $\vec{R} = \vec{A}+(-\vec{B})$ $\vec{R} = \vec{A}-\vec{B}$
- Vector can be added and subtracted according to HTR.
- Minimum number of vectors which can be added by HTR are 2.
- The sum of non-coplanar forces can never be zero.

Multiplication of a Vector by a Number or Scalar:

- If n=0, then nxA=0 ⇒ Null vector
- If n=1, then nxA=A ⇒ Neither magnitude nor direction change
- If n=-1, then nxA=-A ⇒ Magnitude remains same but direction opposite.
- If n>1, then nxA=nA ⇒ Only magnitude change but does not direction.
- If n<1, then nxA=-nA ⇒ Both magnitude & direction change.
- If n=scalar, then nxA ⇒ New quantity is formed.

Resolution of Vectors: Splitting of a vector into its rectangular components.

- It is the reverse process of addition of vectors by HTR.
- $F_x = F\cos\theta$ & $F_y = F\sin\theta$
- θ is the angle which R makes with + x-axis.
- If x-component of a vector is equal to its y-component then the angle made by the resultant is 45°.

Composition of a Vector: Composed a vector from its components.

- Magnitude of single vector in 2D: $R = \sqrt{x^2 + y^2}$
- Magnitude of single vector in 3D: $R = \sqrt{x^2 + y^2 + z^2}$
- $R_x = (A_x+B_x)\hat{i}$ $R_y = (A_y+B_y)\hat{j}$ $R = R_x+R_y$
- $\theta = \tan^{-1}(R_y/R_x)$

Magnitude of Resultant of 2 Vectors: V = $\sqrt{V_1 + V_2 + 2V_1V_2\cos\theta}$

- When $\theta=0°$ then **$V = V_1+V_2$**
- When $\theta=120°$ then **$V_1 = V_2 = V$**

- When θ=180° then $V = V_1 - V_2$ $(V_1 \neq V_2)$
- When θ=180° then $V = 0$ $(V_1 = V_2)$

Rules for Finding the Direction of Resultant: $\varphi = \tan^{-1}(R_y/R_x)$

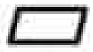
X-component (R_x)	Y-component (R_y)	Final Direction
+	+	θ = φ
---	+	θ = 180° - φ
---	---	θ = 180° + φ
+	---	θ = 360° - φ

Scalar/Dot Product: A.B = ABcosθ

- Examples: W=F.S, P=F.V, Φ_e=E.A, V=E.r
- A.B = A.B_x (B_x = Projection of B along A) ⇒ B_x = A.B/A
- A.B = A_x.B (A_x = Projection of A along B) ⇒ A_x = A.B/B
- A.B = +ve, when 0°≤θ<90°
- A.B = -ve when 90°<θ≤180°
- Parallel: A.B = ABcos(0) = AB (i.i=j.j=k.k=1)
- Antiparallel: A.B = ABcos(180) = -AB
- Perpendicular: A.B = ABcos(90) = 0 (i.j=j.k=k.i=0)
- Self-scalar product: A.A = A^2
- Obey commutative law: A.B = B.A
- Obey associative law: mA.nB = nA.mB = nm(A.B)
- Obey distribution law: A.(B+C) = (A.B) + (A.C)
- $\vec{A}.\vec{B} = A_xB_x + A_yB_y + A_zB_z$

Vector/Cross Product: AxB = ABSinθ$\hat{n}$

- Direction is given by right hand rule and represented by $\hat{n}$.
- Examples: τ=rxF L=rxP F=q(VxB) V=ωxr
- Parallel: AxB = ABsin(0) = 0 (ixi=jxj=kxk=0)
- Antiparallel: AxB = ABsin(180) = 0
- AxB = ABsin(270) = -AB$\hat{n}$
- Perpendicular: AxB = ABsin(90) = AB$\hat{n}$ (ixj=k,jxk=i,kxi=j)
- Self-vector product: A.A = 0
- Not obey commutative law: AxB ≠ BxA
- Obey associative law: mA x nB = nA x mB = nm(AxB)
- $\begin{vmatrix} i & j & k \\ Ax & Ay & Az \\ Bx & By & Bz \end{vmatrix}$ = AxB
- If |A|=|B| then |AxB|= area of square (at θ=90°) □
- If |A|≠|B| then |AxB| = area of rectangle (at θ=90°) ▭

- If |A|≠|B| then ½|AxB| = area of triangle (at θ=90°) 
- If |A|≠|B| then |AxB| = area of parallelogram (at θ≠90°) 
- If the magnitude of cross product is equal to dot product then the angle b/w both vectors is 45°.

Scalar Triple Product: Dot product of a vector with "cross product of 2 vector". It is scalar.

- A.(BxC) = B.(CxA) = C.(AxB)
- On changing the order of A.B.C, sign of product changed.
- Volume of parallelepiped = A.(BxC)
- If A.(BxC) = 0, then A.B.C are coplanar vectors.

Vector Triple Product: Vector product of a vector with "cross product of 2 vector". It is vector. Ax(BxC) = (A.C)B – (A.B)C

FORCE AND MOTION

Kinesis: Study of motion of objects.
Kinematics: Study of motion without discussing reason of motion.
Dynamics: Study of motion along discussing reason of motion.
Distance: Actual path b/w two points and always ≥ +1. Scalar, m, [L]
Displacement: Shortest directed distance b/w two points. Vector, m, [L], ±/0
Speed: Rate of change of distance. Scalar, m/s, $[LT^{-1}]$, V = S/t

- It is magnitude of velocity.

Velocity: Rate of change of displacement. Vector, m/s, $[LT^{-1}]$, **V** = d/t

- **Uniform Velocity**: Rate of change of displacement is constant. Equal displacement covers in equal interval of time.
- **Non-Uniform Velocity:** Rate of change of displacement is not constant. Different displacement covers in equal interval of time.
- **Instantaneous Velocity**: $V = \lim_{\Delta t \to 0}(\Delta d/\Delta t)$
- **Average Velocity**: Total change in displacement in total time.
- Average velocity when body covers different displacement in different intervals of time: $\langle v \rangle = \Sigma S/\Sigma t$
- Average velocity when body covers same displacement in different intervals of time: $\langle v \rangle = 2V_1V_2/V_1+V_2$
- Average velocity when body moves with different velocities in different intervals of time: $\langle v \rangle = \Sigma Vt$
- Average velocity when body moves with different velocities in same intervals of time: $\langle v \rangle = \Sigma V/n$
- When a body is moving with uniform velocity/speed, its average and instantaneous velocity/speed remain the same.

Acceleration: Rate of change in velocity. Vector, m/s^2, $[LT^{-2}]$, **a** = $\Delta V/\Delta t$

- **Positive Acceleration**: When velocity is increase.
- **Negative Acceleration**: When velocity is decrease.
- **Retardation:** Velocity reduces to zero.
- **Deceleration:** Velocity reduces but not zero.
- **Uniform Acceleration**: Rate of change of velocity is constant.
- **Non-Uniform Acceleration**: Rate of change of velocity is not constant.
- **Instantaneous Acceleration**: $a = \lim_{\Delta t \to 0}(\Delta V/\Delta t)$
- **Average Acceleration**: Total change in velocity in total time.
- **Tangential/Linear Acceleration**: Acceleration produced due to change in magnitude of linear velocity. a_t

- **Radial/Centripetal Acceleration**: Acceleration produced due to change in direction of linear velocity. $a_c = V^2/r$
- When both magnitude & direction of linear velocity change then net acceleration is: $a = \sqrt{a_t^2 + a_c^2}$
- Velocity is always in the direction of displacement while acceleration is in the direction of change of velocity.

Graph:

- Area of Triangle: A = ½ (base x height)
- Area of Rectangle: A = length x breadth
- Slope of the graph: tanθ = perp/base
- Slope of displacement-time graph gives velocity.
- Slope of velocity-time graph gives acceleration.
- Slope of acceleration-time graph gives jerk.
- Area of velocity-time graph gives distance covered.
- Area of acceleration-time graph gives velocity.

Newton's 1st law/Law of Inertia: Body remains at rest/motion unless a force change its state.

- $a = 0 \Rightarrow$ Rest(V=0/uniform) $F_{ext} = 0$
- Gives qualitative definition of force.
- When V = 0, Inertia depends on mass of body.
- When V is uniform, Inertia depends on momentum.
- **Inertia**: Property of body with which it resist motion. $J \propto m$

Newton's 2nd law: $a \propto F$ $a \propto 1/m$ $F = ma$

- **Force**: Agent that tries to move anybody. Vector, N, $[MLT^{-2}]$
- Gives quantitative definition of force.
- Newton 2^{nd} law in term of momentum: $\Delta P/\Delta t = F$

Newton's 3rd law: $F_{action} = -F_{reaction}$

- It means forces occurs in pairs.
- Action and reaction never acts on same body.
- Newton's laws of motion are valid in Inertial frame of reference. $V << C$

Applications of Newton's Law:

- Hanged mass (m_1) and block (m_2) with pulley on table. $m_1>m_2$
- $a = m_1g/m_1+m_2$ $T = m_1m_2g/m_1+m_2$
- **Atwood Machine**: 2 mass hang on pulley. $m_1>m_2$
- $a = (m_1-m_2)g/m_1+m_2$ $T = 2m_1m_2g/m_1+m_2$

Equations of Motions:

- Motion should be one – dimensional.

- Acceleration should be uniform.
- Frame of reference should be inertial.
- $V_f = V_i + at$ $S = V_i t + ½at^2$ $2aS = V_f^2 - V_i^2$

Pressure: Force acting externally ⊥ on any surface.

- Scalar, Pa, N/m^2, $[ML^{-1}T^{-2}]$, $P = F/A$
- It also act on fluids.
- It always +ve and can be measure by device.

Friction: Resistive force b/w 2 sliding surfaces on each other.

- **Static Friction**: Friction b/w 2 surfaces at rest. $f_s \leq \mu_s R$
- **Kinetic Friction**: Friction b/w 2 moving surfaces. $f_k = \mu_k R$
- **Coefficient of Friction**: Ratio b/w "max force of friction" to "mag of norma reaction" $\mu_s = f_s/R$ $\mu_k = f_k/R$ $\mu_s > \mu_k$
- For road and tire: $\mu_s = 1$
- **Limiting Friction**: Max value of static friction.
- Rolling friction < Sliding friction
- Intermolecular forces b/w contact points due to cold welds are called surface adhesion.
- Direction of motion and friction force remain opposite.
- Friction exist even if there is no relative motion.

Linear Momentum: P = mv = F.t = J

- Vector, Ns, Kgm/s, $[MLT^{-1}]$, direction is along velocity.
- Relation b/w K.E & P: $K.E = P^2/2m$
- For particles having same momentum, lighter one will have max K.E
- If m=constant, then $P \propto \sqrt{K.E}$
- Linear momentum depends upon frame of reference.
- $P = h/\lambda$ (for particle wave) $P = E/c$ (for photon)

Impulse: $\Delta P = J = F.\Delta t$

- Vector, Ns, $[MLT^{-1}]$
- **Impulsive Force**: Time dependent, very large, sudden, immeasurable.
- **Impulse Momentum Theorem**: $\Delta P/\Delta t = F$
- Thermo-pores protect dinner set by delaying acting force.

Law of Conservation of Momentum: Total P → constant

- $P_i = P_f \Rightarrow$ $m_1v_1 + m_2v_2 = m_1u_1 + m_2u_2$
- **Isolated System**: $F_{ext} = 0$ and all particles exert force on each other.
- Law of conservation of momentum is accordance to Newton's 3rd law.
- Recoil velocity of gun: $V = -mv/M$
- Force of water on wall: $F = mv/t$

Collision: Two particles collides with one another.

- **Head-on/Direct/1D Collision**: Collision of two bodies in which direction remains the same. They move along same line.
- **Sidewise/Oblique Collision**: Collision in which direction of bodies change.
- **Elastic Collision**: P = conserved and K.E/P.E = conserved.
- **Inelastic Collision**: P = conserved and K.E/P.E = not conserved.
- Collision of billiard balls and air molecules is perfectly elastic collision.
- Throwing mud on wall and firing bullet in bag is perfectly inelastic collisior
- Collision b/w atomic & subatomic particles may be elastic.

Relative Velocity: Velocity of two bodies relative to each other.

- Relative velocity in same direction: $v = v_2 - v_1$
- Relative velocity in opposite direction: $v = v_1 + v_2$
- Speed of approach = Speed of separation
- Two photons traveling in vacuum has relative velocity equal to C.
- **Projectile**: Mass m_1 which hit 2nd mass with V_1, after collision V_1'
- **Target**: 2nd mass m_2 with V_2, after collision V_2'
- $V_1' = (m_1\text{-}m_2/m_1\text{+}m_2)V_1 + (2m_2/m_1\text{+}m_2)V_2$
- $V_2' = (2m_1/m_1\text{+}m_2)V_1 + (m_2\text{-}m_1/m_1\text{+}m_2)V_2$

After collision, final velocities of projectile and target.

Before Collision		After Collision		
Mass		Projectile(V_1)	Target(V_2)	Change in Velocity
$m_1 = m_2$	Both motion	V_2	V_1	Interchanged
$m_1 = m_2$	T (rest)	0	V_1	T move with P speed
$m_1 < M_2$	T (rest)	$--V_1$	0	P bounce back
$M_1 > m_2$	T (rest)	V_1	$2V_1$	T move with double o P speed

Ballistic: Study of projectile motion.

- **Projectile**: Body thrown at some angle.
- **Projectile Motion**: Two dimensional motion under constant 'g'
- **Trajectory**: Path followed by projectile which is parabolic.
- Position of projectile: $x = V_i\cos\theta t$ $\quad y = V_i\sin\theta t - \frac{1}{2}gt^2$
- Distance of projectile: $S_x = V_x t$ $\quad S_y = \frac{1}{2}gt^2$
- Components of final velocity: $V_{fx} = V_i\cos\theta$ $\quad V_{fy} = V_i\sin\theta - gt$
- Velocity of projectile: $V = \sqrt{V_x^2 + V_y^2/V_x}$
- Horizontal motion: $F_x = 0$, $\quad V_x$ = constant, $\quad a_x = 0$
- Vertical motion: F = gravity, $\quad V_y$ = change, $\quad a_y = -g$
- Equation of trajectory: $y = x\tan\theta - gx^2/2V_i^2\cos^2\theta$

- Maximum height of projectile: $H = V_i^2 \sin^2\theta / 2g$ $\theta = 90^o$
- Time of total flight: $T = 2V_i \sin\theta / g$
- Time to reach at max height: $t = V_i \sin\theta / g$
- Horizontal range: $R = V_i^2 \sin 2\theta / g$
- Maximum range of projectile: $R_{max} = V_i^2 / g$ $\theta = 45^o$
- $\theta = 76^o$ than R = H
- Relation b/w height & time of flight: $8H = gT^2$
- Relation b/w height & time to summit: $2H = gt^2$
- Ratio of momentum at summit point & projection point: $P_s/P_p = \cos^2\theta$
- Ratio of K.E at summit point & projection point: $K.E_s/K.E_p = \cos^2\theta$
- Ratio of P.E & K.E at summit point: $P.E_s/K.E_s = \tan^2\theta$
- $K.E_s = P.E_s$ at $\theta = 45^o$
- $H_{pole} < H_{equator}$ $g_{pole} > g_{equator}$ $(H \propto 1/g)$
- $T_{pole} < T_{equator}$ $g_{pole} > g_{equator}$ $(T \propto 1/g)$
- $H_{moon} = 6H_{earth}$ $T_{moon} = 6T_{earth}$

WORK AND ENERGY

Work: Scalar product of force and displcament. $W = F.S = F.S\cos\theta$

- Scalar, Nm, J, $[ML^2T^{-2}]$
- **Positive Work**: 1st/4th quadrate $270^o<\theta<90^o$
- **Negative Work**: 2nd/3rd quadrate $90^o<\theta<270^o$
- **Zero Work**: $\theta = 90^o/270^o$
- **Work Energy Theorem**: $W = \Delta K.E$
- Mass Spring System: $W = \frac{1}{2}kx^2$
- Work done by gravitational force: $W = mgh$
- Work done along a closed path is zero. F_c
- Satellite revolving around earth does no work.
- Electrons revolving about nucleus does no work.
- Body in static or dynamic equilibrium does no work.
- Work done by force of friction is always negative.
- Work done in lifting a body up against gravity is negative.
- Work done in lowering body in direction of gravity is positive.
- Area under force & displacement graph is equal to work.
- If F is not in direction of S,then graph is ploted b/w $F\cos\theta$ & S.
- In particle physics, unit of work is eV.

Conservative Field: Field in which work done is path independent.

- Total work done along close path is equal to zero.
- P.E only exist in conservative field.
- Position dependent forces makes conservative fields.
- Electric force, gravitational force, elastic force in spring.

Non Conservative Field: Field in which work done is path dependent. $W\neq0$

- K.E only exist in non-conservative field.
- Velocity dependent forces makes non-conservative fields.
- Drag force, magnetic force, force of friction, tention in string, air resistance, normal force, propultion force of motor and rocket.

Power: Rate of doing work. $P = W/t = E/t = FV = \tau.\omega$

- Scalar, Watt, J/s, $[ML^2T^{-2}]$
- **Avarage Power**: Total work done in total time.
- **Instantaneous Power:** $Lim_{\Delta t\to 0}\Delta W/\Delta t = dw/dt$
- If rate of doing work is constant then $<P> = P_{inst}$
- **Killowatt Hour:** 1000W used in 1 hour. 1KWh = 3.6MJ
- 1hp = 746 Watt = 550 foot-pound/sec
- Average power of a man walking upstairs is 0.33 kW.

Energy: Ability/capacity/capability of a body to do work.

- **Kinetic Energy**: Energy due to motion. K.E = $\frac{1}{2}mv^2 = P^2/2m$
- **Potential Energy**: Energy due to position. P.E = Wh = mgh
- Negative of PE gradient is equal to applied force. F = -dU/dr
- **Elastic P.E**: Energy in stretched or compressed spring. W = $\frac{1}{2}kx^2$
- **Electric P.E**: Ability to do work due to position in EF. W = kq/r
- **Gravitational P.E**: Energy due to position of a body in space. P.E = mgh
- **Absolute G.P.E:** P.E at height (r) wrt a point of zero potential. U = -GMm/R
- Food we eat in one day has same energy as 0.33 liters of petrol.

Efficiency: η = output/input

- **Input**: Effort and distance through which effort acts.
- **Output**: Load and distance covered by the load.
- **Percentage Efficiency**: η = (output/input) x 100
- Ideal machine has 100% efficiency. (output = input)
- Efficiency of automobiles is only around 15%.
- Light bulb is 2% efficiency in lighting and 98% in heating room.
- Efficiency of petrol engine is 25-30% & diesel engine is 35-40%.
- Efficiency of an electric motor is 95%.

Law of Conservation of Energy: Total energy remains constant in a process.

- Law of conservation of energy is valid only in classical mechanics.
- P.E loss = K.E gain + work done against friction
- mgh = $\frac{1}{2}mV^2$ + fh

Energy Sources:

- **LNG**: Liquefied Natural Gas.
  95% methane, 4% ethane, 1% butane, propane, trace amount of N.
- **CNG**: Compressed Natural Gas.
  Methane, 6% ethane, propane, some heavier hydrocarbons.
- **LPG**: Liquefied Petroleum Gas.
  Propane, butane, isobutene.
- **Lignite**: Softest coal has about 50% carbon.
- 5 billion metric tons of coal is consumed per year.
- **Solar/Photo Cell**: Solar penal made from Si wafer.
- Temperature at center of earth is approximately 4000^{o}C.
- Solar energy incidence on earth is 1.4 KW/m^2 but reaching 1 KW/m^2
- **Geothermal Well**: U-shape well made into earth to get energy from magma.
- 100 billion watt per year can be obtained from wind energy.
- 85% of energy used in world is obtained from non-renewable sources.

- 16% of world's electricity is provided by nuclear energy.
- Moon pulls the land up and down by 0.25m.
- Tides raise water in sea twice a day.
- Mangla Dam on river Jehlum generates about 900 MW.

ANGULAR MOTION

Rotational Motion: Rolling of all points of body about an axis that is passing inside of it. Motion of wheel of vehicle about axel.

Circular/Angular/Orbital Motion/Revolution: Rotational motion in which axis of rotation (fix) lies outside body. Motion of electron around nucleus.

- **Spin Motion**: Rotational motion about an origin lies inside body. Motion of electron about its own axis.
- In curvilinear motion: $F\neq0$, $\tau\neq0$, $a_c\neq0$, $a\neq0$, $\alpha\neq0$
- In uniform circular motion, $a_c\neq0$, $a=0$, $\alpha=0$, speed=constant.

Rotational Motion	*Circular Motion*
It cannot be circular	It is type of rotational motion
Center may be fix/variable	Center is fixed
Axis of rotation may change	Axis of rotation not change
Axis of rotation is inside of body	Axis of rotation is not inside of body
Center of mass may change	Center of mass not change

Angular Displacement: Angle at center of circle b/w 2 radii by position vector.

- Radian, degree, revolution, Vector, $\theta = S/r$
- Its direction is along axis of rotation by RHR.
- Clockwise θ is +ve and anti-clockwise is –ve.
- Relation b/w linear & rotational displacement: $S = \theta \times r = \theta r\sin\theta$

Angular Velocity: Angular displacement per unit time.

- rad/s, deg/s, rev/s, Vector, $\omega = \theta/t$
- Its direction is along axis of rotation by RHR.
- Relation b/w linear & rotational velocity: $V = \omega \times r = \omega r\sin\theta$
- ω_{rot} of earth = 2πrad/24hr, ω_{rev} of earth = 2πrad/1year.
- $\omega_{hour} = 2\pi$rad/12hr, $\omega_{mint} = 2\pi$rad/60mint, $\omega_{sec} = 2\pi$rad/60sec.

Angular Acceleration: Change in angular velocity per unit time.

- rad/s^2, deg/s^2, rev/s^2, Vector, $\alpha = \Delta\omega/\Delta t$
- Its direction is along axis of rotation by RHR.
- Relation b/w linear & rotational acceleration: $a = \alpha \times r = \alpha r\sin\theta$
- Angular acceleration is directly proportional to torque. $\alpha \propto \tau$
- If ω increase, then ω and α are in same direction and vv.
- All points on a rotating rigid body have same: θ, ω, α.

Linear	*Angular*	*Linear*	*Angular*
$W = F.S$	$W = \tau\theta$	$K.E = ½\, mV^2$	$K.E = ½\, I\omega^2$
$P = F.V$	$P = \tau\omega$	$P = mV$	$L = I\omega$
$F = ma$	$\tau = I\alpha$	$S = Vt$	$\theta = \omega t$

$V_f = V_i + at$	$\omega_f = \omega_i + \alpha t$	$S = V_i t + ½ at^2$	$\theta = \omega_i t + ½ \alpha t^2$
$2aS = V_f^2 - V_i^2$	$2\alpha\theta = \omega_f^2 - \omega_i^2$	$a_c = V^2/r$	$a_c = r\omega^2$

Centripetal Force/Center Seeking/Radial Force: Force which bend a body into circular path. $F_c = mV^2/r = mr\omega^2$

- It produces radial acceleration in a body.
- Work done by $F_c = 0$
- Its direction is towards center.
- **Centripetal Acceleration**: It is produced by F_c. $a_c = V^2/r = r\omega^2$
- Its direction is toward center.
- Bodies revolving in horizontal circle, tension in string remains constant.
- Bodies revolving in vertical circle, tension at top: $T = m(a_c - g)$
- Bodies revolving in the vertical circle, tension at bottom: $T = m(a_c + g)$
- Relation b/w linear & rotational force: $\tau = r \times F = rF\sin\theta$

Centrifugal Force/Center Fleeing Force: Force produced due to inertia of body.

- $F_f = -mV^2/r = -mr\omega^2$
- Its direction is outward from center.
- It is reaction of centripetal force. $F_c = -F_f$
- F_c and F_f form pair but it not act on same body.
- Centrifugal force always act on source of centripetal force.
- **Centrifugal Acceleration**: It is produced by F_f. $a_c = -V^2/r = -r\omega^2$
- Its direction is outward from center.
- **Banked Curve**: Outer edge of roads is raise than inner edge that helps in taking safe turns with high speed: $\theta = \tan^{-1}(V^2/R_g)$
- Normal force act vertically upward on car.
- $N\cos\theta \rightarrow F_c$ $\quad$ $N\sin\theta \rightarrow$ weight
- Speed of car: $V = \sqrt{gR\tan\theta}$
- **Washing Machine Dryer**: F_f expelled water from wet clothes.
- **Cream Separator**: F_f pushed skimmed-milk at corner and kept light cream near axis.

Torque/Moment of Force: Turning effect produced in a body about a fixed point due to an applied force. $\tau = rxF = rF\sin\theta$

- Vector, Nm, $[ML^2T^{-2}]$, $\tau = I\alpha$
- **Line of Action**: Point where force acts to produced torque.
- **Point of Rotation**: Point about which body rotates.
- **Moment Arm**: Perp distance b/w line of action and point of rotation.
- **RHR**: Curl your fingers in direction of turning then thumb will indicate or show direction of torque.

- Torque is the rotational analogue of force. (τ = F)
- Torque produces angular acceleration in a body.
- If body is at rest or moving with uniform angular velocity then $\tau = 0$
- If line of actin is passing through origin then $\tau = 0$ → $r = 0$
- Clockwise torque → –ve while anti-clockwise torque → +ve.
- On reversing direction of both r & F, direction of τ remains same.
- To close screw, have to apply clockwise torque.
- To open screw, have to apply anti-clockwise torque.
- Central force cannot produce torque in a body.
- Door automatically close due to torque of H-component of its weight.
- **Center of Mass**: Point, where acting force not produces torque in body.
- **Center of Gravity**: Point, from where on hanging, no τ produces in body.

Principle of Moments: clock-wise τ = anti-clockwise τ

Couple: Two equal, anti-parallel and non-concurrent forces that produce only angular acceleration in a body.

- Torque of couple: $\tau_c = FD$ (D → distance b/w both forces)

Equilibrium: Body is either at rest or moving with uniform motion.

- **Static Equilibrium**: Rest, V=0, a=0
- **Dynamic Equilibrium**: Motion, V=constant, a=0
- **1st Condition**: $\Sigma F = 0$
- **2nd Condition**: $\Sigma \tau = 0$
- When V=0, then body will be in static translational equilibrium.
- When V=uniform, then body will be in dynamic translational equilibrium.
- When ω=0, then the body will be in static rotational equilibrium.
- When ω=uniform, then body will be in dynamic rotational equilibrium.
- First condition of equilibrium is valid only for coplanar forces.
- Minimum no of forces that can keep a body in equilibrium are 2.
- **Stable Equilibrium**: When a body slightly displaced and leave, that body restore its original state.
- **Un-Stable Equilibrium**: When a body slightly displaced and leave, that body cannot restore its original state.
- **Neutral Equilibrium**: When a body displaced from its position, that body looks same at new position.

Moment of Inertia: Measure of hindrance offered by a rigid body against angular motion, when a disturbing torque act over body.

- It is product of mass of body and square of distance from axis of rotation.
- Kgm^2, [ML^2], $I = mr^2$
- It is rotational mass of body. It is 2nd moment of mass.

- 1^{st} moment of mass about centroidal axis is zero but 2^{nd} moment of mass is not.
- **Rigid Body**: Body which has constant distance among all points when rotating or subjected to load.
- **Parallel Axis Theorem**: Tool used for computing moment of inertia of any body. $I = I_{cm} + Md^2$
- $I_{cm} \rightarrow I$ about center of mass — d → distance b/w cm & axis
- Solid cylinder: $I = MR^2/4 + ML^2/12$ (axis along length from center)
- Hollow cylinder: $I = ½MR^2$ (axis along length from center)
- Rigid rod: $I = ML^2/12$ (axis passing ⊥ to length about cm)
- Rigid rod: $I = ML^2/3$ (axis passing ⊥ through 1 end)
- Solid rectangular plate: $I = ML^2/12 + MW^2/12$ (axis passing ⊥ to center)
- Solid disc: $I = MR^2/2$ (axis passing ⊥ through center)
- Solid disc: $I = MR^2/2$ (axis passing along diameter)
- Hoop/ring: $I = MR^2$ (from center)
- Solid sphere: $I = 2MR^2/5$ (axis along diameter)
- Spherical shell: $I = 2MR^2/3$

Rotational Kinetic Energy: Energy due to spinning of a body.

- $K.E = ½I\omega^2 = ½mr^2\omega^2$
- K.E of Hoop/Ring = $½mV^2$, K.E of disc = $¼mV^2$

Object	*Moment of Inertial*	*Speed of Rolling*	*$K.E_{rot}:K.E_{tran}$*
Ring/Hoop	mr^2	$\sqrt{gh}$	1:1
Disc	$½mr^2$	$\sqrt{4/3gh}$	1:2
Sphere	$2/5mr^2$	$\sqrt{10/7gh}$	2:5
Rod	$1/12mr^2$	$\sqrt{3/2gh}$	1:12

Angular Momentum: Product of position vector and linear momentum.

- $L = r \times P = mVr = I\times\omega = rP\sin\theta$
- Vector, Js, kgm^2/s, $[ML^2T^{-1}]$
- Its direction is perpendicular to plan form by r and P by RHR.
- $\Delta L/\Delta t = \tau$
- Relation b/w linear & rotational momentum: $L = r \times P = rP\sin\theta$
- **Spin Angular Momentum**: L due to spinning of body about its own axis. L_s
- **Orbital Angular Momentum**: L due to rotation of a body about an axis. L_o
- For electron: $L_o > L_s$
- **Law of Conservation of Angular Momentum**: In an isolated system total angular momentum is constant when external $\tau = 0$
- L_{total} = Constant — $L_i = L_f$

- At rotating wheel, on closing arms, speed inc: L=mvr, r(dec) → V(inc)
- At springboard, on tucking body, get more rotation: L=mvr, r(dec) → V(inc)

Conical Pendulum: Pendulum rotating in horizontal circle, such that it makes cone. V = $\sqrt{gRtan\theta}$

- $T\cos\theta$ → weight $T\sin\theta$ → F_c
- T = $2\pi\sqrt{Lcos\theta/g}$

Rotor: Hollow cylindrical drum which rotates about an axis.

- Friction force balance object by clunking it with wall. W = $\mu_s N$
- V = $\sqrt{gR/\mu_s}$
- Normal force act along radius towards center.

OSCILLATIONS

Vibratory Motion: To and fro motion of a body about a mean position with higl frequency and low amplitude. Motion of string of guitar.

Oscillation: To and fro motion about a mean position with low frequency and high amplitude. Motion of simple pendulum.

- **Damped Oscillation**: Amplitude is decreases due to external damping force.
- **Un-damped Oscillation**: Amplitude remains same such that external damping force = 0
- **Free Oscillation**: Oscillator performs motion under natural frequency without interference of external force.
- **Forced Oscillation**: Oscillator performs motion under repeated external force.
- **Harmonic Motion**: Repeated motion of a body about mean position.
- **Periodic Motion**: Repeated motion of a body about a mean position at regular intervals of time.

Oscillator: Object which performs oscillations.

- **Vibration**: One complete round trip of oscillator.
- **Displacement**: Distance of oscillator from mean position on either side. x
- **Amplitude**: Maximum distance of oscillator on either side. x_m
- **Time Period**: Time taken to complete one vibration. $T = 2\pi/\omega$
- **Frequency**: No of vibrations completed in one second. $f = \omega/2\omega$
- **Angular Frequency**: No of revolutions completed in one second. $\omega = 2\pi f$
- To continue oscillation, restoring force and inertia is necessary.
- All vibrating bodies produced waves.

Mass Spring System: $F \propto x \quad \Rightarrow \quad F = kx$ (Hooke's law)

- **Spring/Force Constant**: $k = F/x$
- K is measure of stiffness of spring.
- High value of K indicates stiff spring/rigid spring.
- Low value of K indicated soft spring.
- **Elastic Restoring Force**: Force which bring mass back to mean position.
- F_r & displacement are opposite. $F_r = -kx$
- K dec in series combination of springs (same k): $k_s = k/n$
- K inc in parallel combination of springs (same k): $k_p = nk$
- If spring is cut into half, then value of spring constant for each part is 2k
- If spring is cut into half, then ratio of their frequency is $1:\sqrt{2}$
- If spring is cut into half, then ratio of their time periods is $\sqrt{2}:1$

- Angular frequency: $\omega = \sqrt{k/m}$
- Frequency: $f = 1/2\pi\sqrt{k/m}$
- Time period: $T = 2\pi\sqrt{m/k}$
- Displacement: $x = x_m\cos(\sqrt{k/m})t$
- Velocity: $V = x_m\sqrt{\frac{k}{m}(1-\frac{x^2}{x_o^2})} = -\omega x$
- Acceleration: $a = -\omega^2 x$
- Eq of motion of SHO: $d^2x/dt^2 + kx/m = 0$

SHM: Simple harmonic motion. To and fro motion in which $a \propto x$

- Acceleration always remains toward mean position.
- Acceleration (F_r) and displacement are opposite.
- If a body is in uniform circular motion, then its projection (N) performs SHM on horizontal or vertical diameter.

Displacement for SHO: Instantaneous distance of projection of pointer.

- $X = X_m\cos\omega t$ (SHM starts from extreme position on horizontal diamet
- $X = X_m\sin\omega t$ (SHM starts from mean position on horizontal diameter
- $Y = Y_m\cos\omega t$ (SHM starts from extreme position on vertical diameter
- $Y = Y_m\sin\omega t$ (SHM starts from mean position on vertical diameter
- $\sin\omega t$ → motion start from mean position. $Y = Y_m\sin(\omega t+\phi)$
- $\cos\omega t$ → motion start from extreme position. $X = X_m\cos(\omega t+\phi)$
- $\theta = \omega t$ $\omega = \theta/t$

Velocity for SHO: $V = \omega\sqrt{x_m^2 - x^2}$

- At means position: $x = 0$ $V_{max} = \omega x_m$
- At extreme position: $x = x_m$ $V_{min} = 0$

Acceleration of SHO: $a = \omega^2 x$

- At mean position: $x = 0$ $a_{min} = 0$
- At extreme position: $x = x_m$ $a_{max} = \omega^2 x_m$

Momentum of SHO: $P = m\omega\sqrt{x_m^2 - x^2}$

- At mean position: $x = 0$ $P_{max} = m\omega x_m$
- At extreme position: $x = x_m$ $P_{min} = 0$

Kinetic Energy for SHO: $K.E = \frac{1}{2}k(x_m^2 - x^2)$

- At mean position: $x = 0$ $K.E = \frac{1}{2}kx_m^2$
- At extreme position: $x = x_m$ $K.E = 0$

Potential Energy for SHO: $P.E = \frac{1}{2}kx_o^2$

- At mean position: $x = 0$ $P.E = 0$
- At extreme position: $x = x_m$ $P.E = \frac{1}{2}kx_m^2$

Total Energy of SHO: $P.E + K.E = \frac{1}{2}kx_m^2$

- SHM follows law of conservation of energy.
- V, P, KE are max at mean position.
- a, PE are max at extreme position.

Phase Angle: Angle which describes displacement and direction of projection of pointer. $\theta = \omega t$ $\omega = \theta/t$

- Phase angle at time t: $(\omega t+\phi) \rightarrow x = x_m\cos(\omega t+\phi)$
- Phase angle at time t = 0: $\phi \rightarrow$ phase constant $\rightarrow x = x_m\cos\omega t$
- For SHO, phase difference between V & x is 90°, V leads x by 90°
- For SHO, phase difference between a & V is 90°, a leads V by 90°
- For SHO, phase difference between a & x is 180°, a leads x by 180°

Simple Pendulum: Small metallic bob suspended vertically by string.

- Perform SHM for small angle $0^\circ<\theta<5^\circ$
- Tension = $mg\cos\theta$ Restoring force = $mg\sin\theta$
- $a = -gx/l$
- Eq of motion: $d^2x/dt^2 + gx/l = 0$
- $x = x_m\cos(\omega t+\phi)$
- $\omega = \sqrt{g/l}$
- $f = 1/2\pi\sqrt{g/l}$
- $T = 2\pi\sqrt{l/g}$
- If $l = R_e$ → T = 84 mint 36 sec
- If $l = R_e/2$ → T = 1 hour
- Time Period is more on equator than pole.
- Time Period is more at mount-everest than earth.
- When simple pendulum in free fall lift as satellite: $T = \infty$
- Pendulum moving in lift upward with uniform a: $T = 2\pi\sqrt{l/g+a}$
- Pendulum moving in lift downward with uniform a: $T = 2\pi\sqrt{l/g-a}$
- Pendulum in train with accelerating or decelerating acceleration or performing uniform circular motion (a_c): $T = 2\pi\sqrt{l/\sqrt{a^2+g^2}}$
- Pendulum is used as time-keeper.

Physical Pendulum: Rigid body pivoted vertically on a horizontal axis that is not passing through center of mass. Rod mounted with a nail on wall. K = Mgd

- Eq of motion: $d^2\theta/dt^2 + k\theta/I = 0$
- $\theta = \theta_m\cos(\omega t+\phi)$
- Rotational inertial: $I = kT^2/4\pi^2$
- $\omega = \sqrt{k/I}$
- $f = 1/2\pi\sqrt{k/I}$

- $T = 2\pi\sqrt{I/k}$

Torsional Pendulum: Disk suspended horizontally from its center of mass like ceiling fan

- On rotating disk, torque is produce in wire with torsional constant. $\tau = k\theta$
- Eq of motion: $d^2\theta/dt^2 + k\theta/I = 0$
- $\theta = \theta_m \cos(\omega t+\phi)$
- Rotational inertial: $I = kT^2/4\pi^2$
- $\omega = \sqrt{k/I}$
- $f = 1/2\pi\sqrt{k/I}$
- $T = 2\pi\sqrt{I/k}$
- Angular velocity: $V = -\omega\theta$ $\alpha = -\omega^2\theta$
- It is use to find G by cavendish balance.

Damped Oscillator: Oscillator which moves in a resistive medium. $\omega' = \sqrt{\omega^2 - \beta^2}$

- Its amplitude dec due to friction f and become zero. $\beta = f/m$
- Eq of motion: $d^2x/dt^2 + (2\beta)dx/dt + \omega^2 x = 0$
- $x = x_m e^{-ft/2m} \cos(\omega' t+\phi)$
- **Mean Time of Oscillation**: Time interval during which amplitude drops to 1/e of its initial value.

GRAVITATION

Gravity: Force with which earth attracts objects.

- Concept of gravity given by Newton in 1665.
- Gravity of the earth is due to its heavy mass, not due to spin motion.

Law of Gravitation: Two objects always attract each other with a force.

- $F \propto Mm$, $F \propto 1/r^2$, $F_g = GMm/r^2$
- Gravitational Constant: $G = 6.67 \times 10^{-11}\ Nm^2/kg^2$
- G is determine by Cavendish experiment: $G = C\theta r^2/MmL$
- Due to small value of G, we cannot feel gravitational force in daily life.
- F_g is non-contact force/field force.
- Uniform spherical shell exerts no F_g on other mass located inside of it.
- Inverse Square Law: $F \propto C/r^2$ $C = GMm$

Gravitational Force: Force due to gravitational field of earth. F_g

Gravitational Field: Conservative field due to gravity directed towards earth.

Gravitational Field Strength: Force on unit mass due to gravitational field of earth. GFS = F/m = 10N/Kg

Gravitational Acceleration: Acceleration produced due to gravitational force.

- At surface of earth: $g_e = GM/R^2$
- At height h from surface of earth: $g_h = GM/(R+h)^2 = g_e(1 - 2h/R)$
- At depth d inside earth: $g_d = g_e(1 - d/R)$
- For falling objects g → +ve, for going up g → -ve
- g depends on planet's altitude, radius, depth. $g \propto 1/h \propto 1/R \propto 1/d$
- $R_{equator} > R_{pole}$ $g_p > g_{eq}$
- h = R, value of g will decrease to one-forth.
- d = R/2, value of g reduces to one-half.
- At center of earth: g = 0
- $g = \rho\pi 4GR/3$

Earth	9.8	Moon	1.6	Mercury	3.7	Mustari	25.94
Sun	274.2	Venus	8.87	Mars	3.73	K-2	

Gravitational Potential Energy:

- Energy due to position of a body in gravitational field. P.E = mgh

Absolute Gravitational Potential Energy:

- PE at height (r) wrt a point of zero potential.
- Absolute GPE on surface of earth: U = -GMm/R
- Absolute GPE from center of earth: U = -GMm/r
- It is always –ve, means object bound to earth and never escape from it.
- At infinity distance from center of earth U = 0

- Absolute Gravitational Potential: PE/mass = W/m = -GM/R
- Absolute Gravitational Force: $F = -GMm/R^2$
- Absolute Gravitational Field Intensity: $g = -GM/R^2$
- KE = GMm/2r PE = -GMm/r TE = -GMm/2r

Earth: Mass of earth: $M = gR^2/G = 6x10^{24}$ kg

- Radius of earth: $R = 6.4x10^6$ m = 6400 km
- Density of earth: $\rho = 5.5x10^3$ kg/m^3
- Distance b/w earth to sun = $1.5x10^8$ km
- Distance b/w earth to moon = 3,80,000 km
- Moon complete 1 revolution in 27.3 days.
- Light takes 1.3 sec to reach at earth.
- Earth rotates counter clockwise from west to east.
- Polar radius of earth is smaller than equatorial radius by 21 km.
- If distance of earth from sun is halved, then no of days/year will be 129.

Sun: $M = 2x10^{30}$ kg

KEPLER'S LAWS

Kepler Law of Area: Line joining sun and planet sweeps out equal area in equal interval of time.

- $dA/dt = L/2m_p$ = constant

Kepler Law of Period: Square of time period of planet is directly proportional to cube of mean distance b/w sun and planet. $T^2 \propto r^3$

- For all planets: T^2/r^3 = constant
- $T = 2\pi\sqrt{r^3/Gm_s}$

Kepler Law of Period: All planets move in elliptical orbits around sun.

- Equation of motion: $r = L/1+e\cos\theta$
- **Latus Rectum**: L
- **Eccentricity of Orbit**: It describes curvature of orbit. (e)
- For elliptical path e always has some value. For circle $e = 0$
- **Perihelion**: Closest distance of planet from sun. R_p
- **Aphelion**: Farthest distance of planet from sun. R_a
- Position of planet at perihelion (θ=180°): $r_p = L/1+e$
- Position of planet at aphelion (θ=0°): $r_a = L/1-e$
- Semi-major axis for elliptical path: a $L/1-e^2$

Satellite: Object revolving around earth.

- It is free falling object.
- Satellite works on microwaves.
- Speed of satellite wrt to earth is zero.

- Gravitational pull of earth held satellites and provide a_c.
- Minimum altitude for satellite: h = 400 km
- Polar satellite moves from north to south at altitude of 600 km.
- Weightless state in satellites is removed by producing artificial gravity.
- **Artificial Gravity**: Satellite is rotated with frequency. $f = 1/2\pi\sqrt{g/r}$
- **Orbital Radius**: Distance from center of earth to satellite. $r_o = R+h$
- Radius of circular path of satellite: $r^3 = GMT^2/4\pi^2$
- **Constant of Motion**: Angular momentum and total energy of a satellite always remains constant.

Geostationary/Geosynchronous Satellite: Satellites which has same period as earth, take exactly 24 hours to orbit earth.

- Surface of earth is covered by 3 geo-sat each covers a longitude of 120°.
- Communication satellites are geostationary satellites.
- Geostationary satellite altitude: h = 36000 km
- Geostationary satellite orbital radius: r_o = 42300 km

GPS: Global Positioning System is a system of 24 satellites which gives us exact position of any object on earth.

- GPS satellites take 2 revolutions in a day with V = 3.87 km/s

Escape Velocity: Initial velocity required to put any satellite out of the earth gravitational field.

- Velocity with which any object is projected from surface of earth.
- $V_{esc} = \sqrt{2GM/R} = \sqrt{2gR}$ = 11.20 km/s

Critical Velocity:Minimum required theoretical velocity to put/launch a satellite into orbit. $V = \sqrt{gR}$ = 8 km/s $\qquad h<R$

- Time period of a satellite: $T = 2\pi r_o/V_o$ = 5060s = 84 mint

Orbital Velocity/Speed: Velocity with which a satellite is revolving in an orbit around earth.

- $V_o = \sqrt{GM/r_o}$
- If $V_i < V_o$ ⇒ projectile motion
- If $V_i = V_o$ ⇒ uniform circular motion
- If $V_i > V_o$ ⇒ elliptical path
- If $V_i \geq V_{esc}$ ⇒ rectilinear path
- Relation b/w escape and orbital velocity: $V_{esc} = \sqrt{2}V_o$
- Satellite in higher orbits moves slowly while in lower orbits it moves faster.

Height h	0	270 km	400 km	36000 km	$r_o = R+h$
Speed V_o	8 km/s	8 km/s	7.6 km/s	3.1 km/s	$V_o = \sqrt{GM/r_o}$

Rocket: It carry O_2 as burning fuel.

- Upward thrust force is equal to rate of change in momentum.
- Expelling rate of gases: $\alpha = -dm/dt$ (-ve→gas dec)
- Rocket Eq:(speed of rocket at any time) $V = -gt - V_o Ln(m/m_o)$
- Mass of rocket: $m = m_o e^{-V/V_o}$

Free-Fall Motion: Falling down of any object due to pull of earth. $g = 10m/s^2$

- **Real Weight**: Gravitational pull of earth on anybody.
- Vector, N, W = mg
- It is measure by spring balance.
- At the center of earth: W = 0
- **Apparent Weight**: Tension in string on hanging any object. T = ma
- Real weight of a body cannot be zero while apparent weight can be negative, positive or zero.
- **Mass**: Amount of matter in any object.
- Scalar, Kg, m = F/a
- It is measure by beam balance.

Body is at rest/moving with uniform motion	T = W	T = mg	T(W)
Body is moving upward uniformly	T > W	T = mg+ma	T(inc)
Body is moving downward uniformly	T < W	T = mg-ma	T(dec)
Body is free falling (no weight)	T = 0	T = mg-mg	T(zero)

MATTER

Matter: Substance which has mass and occupy space. Solid, liquid, gas, plasma.

Kinetic Molecular Model: Matter consists of a large no of particles.

- Molecules are in continuous motion.
- They have force of attraction among them.

Physics of Solids: Study nature and properties of solid materials.

Solid: Substance which has define shape and volume.

Types of solids: Crystalline, amorphous and polymeric.

Crystalline Solids:

- Materials made of small crystals. They have regular arrangement of molecules and ordered structure.
- **Crystals**: Crystalline material in which atoms and molecules arranged in definite 3D pattern. Quartz, sucrose, diamond and NaCl
- **Point**: Dimensionless and shapeless entity.
- **Lattice**: Collection of infinite no of points in periodic arrangement.
- **Lattice Sites**: Points which are forming lattice.
- **Lattice Constant**: Distance b/w consecutive neighbour sites.
- **Lattice Translational Vector**: Vector used to show direction of lattice constant.
- **Crystal Lattice**: 3D repetition of unit cell/specific pattern in crystalline solid.
- **Unit Cell**: 3D basic geometrical structure of crystal lattice whose periodic repetition form a crystal.
- Size of grain/crystallite: 10^3–10^4A°
- Ionic solids, covalent solids, metallic solids & metals.

Amorphous/Grassy Solids:

- No regular arrangement of atoms.
- Gradually soften at 800°C
- No definite melting point.

Polymeric Solids:

- Intermediate b/w solids of regular/irregular arrangement.
- It consists of polymers (plastic and rubbers).
- 3D structure and massive long chain molecules.
- Polythene, nylon, polystyrene.

BCC: Body centered cube crystal structure. Its unit cell has 9 atoms.

FCC: Face centered cube crystal structure. Its unit cell has 14 atoms.

Isotropic: Homogeneous particles having identical properties in all directions.

Crystalline solids and amorphous solids are isotropic.
Anisotropic: Heterogeneous particles having different properties in different directions. Crystals are anisotropic.
Strength: Ability of a material to withstand with an applied force.
Hardness: Measure of how easily a material can be scratched.
Brittleness: Tendency to break-up suddenly without any extension.
Brittle Materials: Substance which break just after elastic limit. Cast iron, glass, concrete, ceramics, urea formaldehyde, high carbon steel.
Toughness: Tendency to absorb impact well. It is opposite to brittleness.
Ductility: Ability to drawn into thin wires.
Ductile Materials: Substances which show plastic deformation after elastic limit until they break. Gold, Cu, Ti, Pb, wrought iron, low carbon steels.
Stiffness: Ability to resist bending. It is opposite to ductility.
Malleable: Ability to drawn into sheets.
Plasticity: Ability to deform permanently on small force.
Deformation in Solids:

- Change in length, shape or volume of a solid due to external force.
- **Elastic Deformation**: Temporary deformation in material.
- **Plastic Deformation**: Permanent deformation in material.

Stress:

- Force on unit area that change length, volume or shape of anybody.
- Vector, N/m^2, Pa, $[ML^{-1}T^{-2}]$ $\sigma = F/A$
- It always acts from inside of body.
- In compression → +ve and in tension → -ve
- **Tensile Stress**: Stress that change length.
- **Volumetric Stress**: Stress that change volume.
- **Shear Stress**: Stress that change shape.

Strain:

- Measure of deformation in solid.
- ε = change in value/original value
- Dimensionless, no unit.
- **Tensile Strain**: Strain due to tensile stress. $\varepsilon_T = \Delta L/L_o$
- **Volumetric Strain**: Strain due to volumetric stress. $\varepsilon_v = \Delta V/V_o$
- **Shear Strain**: Strain due to shear stress. $\gamma = \Delta a/a = \tan\theta$

Hooke's Law: Under elastic limits, stress $\propto$ strain. K = stress/strain
Elasticity: Ability to regain its original state after removal of force.

- Elasticity of a material decreases on heating.
- **Modulus of Elasticity**: Ratio of stress to strain.

- Dimensionless, N/m^2, Pa
- Young modulus, Bulk modulus, Shear modulus.

Young's Modulus:

- Ratio of tensile stress to tensile strain.
- $Y = FL_o/A\Delta L$
- A thick and a thin, both steel wires have same Young's modulus.
- For perfect plastic material: Y = 0
- For perfect rigid material: $Y = \infty$

Bulk Modulus:

- Ratio of volumetric stress to volumetric strain.
- $B = FV_o/A\Delta V$
- **Compressibility**: Reciprocal of Bulk modulus. C = 1/B

Shear/Rigidity Modulus:

- Ratio of shear stress to shear strain.
- $G = F/A\tan\theta$

Stress-Strain Curve:

- Graph b/w stress and strain that explains different states of deformation.
- **Proportional Limit**: stress $\propto$ strain. Hooke's law follow. σ_p
- **Ultimate Tensile Stress**: Max stress with which a material can withstand. σ_m
- **Elastic Limit**: Max stress up to which a body returns to its original shape after removal of force. σ_e
- **Yield Point**: Point beyond that permanent deformation occurs in material.
- **Fracture Stress**: Stress at which material breaks. σ_f

Strain Energy:

- P.E store in a body due to elastic deformation.
- Gain in P.E by molecules is due to their displacement from mean position.
- Work done = Area of Δ = $\frac{1}{2}FL = \frac{1}{2}EA\Delta L^2/L_o$

Liquids: Substance which has define volume but no regular shape.

Density: Mass in unit volume. $\rho = m/v$, Kg/m^3, $1m^3 = 1000L$

Relative/Specific Density: ρ of substance/ρ of water at 4°C.

Water=1000kg/m³	Ice = 920kg/m³	Petrol = 800kg/m³	Air = 1.3kg/m³

Pressure: Force on unit area. P = F/A, N/m^2, Pa

- **Static Pressure**: P due to static fluid.
- **Dynamic Pressure**: P due to dynamic fluid.
- Pressure in liquid with depth: $P = P_o + \rho gh$ ($P \propto$ depth)
- **Atmosphere**: Layer of air around earth.
- **Atmosphere Pressure**: Pressure due to weight of air around earth.

- Pressure on sea level: $P_o = 101325Pa$
- Pressure in air with altitude: $P = P_o e^{-h/a}$ ($P \propto 1/h$)
- $h = 0 \rightarrow P = P_o$ $h = \infty \rightarrow P = 0$
- **Barometer**: Instrument used to measure pressure. Mercury Barometer
- Air also exerts 101325N force on area of $1m^2$ means 1Pa pressure.
- 76cm (0.76m) long column of mercury also exerts 101325N force.
- To make water barometer, we need 10.34m long tube.

Pascal's Law: Within a closed pot, pressure will be constant everywhere.

- It is applicable on liquids and gases.
- Vehicles break system, hydraulic lift, hydraulic press, hydraulic jack.
- **Force Multiplier/Hydraulic Lift**: $F_o = F_i(A/a)$

Archimedes Principle: Up-thrust force acting on a body in liquid is equal to weight of liquid, displaced due to size of body. $F_{up} = \rho gV$

- It is applicable on liquids and gases.
- Density of object sink in liquid: $d = \rho(W_{air}/W_{air}-W_{water})$
- **Principle of Floatation**: Submarines float/sink by ejecting/filling water into tanks.
- Body float $\rightarrow F_{up} \geq W_{Body}$ ($\rho_{body} < \rho_{liquid}$)
- Body sink $\rightarrow F_{up} < W_{Body}$ ($\rho_{body} > \rho_{liquid}$)

- It is only valid on slowly upward moving spherical objects having small radius r.
- **Poiseuille's Law**: Mass flux of fluid flowing under pressure. $M=\rho\pi PR^2/8\eta L$

Terminal Velocity: Maximum uniform velocity attained by body when drag force becomes equal to its weight.

- At V_T $F_d = W$ $(F_{net} = 0)$
- $V_T = mg/6\pi\eta r = 2\rho gr^2/9\eta$ $(V_T \propto r^2)$
- At V_T body is in dynamic equilibrium and follows Newton's 1st law.
- Acceleration decreases before achieving terminal velocity.
- Lighter body attains the terminal velocity very soon but having low value.
- Heavier body attains the terminal velocity later but having higher value.

Surface Tension: Surface PE per unit area of surface. $\gamma = \Delta U/\Delta A = F/L$

- Property of liquid with which surface behaves as a stretched membrane & can support small objects placed on it. $\gamma \propto 1/T$
- Surface tension is due to intra-molecular forces among molecules.
- J/m^3, N/m, H_2O = 0.073N/m, Hg = 0.487N/m
- Razor, blade, leaves and insects float due to γ.
- Edges of a glass become round on heating due to γ.
- Liquids tends to minimizes its surface area due to γ.
- Rize & fall of liquid in capillary tube is due to γ. $\gamma = \rho ghr/2\cos\theta$

Laminar/Streamline Flow: If every particle that passes through a particular point moves along exactly the same smooth path followed by previous particle passing through that point.

- It is steady, regular and non-noisy flow.
- Different streamlines cannot cross each other.
- Pressure, density and velocity remain constant.

Turbulent/Eddy/Chaotic Flow: Non-steady, irregular and noisy flow. Smoke

- Pressure, density and velocity is not constant.
- **Critical Velocity**: Velocity at which laminar flow changes to turbulent flow.
- **Ideal Fluid**: Fluid having laminar flow, non-viscous, incompressible.

Equation of Continuity: Rate of volume flow is constant. $V/t = AV = \text{constant}$

- For steady state flow, mass flow rate into volume, must be equal to mass flow rate out of volume.
- If there is no source/sink, then mass in any volume remains constant.
- $A_1V_1 = A_2V_2$ $AV = \text{Constant}$
- $V \propto 1/A \Rightarrow V \propto 1/r^2 \Rightarrow V \propto 1/d^2$
- Equation of continuity is based on law of conservation of mass.

Bernoulli's Equation: (P+K.E+P.E)/Volume = constant

- Relationship b/w pressure, flow speed and height for flow of an ideal fluid.
- It is based on law of conservation of energy.
- It is equation for motion of fluid.
- $P_1 + ½\rho V_1^2 + \rho gh_1 = P_2 + ½\rho V_2^2 + \rho gh_2$
- $P + ½\rho V^2 + \rho gh = constant$ (for horizontal pipes)
- $P = PV \rightarrow$ Energy due to pressure per unit volume
- $½\rho V^2 = ½mV^2 \rightarrow$ K.E per unit volume
- $\rho gh = mgh \rightarrow$ P.E per unit volume
- Static Pressure: $P + \rho gh$ Dynamic Pressure: $½\rho V^2$
- Static pressure always apply even if $V = 0$
- According to Bernoulli Eq: $V \propto 1/P$
- Fluid should be steady, in-compressible, non-viscous, and non-rotational.
- It is used in plumbing system, hydroelectric generation, flight of aeroplane, reverse swing, filter pump, engine carburetor.

Thrust on Rocket: Up-ward thrust force acting on rocket is due to expelling of gases. $F = 2A(P_2 - P_1)$

- Cross sectional area of nozzle (A) with pressure (P_1), chamber pressure (P_2)

Torricelli's Theorem: $V_e = \sqrt{2gh} = \sqrt{2g(h_2 - h_1)}$ (for ideal fluid)

- **Speed of Efflux**: Speed with which fluid flow out of any hole.
- In fact $V_e < \sqrt{2gh}$ due to friction and viscosity of liquid.

Venture-meter: Device used to measure rate of flow of liquid in a pipe.

- $V_e \propto \sqrt{h}$ ⇒ $V_1/V_2 = \sqrt{h_1}/\sqrt{h_2}$
- $T \propto \sqrt{h}$ ⇒ $T_1/T_2 = \sqrt{h_1}/\sqrt{h_2}$
- Pressure in horizontal pipe: $P = ½\rho(V_2^2 - V_1^2)$
- Net thrust on wings of birds and aero plane: $F = ½\rho A(V_2^2 - V_1^2)$

Aero-Foils (Dynamic Lift): Bodies which are so shaped/made that flow of fluid produces a force perpendicular to them.

- Fluid flows faster over top surface than bottom which decreases pressure above then bottom and hence body is pushed upward. (dynamic lift) bcz air moves from high pressure zone to fill low pressure zone.
- Different pressure on opposite sides of ball, creates swing in it.

Blood Flow Meter: Instrument used for measurement of blood pressure.

- **Systolic Pressure**: Higher pressure of blood for normal human is 120 torr.
- **Diastolic Pressure**: Lower pressure 75–80 torr.
- If external pressure = systolic pressure, blood flow with high speed but turbulent flow.

- If external pressure < diastolic pressure, blood flow with low speed but laminar flow.

WAVES (Sound)

Wave: Disturbance in medium.

- Cooperative motion of a collection of particles.
- It carry energy and momentum.
- It cannot transfers matter and mass.

Crest: Part of wave above of mean position.
Trough: Part of wave below of mean position.
Compression: Portion of medium where particles are overcrowded.
Rarefaction: Portion of medium where particles are least overcrowded.
Visible Waves: Water waves, String waves.
Invisible Waves: Sound waves, tv/radio waves, matter waves.
Matter Waves: Waves associated with moving particles.

- These are medium independent waves. de-broglie waves

Mechanical Waves: Waves produced by mechanical work.

- These are medium dependent waves.
- Their motion is governed by newton's laws. Sound, string, water waves.

Electromagnetic Waves: Waves produced by vibrating charges.

- These are medium independent waves.
- Their motion is governed by Maxwell's equation. Radio, heat, light waves.

Periodic Waves: Waves of same amplitude and frequency which are produced by continuous and regular disturbance in any medium, which are repeated in regular interval of time.
Progressive/Travelling Waves: Waves carry energy moving away from one place to another in space. Waves on string and water.
Transverse Waves: Oscillation of particles of medium is perpendicular to direction of propagation of wave. Having crest and trough. EM wave, light wave tv radio wave and mobile signals.
Longitudinal Waves: Oscillation of particles of medium is parallel to direction o propagation of wave. Having compression and rarefaction. Spring waves, sounc waves, seismic waves.

- Mechanical waves move faster in solids > liquids > gases.
- EM waves move faster in vacuum > air > liquid > solid.

Sinusoidal Wave: Eq of sine-wave traveling along +x-axis. $Y(x,t) = Y_m \sin(kx-\omega t)$

- Eq of sine-wave traveling along -x-axis. $Y(x,t) = Y_m \sin(kx+\omega t)$

Wave Number: $K = 2\pi/\lambda$
Wave Speed: Distance traveled by wave per unit time. $V = \sqrt{F/\mu}$

- Transverse velocity of wave particle: $V = -\omega Y$

- Transverse velocity of wave particle: $a = -\omega^2 Y$

Wavelength: Distance b/w two successive particles which are exactly in same state of vibration.

Time Period: Duration which a wave take to passes through a point.

Amplitude: Maximum displacement from mean position.

Intensity of Wave: Rate of energy transmitted per unit area placed prepend to direction of propagation of waves. $I = (E/t)/A = P/A = \mu V\omega^2 Y_m^2/2A$

Frequency of Waves: No of waves passing certain point in unit time. $V = f\lambda$

- Frequency in sound determines pitch while in light determines color.

Path Difference: Difference b/w lengths of path followed by two waves.

- Phase-diff is equal to wave-no times of path-diff: $\Delta\phi = \frac{2\pi}{\lambda}pd$
- Phase velocity: $V = \omega/K$

Power of Wave: $\langle P\rangle = \frac{1}{2}\mu V\omega^2 Y_m^2$

Wave Equation: $\frac{\partial^2 Y}{\partial x^2} = \frac{1}{V^2}\frac{\partial^2 Y}{\partial t^2}$

Reflection of Waves:

- When waves is reflected from denser medium, there is a phase change of 180° (π radian) but when waves is reflected from rare medium, if suffers no phase change.
- **Echo/Resound**: When d≥17m, then reflected sound waves will be reheard after 0.1s of original sound.
- **Reverberation**: When d<17m, then reflected sound waves will be received before 0.1s of original sound. It will not be distinguished due to multiply reflection and cause confusion.

Refraction of Waves:

- When transverse waves enters from rare to denser medium, then its speed increases and frequency (λ dec) remain same and vice versa.
- When longitudinal waves enters from rare to denser medium, its speed and wavelength increases and frequency remain same and vice versa.

Sound:

- Vibrating body produces sound.
- Sound waves are longitudinal having 3 dimensions.
- Sound waves can do reflection, refraction, diffraction and interference.
- Sound waves not do polarization bcz these are longitudinal.
- **Loudness**: Difference in loud and faint sound. It depends on amplitude. $L \propto A \propto$ amplitude $\propto$ 1/distance
- **Sound Level**: Difference in loudness of 2 sounds. $\Delta L = 10\log I/I_o = 10\log I/10^{-12}$ (dB)

Bell: Loudness of sound having 10 times move intensity than ref intensity.

- **Pitch**: Difference in shrill and grave sound. It depends on frequency. $f \propto P$
- **Quality**: Check difference of pitch and loudness at a time.
- **Intensity**: Transfer of sound energy. $I = (E/t)/A$ (w/m^2)
- For human intensity level: $10^{-12} w/m^2 \rightarrow 1 w/m^2$
- **Reference Intensity**: Intensity of faintest audible sound. $I_o = 10^{-12} w/m^2$
- Reference intensity has zero bell level.

Speed of Sound in Air:

- At 0°C speed of sound in air is 330m/s
- At 819°C speed of sound in air becomes double.
- Speed of sound in liquid is 1400m/s.
- Speed of sound in solid is 5000m/s.
- Newton say propagation of sound wave through air is an isothermal process and he apply Boyle's law to find its speed. PV = constant
- $V_{iso} = \sqrt{E_Y/\rho}$
- Young modulus of elasticity: Ratio of stress to linear strain. $E_Y = P/(\Delta L/L)$
- Sound waves travel in form of compressional wave in gases.
- $V_{iso} = \sqrt{E_B/\rho}$
- Bulk modulus of elasticity: Ratio of stress to volume strain. $E_B = P/(\Delta V/V)$
- Newton proved that at STP: E_B = Pressure
- $V_{iso} = \sqrt{P/\rho} = 281 m/s$
- Theoretical value obtain 281 m/s which is 16% less than actual value.
- According to Laplace, propagation of sound wave through air is an adiabatic process bcz air is a thermal insulator and Boyle's law is not applicable. PV^{γ} = constant
- $V_{adi} = \sqrt{\gamma P/\rho} = 333 m/s$

  $\gamma = C_p/C_v = 1.42$ for air
- $V_{Lap} = \sqrt{2} V_{New}$
- Speed of sound in ideal gas: $V = \sqrt{\gamma RT/M}$ (M → molarity)
- Speed of sound with change of temperature: $V_t = V_o + 0.61t$
- For each 1°C rise in temp, speed of sound increases by 0.61m/s or 61cm/s.
- speed in H_2 = 4(speed of O_2)

Dependence of Speed of Sound:

- $V \propto$ moisture
- $V \propto \sqrt{T}$

- $V \propto 1/\sqrt{\rho}$
- Pressure has no effect on speed of sound.

Superposition: Overlapping of waves.

- **Principle of Superposition**: When waves overlap, the amplitude of resultant wave is vector sum of amplitude of individual waves.
- $Y = Y_1 + Y_2 + Y_3 + \ldots\ldots\ldots\ldots + Y_n$.
- It is only applicable for equal or comparable amplitudes.
- When waves overlap, then V, λ, f and phase are not affected.
- Applications of superposition: Interference, beat, standing waves.

Interference:

- Overlapping of identical waves of same frequency (λ) from a coherent sources passing through same medium in same time/direction.
- It is a superposition phenomenon in space.
- Resultant of two waves: $Y(x,t) = [2Y_m\cos(\Delta\phi/2)]\sin(kx-\omega t-\phi')$
- **Constructive Interference**: Increase in amplitude of resultant wave, when two coherent waves arrive at same place in same time in phase. $I \to$ max
- Crest meet with crest and trough meet with trough.
- Echoing zone is a region of constructive interference.

Path Difference	*Phase Difference*
pd = mλ	Δφ = m(2π)
pd = 0, 1λ, 2λ, 3λ, 4λ …………	Δφ = 0, 2π, 4π, 6π, 8π ………
m = 0, 1, 2, 3, 4 ……..	m = 0, 1, 2, 3, 4 ……..

- **Destructive Interference**: Decrease in amplitude of resultant wave, when two coherent waves arrive out of phase at same place in same time. $I \to 0$
- Crest meet with trough and trough meet with crest.
- Silence zone is a region of destructive interference.

Path Difference	*Phase Difference*
pd = (m+½)λ	Δφ = (m+½)π
pd = 1λ/2, 3λ/2, 5λ/2, 7λ/2 ……….	Δφ = 1π, 3π, 5π, 7π ………
m = 0, 1, 2, 3, 4 ……..	m = 0, 1, 2, 3, 4 ……..

Beat: Periodic alternations of sound b/w max and mini loudness.

- It is a superposition phenomenon in time.
- Waves have slightly different frequencies and in same direction/medium.
- It is interference of longitudinal waves.
- Resultant wave has time varying amplitude.
- $\Delta P(t) = [2\Delta P_m\cos\omega_{amp}t]\sin\omega_{ave}t$
- For beating no of frequency < 10Hz

- **Beat Frequency**: No of beats heard per second. $f_b = \Delta f$
- Max beat frequency for a normal ear is 10Hz.
- It produces variety of sounds.
- Tuning of musical instruments.
- Finding unknown frequency of sound.

Standing/Stationary Waves:

- Superposition product of two identical waves of same frequency (λ) moving in opposite direction in same medium.
- Both constructive and destructive interference takes place in stationary waves with displacement: $Y(x,t) = [2Y_m \sin kx]\cos\omega t$
- It obeys quantization of frequency.
- **Node**: Points of destructive interference where amplitude is mini.
- **Antinode**: Points of constructive interference where amplitude is max.
- Energy is trapped b/w nodes so they not allowed to transmit energy.
- All particles except nodes perform SHM.
- Node remains at rest and fixed.
- Antinode oscillates with maximum displacement.
- There are no two constructive nodes or antinodes.
- Distance b/w two consecutive node and antinode is $\lambda/2$
- Distance b/w node and antinode is $\lambda/4$
- Location of node points: $x = 0, \lambda/2, \lambda, 3\lambda/2, 2\lambda, 5\lambda/2$ ....
- Location of antinode points: $x = \lambda/4, 3\lambda/4, 5\lambda/4, 7\lambda/4$ ....
- Energy store at antinode is P.E while at equilibrium is K.E
- At node, displacement/density → min, strain/pressure → max
- At antinode, displacement/density → max, strain/pressure → min

Standing Waves in Stretched String/Spring:

- At fixed end of string node is formed.
- At free end of string antinode is formed.
- If string is fixed from both ends then: $N = A+1$
- If string is free from one end then: $N = A$
- Speed of string waves: $V = \sqrt{T/\mu} = \sqrt{F/\mu}$ (μ = mass/length)
- **Harmonics**: No of loops or No of half λ
- **Fundamental/Basic Frequency**: Lowest characteristic frequency at which 1st stationary wave is formed. It is also called 1st harmonics.
- $f_1 = 1/2L\sqrt{T/m}$
- Frequency of string waves: $f_n = nf_1$
- It obeys quantization of frequency.

- **Overtones/Harmonics**: Frequencies above fundamental frequency. f_2, f_3
- When string vibrates in more loops, f increases while λ decreases.
- Speed of stationary wave is independent of no of loops.

Standing Waves in Air Columns:

- Sound waves also formed stationary waves in air column.
- **Organ Pipe**: It produces sound by mean of vibrating air column.
- **Open Organ Pipe**: Open at both ends. It produces shrill sound.
- Open end is a seat of antinodes.
- No phase change at open end.
- Fundamental frequency of open organ pipe: $f_1 = V/2L$
- All harmonics are present in open organ pipe. $f_n = nf_1$
- **Closed Organ Pipe**: Closed at one end. It produces grave sound.
- Close end is a seat of nodes.
- Phase change of 180° at close end.
- Fundamental frequency of close organ pipe: $f_1 = V/4L$
- Only odd harmonics are present in close organ pipe. $f_n = (n+½)f_1$
- Fundamental frequency of open pipe is double of closed pipe. $f_{1O} = 2f_{1C}$
- No of harmonics in open pipe is double of in closed pipe.
- Open end behaves as antinode while closed end as node.

Doppler's Effect:

- Apparent change in pitch (frequency) due to relative motion of source of sound waves and observer/listener.
- John Doppler in 1845
- V: Velocity of sound. $V = f\lambda$
- f: Frequency of sound. $f = V/\lambda$
- μ_o: Velocity of observer
- μ_s: Velocity of source

Relative Motion	*Apparent Freq*	*Pitch*
listener moving towards stationary source	$f_a = f(V+\mu_o/V)$	inc
listener moving away from stationary source	$f_a = f(V-\mu_o/V)$	dec
source is moving towards stationary listener	$f_a = f(V/V-\mu_s)$	inc
source is moving away from stationary listener	$f_a = f(V/V+\mu_s)$	dec
listener/source both are moving towards each other	$f_a = f(V+\mu_o/V-\mu_s)$	inc
listener/source both are moving away from each other	$f_a = f(V-\mu_o/V+\mu_s)$	dec
listener is chasing a moving source in same direction	$f_a = f(V+\mu_o/V+\mu_s)$	
source is chasing a moving listener in same direction	$f_a = f(V-\mu_o/V-\mu_s)$	

- When distance b/w source and listener decreases, frequency increases and pitch of sound is high.
- When distance b/w source and listener increases, frequency decreases and pitch of sound is low.
- Light also follow doppler effect.

Applications of Doppler's Effect:

- In sonar system.
- Bats use for traveling.
- Reflection of radar waves from an aero plane.
- Determine velocity of any star wrt earth.
- To monitor blood flow in arteries.

Audible Frequency:

- Frequency of sound which can be heard by human ear. 20Hz–20kHz
- Ultrasonic: $f > 20$ kHz
- Infrasonic: $f < 20$ Hz
- Ultrasonic is used in cavitation, drugs, medical diagnosis.

LIGHT

Light: It is EM waves in which electric and magnetic fields vibrate perpendicular to the direction of propagation of waves. (Maxwell, 1873)

- **Dual Nature**: Light has dual nature. Sometimes it behaves like wave & sometimes like particle.
- Reflection, refraction, diffraction, interference and polarization of light, young double slit exp shows wave nature of light.
- Photoelectric effect and compton effect shows particle nature of light.
- Albert Einstein suggested that light has dual nature.
- Thomas Young discovered wave nature of light.
- Einstein discovered the particle nature of light.
- James Clerk Maxwell discovered electromagnetic nature of light.
- Louis de-droglie discovered wave nature of electron.
- **Physical Optics**: Study of wave nature of light.
- **Coherent Light**: Light of same amplitude (f) and zero phase difference.
- **Monochromatic Light**: Single color light having single wavelength.
- **Refractive Index**: Ratio of speed of light in vacuum to speed of light in material. $n = c/v$
- **Optical Path**: Product of refractive index of medium and distance travel by light. $x = nd$

Wave Front: Points of light lying on a surface having same state of vibration and phase.

- **Spherical Wave Front**: A surface of sphere having constant phase because light travels in 3D.
- **Circular Wave Front**: A surface of circle having constant phase or a portion of the spherical wave front.
- **Plane Wave Front**: A straight portion of special wave front when we move away from source.
- **Rays**: Arrows drawn from source to indicate the direction of wave front. They are always perpendicular to the wave fronts.
- Distance b/w two consecutive wave fronts = λ

Huygens's Principle:

- It explains wave propagation.
- Shape and position of new wave front can be predicted from already known wave front.

- Every point of a wave front may be considered as a source of secondary spherical wavelet, which propagates in forward direction with a speed equal to speed of propagation of the wave.
- New position of wave front can be found by drawing a tangential plane of secondary wavelet.
- Radius of new wave front sphere = $C\Delta t$

Speed of Light: In air $C = 3 \times 10^8$ m/s (H$_2$O = 2.3×10^8 m/s, glass = 2×10^8 m/s)

- 1st attempt made by Galileo.
- 1st time accurately measured by Michelson. C = 16fd
- f → frequency of rotation of octagonal mirror.
- d → distance b/w plane mirror and octagonal mirror.

Reflection of Light:

- Phenomenon of reflection were studied by Alhozen.
- Turing back of light in same medium on striking surface of other medium.
- **1st law**: Incidence ray, reflected ray and normal lies in same plane.
- **2nd law**: Angle of incidence is equal to angle of reflection. $\hat{\imath} = \hat{r}$
- When wave travels from a medium of lower n to medium of higher n it undergoes a phase change of 180° after reflection.
- When waves travels from a medium of higher n to medium of lower n it suffers no phase change after reflection.
- **Total Internal Reflection**: On entering from denser to rare medium, if $\hat{\imath} > \hat{C}$ then light rays completely reflected into same medium.
- **Critical Angle**: Light going from rare to denser medium, angle of $\hat{\imath}$ for which angle of $\hat{r}$ is 90°

Refraction of Light:

- Phenomenon of refraction were studied by Alhozen.
- Bending of light from its straight path on entering in any other medium.
- **1st law**: Incidence ray, refracted ray and normal lies in same plane.
- **2nd law**: Sine of both angles are equal. $\sin\hat{\imath} = \sin\hat{r}$
- **Snell's Law**: Ratio of angle $\hat{\imath}$ to angle $\hat{r}$ is a constant. $\sin\hat{\imath}/\sin\hat{r} = n$

Interference of Light:

- Overlapping of two identical light waves of same frequency from a coherent sources passing through the same medium in the same time/direction.
- **Conditions for Light to Interference**: Coherent light, monochromatic light, same frequency/amplitude, small path diff, linearly super-positioned.
- **Fringes**: Colorful band of max and mini intensity due to interference.
- Maxima: Bright fringe of max intensity due to constructive interference.

- Minima: Dark fringe of mini intensity due to destructive interference.
- **Constructive Interference**: Increase in amplitude of resultant wave, when two coherent waves arrive at same place in same time in phase. $I \rightarrow$ max
- Crest meet with crest and trough meet with trough.
- In result a bright fringe is produced, having max intensity of light.

Path Difference	*Phase Difference*
$\Delta d = m\lambda$	$\Delta\phi = (m)2\pi$
$\Delta d = 0, 1\lambda, 2\lambda, 3\lambda, 4\lambda$	$\Delta\theta = 0, 2\pi, 4\pi, 6\pi, 8\pi, 10\pi$ ....

- **Destructive Interference**: Decrease in amplitude of resultant wave, when 2 coherent waves arrive out of phase at same place in same time. $I \rightarrow$ mini
- Crest meet with trough and trough meet with crest.
- In result a dark fringe is produced, having mini intensity of light.

Path Difference	*Phase Difference*
$\Delta d = (m+½)\lambda$	$\Delta\phi = (m+ ½)2\pi$
$\Delta d = \lambda/2, 3\lambda/2, 5\lambda/2, 7\lambda/2$..........	$\Delta\theta = 1\pi, 3\pi, 5\pi, 7\pi, 9\pi$ ....

- If pd remains constant, then interference pattern will be stationary otherwise it will change continuously.
- From ordinary light we cannot get interference pattern bcz phase change is rapid and irregular.
- Distortion of picture on tv screen takes place when waves reflected from aircrafts and tv signals interfere destructively.

Young's Double Slit Experiment:

- It is based on principle of wave front division of same monochromatic light (Thomas Young 1801)
- Let two slits, emerging light, which interfere on the screen.
- Distance b/w both slits = d
- Distance b/w slits and screen = L
- Distance from center of screen to any fringe = y
- Path difference = $d\sin\theta$ (m = 0, ±1, ±2, ±3, ±4)
- Constructive interference/bright fringe: $d\sin\theta = m\lambda$
- Destructive interference/dark fringe: $d\sin\theta = (m+½)\lambda$
- Position of bright fringe: $Y_B = m\lambda L/d$

m	0	1	2	3	4	5
Y_B	0	$1\lambda L/d$	$2\lambda L/d$	$3\lambda L/d$	$4\lambda L/d$	$5\lambda L/d$
Order No	zero	1st	2nd	3rd	4th	5th

- Position of dark fringe: $Y_D = (m+½)\lambda L/d$

m	0	1	2	3	4	5

Y_D	$1\lambda L/2d$	$3\lambda L/2d$	$5\lambda L/2d$	$7\lambda L/2d$	$9\lambda L/2d$	$11\lambda L/2d$
Order No	1st	2nd	3rd	4th	5th	6th

- **Fringe Spacing/Width**: Separation b/w 2 consecutive bright/dark fringes. $\Delta Y = \lambda L/d$
- Bright and dark fringes are of equal width.
- Fringes width for material of refractive index: $\Delta Y = \Delta Y/n$
- If young double slit experiment setup is immersed in water, then fringes width decreases because wavelength decreases.
- If we use white light in young double slit experiment, we obtain colored interference.
- **Angular Separation**: $\Delta\theta = \lambda/d$
- Resultant of waves in form of EF. $E = E_\theta \sin(\omega t+\beta)$
- Intensity of resultant wave. $I = 4I_o\cos^2(\phi/2)$
- Amplitude of resultant wave. $E_\theta = 2E_o\cos\beta = 4A^2\cos^2(\phi/2)$

Interference in Thin Films:

- **Thin Film**: Refracting medium having thickness ≈ λ of light.
- Oil film: Layer of oil on water surface.
- Soap film: Soap bubbles.
- Air film: Bands of air.
- **Uniform Thin Film**: Whose thickness is uniform and gives parallel sets of fringes.
- **Wedge Shape Film**: Whose thickness is zero at one end and then increase uniformly towards other end.
- Thinnest part of wedge film shaped is always dark, due to additional path diff of $\lambda/2$, caused by phase reversal at denser medium.
- When exposed to white light, thin film produces colorful pattern due to interference. Soap bubble
- When exposed to monochromatic light, thin film produces bright and dark fringes due to interference. Newton ring
- Constructive interference: $pd = (m+½)\lambda_n$ $\Delta\phi = (m+½)\pi$
- Destructive interference: $pd = m\lambda_n$ $\Delta\phi = (m)2\pi$
- Thickness of film during constructive interference: $2t = (m-½)\lambda_n$
- Thickness of film during destructive interference: $2t = m\lambda_n$
- Light wavelength in air is λ and in thin film is λ_n and width is d. $\lambda = n\lambda_n$

Newton's Rings:

- Wedge shape thin film is used in newton rings experiment.
- Monochromatic source: To produce black and white fringes.

- Beam splitter: Semi silvered glass plate reflect rays towards air film and microscope.
- Plano convex lens: Large focal length.
- Flat glass plate: Reflect light rays as denser medium.
- Microscope: To view pattern.
- Air b/w glass plate and lens acts as a thin film.
- Point of contact b/w glass plate and lens have thickness of air = 0
- Newton rings are concentric circular fringes.
- Bright circles are due to constructive interference. $\Delta d = (m+½)\lambda$
- Dark circles are due to destructive interference. $\Delta d = m\lambda$
- Point of contact is always dark, due to additional path diff of $\lambda/2$, caused by phase reversal of 180° at denser medium. (flat glass plate)
- Radius of bright fringe: $r_B = \sqrt{(m+\frac{1}{2})\lambda R}$
- Radius of bright fringe: $r_D = \sqrt{m\lambda R}$

Michelson Interferometer:

- A precise length measuring instrument.
- It shows 15531635 wavelengths of red Cd light = 1m
- It is used to test optical instrument, to measure distance and ref index.
- It is based upon principle of division of wave front.
- 1st mirror: M_1 (movable and have micrometer)
- 2nd mirror: M_2 (fixed)
- Beam splitter: G_1 (slightly silvered glass plate)
- Compensator: G_2 (non-silvered glass plate)
- Telescope: Observe interference pattern.
- Constructive interference: $d = m\lambda$
- Destructive interference: $d = (m+½)\lambda$
- If mirror is moved by distance $\lambda/2$ (path-diff λ) then a bright fringe will replace next bright fringe or a dark fringe to next dark fringe.
- If mirror is moved by distance $\lambda/4$ (path-diff $\lambda/2$) then bright fringe will replace next dark fringe or a dark fringe to next bright fringe.
- Wavelength of light through michelson's interferometer: $\lambda = 2L/m$
- L → distance in mm through which movable mirror is moved.
- m → total no of fringes pass before eye.
- Michelson and Morley proves by Michelson interferometer that ether is not present in space.

Diffraction of Light:

- Bending of light waves into geometrical shape around corners of obstacle.

- Spreading of light into region behind an obstacle.
- Redistribution of light intensity resulting in dark and bright fringes.
- Diffraction occurs in all types of waves.
- X–Rays are not diffracted by slit but diffracted by crystals.
- Clear shadow of object is not casted due to diffraction.
- We get light in rooms/halls due to diffraction.
- Size of obstacle/slit ≈ wavelength of light.
- Smaller is size of obstacle higher is degree of diffraction.
- **Fraunhofer Diffraction at a Single Slit**: Diffraction of light produced by narrow slit when plane light waves are incident normally on the slit and light waves emerging from slit are also plane.
- Destructive Interference for m^{th} order from slit of width d: $d\sin\theta = m\lambda$
  Diffraction Equation: $d\sin\theta = m\lambda$
- All fringes do not have same intensity because $I \propto (\text{Amp})^2$
- At center of screen there is a bright spot and then alternate minima & maxima on either side of screen exist.
- Intensity and width of bright fringes is maximum at center of screen but decreases as we move away from center of screen.
- Intensity and width of dark fringes is minimum at center of screen but increases as we move away from center of screen.
- Intensity of fringe: $I_0 = I_m[{}^{\sin\phi/2}/_{\phi/2}]^2$
- Mini intensity: $\Delta\phi = m(2\pi)$
- Max intensity: $\Delta\phi = (m+½)\pi$
- Angular width of maxima: $\delta\theta = \lambda/Nd\cos\theta$
- Diffraction proves λ of light < λ of sound.

Interference	*Diffraction*
Superposition of few secondary wavelets	Superposition of large no of secondary wavelets
Fringes are equal in size	Wider near object and then thinner
Fringes are equally spaced	Become thinner and thinner as go away
Points of destructive interference are perfectly dark	Point of mini intensity are perfectly dark

Diffraction Grating:

- A transparent glass or plastic plate on which a large no of parallel equally spaced opaque lines are drawn.
- Length → 2-3cm & width → 2-3mm
- It has about 400-5000 lines per cm.

- Lines are opaque while separation b/w them is transparent that acts as slits.
- **Grating Element**: Separation b/w two slits. d = length/no of lines = L/N
- Grating Equation: $d\sin\theta = m\lambda$
- **Dispersion**: Space to till a bright or dark fringes is spread over.
- Angular separation b/w spectral line per unit wavelength interval.
- $D = m/d\sin\theta = \Delta\theta/\Delta\lambda$ rad/m
- **Resolving Power**: Ability of a grating to separate two wavelengths of light. $R = Nm = \lambda/\Delta\lambda$

Diffraction of X-rays by Crystals:

- Solid crystals behaves as natural diffraction gratings.
- For diffraction: size of slit ≈ wavelength of light
- X-Rays are not diffracted by slit but diffracted by crystals.
- 1913, Max Von Laue says atomic layer separation of solid NaCl (10^{-10}m) so x-rays can be diffracted from it.
- Max Von Laue pattern is in form of bright and dark spots.
- **Bragg's law**: $2d\sin\theta = m\lambda$ (d:atomic layer spacing,θ:angle of diffraction)
- **Lattice Constant**: Inter atomic layer distance.
- Structure of hemoglobin, DNA, crystals is find through x-Ray diffraction.

Polarization of Light:

- Human eye is sensitive to electric vectors only.
- Confinement of electric vibrations of light into a single plane of vibration.
- Polarization is property of transverse waves only. EM waves
- Metallic surfaces cannot cause polarization
- Dielectric surfaces can produce polarization.
- **Polarizer**: Materials which produces polarization. Tourmaline crystals
- **Polaroid/Polaring Sheet**: Commercial polarizing material. (polarizer)
- **Polarized light**: Beam of light having vibration along one particular direction.
- **Un-polarized Light**: Both EF/MF vibrations are in wave.
- **Birefringence/Double Reflection**: Splitting of ray into two rays (P/B) after transmitting through a birefringent material. Calcite
- **P**-rays follow snell's law and B-ray does not follow it.
- **Plane of Polarization**: Plane determine by direction of propagation and electric vectors of light.
- **Optical Activity**: Rotation of vibration of transmitted polarize light.
- **Polari meter**: Instrument used to measure concentration of solution.

- **Polarization by Selective Absorption**: It is done by any polaroid crystals (dichroic substance) made up of tiny crystals of quinine iodosulphate.
- Quinine iodosulphate transmit all vibrations parallel to its crystallographic axis while absorbs all remaining vibrations.
- **Polarization by Reflection**: When un-polarized light falls on glass or water reflected light is partially plane polarized.
- **Angle of Polarization**: Angle of incidence ray at which angle of reflection becomes 90° to angle of refracted ray. Polaring angle → θ_p
- **Brewster's Law**: If reflected light wave is completely polarized, then angle b/w reflected and refracted light is 90°. $\tan\theta_p = n$
- **Application of Polarized Light**:
- Determine sugar in blood and urine.
- Curtain-less window
- To enhance effect of clouds and sky in photography.
- Polarized sun glasses are used to reduce glare in sunny days due to reflection of polarized light from water and roads.
- Safe driving of car is possible at night due to polarizing headlight and using polarized light viewer.
- When glass, polythene and plastic are stressed, they become doubly refracted and in white light, colored fringes are seen around region of strain called photo-elasticity.
- Photo-elasticity is used to analyze stresses in plastics.

OPTICS

Geometrical Optics: Study of image formation by lens and mirrors.
Real Image: Image form due real combination of rays that can be got on screen.
Virtual Image: Image form due virtual rays that cannot be got on screen.
Converging Instrument: That converge all rays.
Diverging Instrument: That diverge all rays.
Convex Mirror: Outer curved surface is reflecting. Diverging mirror
Concave Mirror: Inner curved surface is reflecting. Converging mirror
Lens: Curved piece of transparent medium.
Convex Lens: Thicker at middle and thinner at the edges. Converging lens
Concave Lens: Thinner at middle and thicker at the edges. Diverging lens
Center of Curvature: Center of spherical surface from which lens is made. Every lens has 2 center of curvature.
Radius of Curvature: Radius of spherical surface from which lens is made. Every lens has 2 radii of curvature.
Principal Axis: Line passing through both center of curvatures.
Pole/Optical Center: Center of lens through which rays are pass un-deviated. Every lens has 2 poles.
Aperture: Size of diameter of lens.
Principal Focus: Every lens has 2 foci on each side.

- For convex lens point of convergence of all refracted rays. It is a real point.
- For concave lens point of divergence of all refracted rays. It is an imaginary point.

Focal Length: Distance b/w pole and principal focus. f

- For convex lens +ve and concave –ve.

Power of Lens: Ability of a lens to deviate rays from their original path. $P = 1/f$

- For convex lens +ve and concave –ve.
- **Diopter**: (D) Power of lens which has f = 1m
- For n lens: $P = P_1 + P_2 + P_3 \ldots\ldots\ldots\ldots + P_n$

Linear Magnification: Ratio of height of image to height of object:

- $M = h_i/h_o = q/p$

Angular Magnification: Ratio of angle formed with aided eye to angle formed with naked eye. $M = \theta_a/\theta_n$
Resolving Power: Ability of any lens to reveal minor details of object under examination.

- Raleigh shows lens with diameter D, λ of light: $\alpha_{min} = 1.22\lambda/D$

Visual Angle: Angle made by an object at eye. apparent object size $\propto \theta$
Far Point: Max distance at which eye can view. $d = \infty$

Near Point: Least distance of distinct vision.

- Mini distance up to which a normal eye can see any object clearly.
- d = 25cm = 10"
- At distance < d, we have to use a convex lens to see.

Lens Formula: 1/f = 1/p + 1/q

p → distance b/w lens and object, q → distance b/w lens and image

Terms	*Positive*	*Negative*
p	Real object	Virtual object
q	Real image	Virtual image
f	Convex lens	Concave lens

Image Formation for Convex Lens:

Position of object	*Position of image*	*Nature of image*
Beyond 2F	b/w F and 2F	Real, inverted, small
At 2F	At 2F	Real, inverted, equal
b/w F and 2F	Beyond 2F	Real, inverted, enlarged
At F	At infinity	Real, inverted, enlarged
Inside F	Beyond object	Virtual, erect, enlarged

Image Formation for Concave Lens:

Position of object	*Position of image*	*Nature of image*
At infinity	At F	Virtual, erect, diminished
Beyond 2F	Inside F	Virtual, inverted
At 2F	At 2F	Virtual, erect, enlarged
b/w 2F and F	Beyond 2F	
At F	At infinity	
Inside F	On same side of lens	

Optical Instruments: Which use light for their operations.

Simple microscope, compound microscope, telescope, camera, periscope, prism, spectrometer, michelson interferometer.

Prism: Object with 3 rectangular and 2 triangle sides.

- **Apex Angle**: Angle of prism. A
- Refractive index of prism: n = sin(A+D_m/2)/sin(A/2)
- **Angle of Deviation**: Angle form at point of concurrent of incident and emergent rays inside of prism. D_m
- Light after passing through splits into 7 colors.
- **VIBGYOR**: $^{400}\lambda_{mini}$ (violet, indigo, blue, green, yellow, orange, red) $^{700}\lambda_{max}$
- Very Important Body Guard of Your Office is Riaz.

Binocular: 2 right angled prism reflects light rays at 180°

- Rays fall on prism (C = 42°) at i = 45°

Camera: Object is kept beyond 2F, so image is obtain b/w F & 2F (film).

- Convex lens is used.

Slide Projector: Object is kept b/w F & 2F, so image is obtain beyond 2F and enlarged.

- 2 plano-convex lens are used as condenser to produce parallel rays.
- Light source is kept at center of concave mirror.

Simple Microscope: Double convex lens of short focal length acts as magnifier.

- $M = 1 + d/f$ (d = 25cm)
- It form real, erect and magnified image at d.

Compound Microscope: $f_o < f_e$

- $M = L/f_o(1 + d/f_e)$
- Objective lens magnification: L/f_o
- Eyepiece lens magnification: $1 + d/f_e$
- Objective form real image and eyepiece form virtual image.
- Objective lens working: Object is b/w F & 2F, so image form beyond 2F.
- Eyepiece lens working: Object (form image) is inside F, so new image form beyond object and enlarged.
- On using blue light of short λ and wider object, compound microscope show less diffraction and more resolution.

Telescope: To see a far off object. $f_o > f_e$

- Set at infinity: $L = f_o + f_e$
- $M = f_o/f_e$
- Objective lens working: Object is beyond 2F, so image form b/w F & 2F.
- Eyepiece lens working: Object (form image) is inside F, so new image form beyond object and enlarged.

Spectrometer: Used to study spectra.

- **Collimator**: It has slit at the focus of convex lens to produced parallel beam of light.
- **Telescope**: Astronomical telescope. It is set at infinity and fixed.
- **Turn Table**: Table with a prism and diffraction grating mark in half degree.

Optical Fiber: Small transparent wire of glass which used light as transmission carrier wave.

- **Core**: Central part of high refractive Index.
- **Cladding**: Outer part of low refractive Index.
- Working Principle: Total internal reflection, Continuous reflection.
- **Single Mode Step Index Fiber**: Core diameter = 5μm
- **Multimode Step Index Fiber:** Core diameter = 50μm
  Constant n, short distance, total internal reflection.

- **Multimode Graded Index Fiber:** Core diameter = 50-1000μm
  Long distance, continuous reflection.

Light Pipe: Bundle of optical fiber used in endoscopy.

- **Gastro-scope**: To examine stomach.
- **Systo-scope**: To examine bladder.
- **Broncho-scope**: To examine throat.

Nearsightedness/Myopia: Man can see near objects and cannot see distant objects. Diverging lens (concave) is used as its cure.

Farsightedness/Hypermetropia: Man can see distant objects and cannot see near objects. Converging lens (convex) is used as its cure.

THERMODYNAMICS

Temperature: Measure of degree of hotness or coldness of a substance.

- Measure of average K.E of molecules of a substance. Kelvin, Scalar

Thermometer: Instrument used to check temperature of any object.

Clinical Thermometer: It is used for human. 35°-42°

Thermometric Substance: Mercury is preferred thermometric material,

- It is non-wetting and visible in glass.
- Its expansion is quite linear and good conductor of heat.
- It has low specific heat capacity.
- Boiling point are high. 357°
- Freezing point is low. -39C°

Temperature Scale:

Scale	*Symbol*	*Lower Point*	*Upper Point*	*Division*	*Formula*
Celsius	°C	0	100	100	C = K-273
Fahrenheit	°F	32	212	180	F = 1.8C+32
Kelvin	K	273	373	100	K = C+273

- $\frac{C-0}{100} = \frac{F-32}{180} = \frac{K-273}{100}$
- °C > °F by 1.8
- °C and °F have same reading at -40°C.

Freezing Point: Temperature at which liquid water, ice and vapors co-exist in equilibrium. 273.16K

Triple Point: Temperature and pressure at which a substance can exist in equilibrium in liquid, solid and gaseous states. H_2O = 273.16 K, 0.01°C, 32.01°F

Thermal Equilibrium: Bodies at same temperature in which net exchange of heat is zero.

Absolute Zero: At which gas in gaseous form have zero volume and exert zero pressure. Zero kelvin. In centigrade → -273.16°C

Thermodynamic Scale: It has lower fix point 0K and upper fix point 273.16K.

- It is independent of thermometric material.
- It can show temperature < 0K.
- If a carnot heat engine has sink with T = 273.16K and eject heat Q_H from HTR and leave Q_L into LTR then temp will be. $T = 273.16(Q_H/Q_L)$

Description	*°C*	*°F*	*K*
M.P/T.P/F.P of water	0	32	273
B.P of water	100	212	373
Human body normal temperature	37	98.6	310
Absolute zero	-273	-459.4	0

Heat: Mechanism through which work is store in any body.

- Energy that flow from one body to another due to difference in temp.
- It is an invisible fluid which flows always from a body of high temperature to a body at low temperature.
- It is form of energy that is in transit and never contained by a body.
- Heat enter to system → +ve
- Heat leave to system → −ve
- **Law of Heat Exchange**: If no heat is lost to surrounding or gained from it then heat lost = heat gained
- **Transfer of Heat**: Conduction, convection, radiation
- **Conduction**: Movement of heat due to motion of free electrons and vibrations of atoms in solid.
- **Thermal Conductivity**: Rate of heat flow. $H = Q/t = KA\Delta T/L$ (J/s)
- $H \propto A \propto \Delta T \propto 1/L$
- Coefficient of thermal conductivity: $K = HL/A\Delta T$ (W/mK)
- **Convection**: Movement of heat due to real motion of atoms in liquid and gas.
- **Convectional Currents**: Path from where heat is flow during convection.
- **Land Breeze**: land → sea, night, at night water surface is hotter than land.
- **Land Breeze**: sea → land, day, at day land surface is hotter than sea.
- **Radiation**: Movement of heat in form of EM waves.
- Poynting vector: $S = {}^{E/t}/A$

Thermodynamics: Study of laws of transformation of heat into other forms of energy. Use of heat to produced motion.

System: Part of universe under scientific observation.

Surroundings: Universe other than system.

Boundary: Imaginary line/surface which separates system and surroundings.

Open System: Mass flow, work & heat

Close System: No mass flow but work & heat

Isolated System: No mass flow, heat & work

Mechanically Isolated System: No mass flow and work, only heat

Thermally Isolated System: No mass flow and heat, only work

Thermodynamics Functions/Variables: Physical quantities which describe state of system. They are only depends on initial and final state. P, V, T, U, ΔS, C, H

Thermodynamics State: State of system in terms of specified value of any thermodynamics variable. P, V, T, C, ΔV

Thermodynamic Process: Any change in state variables.

Kinetic Molecular Theory of Gases/Ideal Gas Model:

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- Gases have identical molecules/particles called point mass.
- They are in continuous random motion.
- They do not exert force on each other.
- They collide elastically.
- They have only K.E, not P.E
- Their collisions exert pressure on walls of container.
- Gravity not affect their motion.
- Distance b/w them is greater as compare to their size.

Pressure	*Temp*	*Amount of gas*	*Result*	
$V \propto 1/P$	constant	constant	Boyle Law	PV = PV
constant	$V \propto T$	constant	Charles Law	V/T = V/T
constant	constant	$V \propto N$	Avogadro Law	V = CN

Avogadro's Law: At same temperature and pressure, equal volumes of all gases contain equal number of molecules. V = CN

Heat Capacity: Amount of heat required to raise temperature of given mass of substance by 1K. $H = \Delta Q/\Delta t = cm$

- **Specific Heat Capacity**: Amount of heat required to raise the temperature of 1kg of a substance by 1K. $Q = Cm\Delta T$
- $C = Q/m\Delta T$ (J/kgK)
- soil = 810, ice = 2100, water = 4200
- **Molar Specific Heat Capacity**: Amount of heat required to raise temperature of 1 mole of a substance by 1K. $Q = Cn\Delta T$
- **Molar Specific Heat Capacity at Constant Volume**: $Q_v = C_v n\Delta T$
- It fails in adiabatic process.
- **Molar Specific Heat Capacity at Constant Pressure**: $Q_p = C_p n\Delta T$
- It fails in adiabatic process.
- $C_p > C_v$
- $C_p - C_v = R$
- $\gamma = C_p/C_v$
- mono-atomic gas = 1.67, di-atomic gas = 1.4, poly-atomic gas = 1.3

Latent Heat of Fusion: Energy required to convert 1kg solid into liquid without change of temperature at MP. $H_f = \Delta Q/m$ (J/kg)

Latent Heat of Vaporization: Energy required to convert 1kg liquid into gas without change of temperature at BP. $H_v = \Delta Q/m$ (J/kg)

Evaporation: Fly off liquid in the form of vapors without heating.

- It continuous at all temperature. $E_v \propto T \propto A \propto$ air
- $E_v \propto$ 1/humidity $\propto$ 1/pressure $\propto$ 1/inter-molecular forces
- **Sublimation**: Conversion of solid directly into gas/vapors.

- **Deposition**: Conversion of gas into solid. Hoar frost
- **Heat of Solidification**: Heat liberated by a unit mass of liquid at its freezing point as it solidifies which is equal to heat of fusion.

Linear Thermal Expansion: $L = L_o(1 + \alpha\Delta T)$

- Coefficient of linear thermal expansion (1/K): $\alpha = \Delta L/L_o\Delta T$

Volumetric Thermal Expansion: $V = V_o(1 + \beta\Delta T)$

- Coefficient of volumetric thermal expansion (1/K): $\beta = \Delta V/V_o\Delta T$
- $\beta = 3\alpha$

Pressure of an Ideal Gas: Momentum transferred by molecules of gas on the walls of container per unit area.

- Mean Square Velocity: $<V^2> = [V_1^2 + V_2^2 + V_2^3 \ldots\ldots/N]$
- Pressure everywhere inside the gas container: $P = 1/3\rho<V^2>$
- $P = 2/3N_o< ½ mV^2>$ (N_o→no of molecules/volume)
- $P \propto <K.E> \propto T$

Translational K.E: Average K.E per unit molecules of gas.

Work: Work is done when a system as a whole expands or contracts. Work is done on system in which gas is enclosed:

- $\Delta W = P\Delta V = P(V_f - V_i)$
- If $V_f > V_i$ ΔV increases → expansion
- If $V_f < V_i$ ΔV decreases → compression
- If ΔW = +ve work done by the system
- If ΔW = -ve work done on the system
- Work = area under curve of PV graph. (P-constant)
- Heat and work are inter-convert-able quantities, both raise temperature.
- Heat flow requires temperature difference while work done requires overall displacement of body.
- **Joule's Law of Heat and Work**: W = JQ
- It has no unit & dimension. J = W/Q

Internal Energy: Sum of all translational/rotational/vibrational K.E & P.E associated with random motion of atoms.

- U is similar to gravitational P.E
- $T \propto <K.E> \propto <U>$
- U = +ve ⇒ T inc due to inc in Q = +ve & W = -ve
- U = -ve ⇒ T dec due to dec in Q = -ve & W =+ve
- Change in internal energy: $\Delta U = Q - W$
- Q → energy flowing in as heat, W → energy flowing out as work
- It is state function, depend on initial and final states.

Equation of State of System/Ideal Gas Equation:

- Relation among state variables but only applicable for ideal and homo

- Relation among state variables but only applicable for ideal and homo geneous gases.
- It is not applicable for solids, liquids and non-homogeneous gases.
- PV = nRT = NKT
- Boltzmann constant: $K = R/N_A = 1.38 \times 10^{-23}$ J/kg = 8.314 J/mol-K

Zeroth Law of Thermodynamics: If A & B are in thermal equilibrium and B & C too, then A & C are also in thermal equilibrium.

- Zeroth law of thermodynamics helps to explain term temperature.

1st Law of Thermodynamics:

- Heat given to system is used to increase internal energy + work done by the system on surroundings.
- $\Delta Q = \Delta U + W$
- Q = + → heat added to system
- Q = - → heat leave the system
- W = + → work done by the system
- W = - → work done on the system
- It is based on law of conservation of energy.
- In cyclic process, heat given to system is only used in work done by system because $\Delta U = 0$
- Change in internal energy: $\Delta U = Q - W$

Applications of 1st Law of Thermodynamics:

Isochoric Process: Volume of system remains constant.

- $\Delta Q = \Delta U + P\Delta V \Rightarrow \Delta Q = \Delta U \quad (\Delta V = 0)$
- Graph of isochoric process is called isochor and is parallel to pressure axis.

Isobaric Process: Pressure of system remains constant.

- $\Delta Q = \Delta U + P\Delta V \Rightarrow \Delta Q = \Delta U + nRT$
- Graph of isobaric process is called isobar and is parallel to volume axis.

Isothermal Process: Temperature of system remains constant.

- $\Delta Q = \Delta U + \Delta W \Rightarrow \Delta Q = \Delta W \quad (\Delta U = 0)$ $\qquad U \propto T$
- PV-graph of isothermal process is called isotherm and it is a curve.
- Melting and boiling are examples of isothermal process.
- Specific heat in isothermal process is directly proportional to work done.
- Isothermal expansion, all heat enter changes into work.
- Isothermal compression, all work done on the system convert into heat.

Adiabatic Process: Heat of system remains constant.

- $0 = \Delta U + \Delta W \Rightarrow \Delta U = -\Delta W \Rightarrow \Delta W = -\Delta U$
- Q = 0: W by system → V-inc(T/U-dec) $\qquad W = -\Delta U$
- IE of system decrease bcz work done by the system.

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- Q = 0: W on system → V-dec(T/U-inc) $W = \Delta U$
- IE of system increase bcz work done on the system.
- PV-graph of adiabatic process is called adiabat and it is a curve.
- Process performed quickly is known as adiabatic process.
- Specific heat in an adiabatic process is zero.
- Adiabatic expansion cause cooling.
- Adiabatic compression cause heating.
- It is an isentropic process.
- Rapid escape of air from tire.
- Rapid expansion and compression of air during sound traveling.
- Cloud formation.

2nd Law of Thermodynamics:

- **Lord Kelvin Statement:** It is impossible to construct heat engine which converts all absorbed heat energy into work without having sink or whose efficiency is 100% or whose output is equal to its input.
- **Rudolf Clausius Statement**: It is impossible to make heat flow from cold body to hot body without expenditure of external work.
- **Entropy Statement**: Entropy of universe during natural process either increase or remains constant.
- Compressor of refrigerator work on clausius statement.

Cyclic Process: Series of process which brings system back to its initial state.

- In cyclic process $\Delta U = 0$

High Temperature Reservoir: Hot reservoir at higher temperature T_H having heat Q_H. HTR

Low Temperature Reservoir/Sink: Cold reservoir at low temperature T_L having heat Q_L. LTR

Work done: $Q_H - Q_L$

Heat Engine: Thermo device which converts heat into mechanical energy/work.

- Gas is used as working substance in the heat engine.
- There exist no perfect heat engine.
- It always operates in a cycle.
- **Efficiency**: Ratio of work done by engine to heat absorbed by engine.
- $\eta = 1 - Q_L/Q_H$
- If $Q_L = 0$, then all input heat is converted into work and engine shows 100% efficiency which is impossible. So Q_L cannot be zero.
- **Percentage Efficiency**: $\eta = (1 - Q_L/Q_H) \times 100$
- Heat Engine Types: External combustion & internal combustion
- Internal Combustion: Petrol engine & diesel engine

- Petrol Engine: Spark ignition & compression ignition (both are 2/4 stroke)

- Petrol Engine: Spark ignition & compression ignition (both are 2/4 stroke)
- Diesel Engine: Compression ignition (2/4 stroke)
- **Refrigerator**: Device which works opposite to heat engine.
- **Heat Pump**: When refrigerator is used for heating in winter. Dispenser

Petrol Engine: Convert heat energy into mechanical work.

- 4 proces: Intake stroke, compression stroke, power stroke, exhaust stroke.
- It works on principle of carnot cycle.
- It was invented by Nikdlus Otto in 1876.
- Bike has 1 and car has 4 cylinders.
- Efficiency of petrol engine is 25–30%

Diesel Engine: Invented by R. Diesel in 1892

- Diesel engine has no spark plug.
- Efficiency of diesel engine is 35–40%

Carnot Heat Engine: 1840, Saudi Carnot

- **Carnot Theorem**: No heat engine has greater η than carnot engine.
- **Percentage Efficiency**: $\eta = (1 - Q_L/Q_H) \times 100$
- $\eta = 100\%$ when $T_L = 0K$ $T_H = \alpha K$
- Ideal/imaginary heat engine whose efficiency is 100%.
- It has no friction, no heat losses.
- Ideal gas is used as working substance.
- It has conducting base. It not be constructed practically.
- Efficiency of actual engine is always less than carnot heat engine.
- Its efficiency depends on temperature of LTR and HTR. $\Delta T \propto \eta$
- Carnot engine is a reversible engine.
- It undergoes 4 cyclic process:
- Isothermal expansion→ Q enter
- Adiabatic expansion→T low
- Isothermal compression→W leave
- Adiabatic compression→ T inc

Reversible Process: Process that can be retraced in reverse direction without producing any change in environment.

- Slow compression and expansion of gas, slowly performed liquefaction and evaporation.
- In reversible process, entropy of the system remain constant.

Irreversible Process: Process that cannot be retraced in reverse direction.

- All processes occur suddenly, involve friction, loss of energy, explosion.
- In irreversible process, entropy of system increases.

Entropy: Rudolph Clausius gives its concept in 1856. J/K

- **Statistical Entropy**: Measure of dis-order-ness of a state of a system.
- **Thermo Entropy**: Unavailability of heat energy of a system due to thermal equilibrium.
- $\Delta S = \Delta Q/T$
- $\Delta S = +ve$ $\Delta Q = +ve$ (heat enter)
- $\Delta S = -ve$ $\Delta Q = -ve$ (heat leave)
- $\Delta S = Q_{HL}[T_H - T_L / T_H T_L]$
- It is a state variable.
- **Law of Increase in Entropy**: Entropy of a thermodynamic system is either remains constant or it is increases.
- **Heat Death**: Entropy increase means degradation of energy or ending up of thermal energy.
- **Isentropic Process**: In which entropy of system remains constant.
- In any natural process, entropy is always increased.
- Entropy remains constant for reversible process.
- Entropy increase for all irreversible process.

Newton's law of Cooling: Rate of cooling is proportional to ΔT b/w body and surrounding, provided ΔT is not very large from surrounding.

- It is a special case of stefan's law.
- It is used in lab for determination of specific heat of liquids.
- Thermal process may be cyclic or irreversible.

Fraunhofer Lines: Dark lines in spectrum of sun which are explained on basis of kirchhoff's law.

DARLING PHYSICS

ELECTROSTATICS

Electrostatics: Study of charges at rest.

Charge: Fundamental property of matter with which it exerts coulomb force.

- **Coulomb**: 1A current flows in 1 second. 1C = 6.25×10^{18} electrons
- There are 2 types of charges: +ve & -ve labels by Franklin.
- Similar charges repel while opposite charges attract each other.
- Excess of electrons creates –ve charge which deficiency of $\bar{e}$ creates +ve.
- Bodies gets charge due to friction/rubbing.
- Charge in universe are in pair.
- 1m apart two charges of 1C exert force of 9×10^{9}N on each other.
- Charge is conserved as well as quantized.
- Quantization of charge: Q = ±ne
- All charges are integral multiple of charge on electron.
- Minimum charge on any object is 1.6×10^{-19}C
- Charge on electron = -1.6×10^{-19}C
- Charge on proton = $+1.6 \times 10^{-19}$C
- Charge on neutron = 0C
- **Continuous Charge Distribution**: Collection of a large no of charges.
- **Linear Charge Density**: $\lambda = Q/L$
- **Surface Charge Density**: $\sigma = Q/A$
- **Volume Charge Density**: $\rho = Q/V$
- Charges shift from higher charge density to lower one.
- Charge spread over hollow sphere, not go inside of it.
- **Source/Filed Charge**: To produce electric field. It exert F_e.
- **Test/Point Charge**: To test electric field. It does not exert F_g. q_o
- **Point Charges**: Size is small as compare to distance b/w them.

Electrification: Process by which anybody is charged.

- **Conduction**: Charge transfer with physical contact.
- **Induction**: Charge transfer without physical contact.
- **Electrostatic Induction**: Development of +ve charge at one end and –ve charge at other end of a body in presence of a charged object.
- **Electroscope**: Device to detect presence of charge on anybody. It works on principle of electrostatic induction.

Electric Monopole: Single isolated charge.

- **Dipole**: 2 opposite charges with constant separation b/w them.
- Electric dipole moment: Product of magnitude of charge and separation b/w both charge of a dipole. p = qd

- Vector, Cm, direction is from –ve to +ve against E, debye = 3.3×10^{-33}Cm
- Electric polarization: Dipole moment per unit volume. $P = qd/V = q/A = \sigma$
- **Quadrupole**: 2 dipole directed antiparallel (oppositely) to each other.
- Electric quadrupole moment: $Q = 2qd^2$
- **Polar Substance**: Has permanent dipole moment. Water, NaCl
- **Non Polar Substance**: Not has permanent dipole moment. They become polarized when subjected to external EF.

Dielectric:

- **Dielectric**: It is a non-polar insulating material. Glass, plastic, rubber, air, paper, mica.
- Dielectric is presented by its relative permittivity in physics.
- **Permittivity**: Penetrating ability of any force from a medium. ε_o
- Relative permittivity/dielectric constant/specific inductive capacity: Factor through which any material reduces an induce force. Ratio of permittivity wrt medium to permittivity wrt vacuum. $\varepsilon_r = \kappa_e = \varepsilon_m/\varepsilon_o$
- Vacuum = 1, air = 1.0006, paper = 2, Ge = 16, water = 78.5
- Displacement vector: $D = \varepsilon_o E + P$ $(D \propto E)$
- Dielectric strength: Measure of electrical strength of an insulator. V/m
- **Susceptibility**: Polarization produced in a dielectric due to external electric field. $\chi = P/E$
- $\kappa_e = 1 + \chi/\varepsilon_o$ $\varepsilon_m = \varepsilon_o\varepsilon_r = \varepsilon_o + \chi$

Millikan's Oil Drop Method:

- 1909 Millikan find charge on electron. $\bar{e} = -1.6\times10^{-19}$C
- Atomizer: spray oil drop which gets charged due to friction.
- Terminal velocity is determined by timing fall of droplet over a measured distance.
- Charge on electron: $q = mgd/V$ (V → voltage, d → separation b/w plates)
- Mass of electron: $m = 9\pi\eta^3V_t^3/2\rho^2g^3$

Coulomb's Law:

- **Electric Force**: Electrostatic force which holds +ve and –ve charges in atoms and molecules.
- Origin of electric force is not known.
- Coulomb used torsion balance to measure it.
- $F_e \propto q_1q_2$ $F_e \propto 1/r^2$
- $F_e = Kq_1q_2/r^2$
- $K = 1/4\pi\varepsilon_o = 9\times10^9$ Nm^2/C^2
- $\varepsilon_o = 8.85\times10^{-12}$ C^2/Nm^2 (permittivity of free space)
- Dielectric medium b/w two charges reduces electric force.

- $F_m = \frac{k}{\ldots}(\frac{q_1q_2}{\ldots}) = \frac{1}{\ldots}(\frac{q_1q_2}{\ldots}) = \frac{1}{\ldots}(\frac{q_1q_2}{\ldots})$

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- $\varepsilon_o = 8.85\times10^{-12}$ C²/Nm² (permittivity of free space)
- Dielectric medium b/w two charges reduces electric force.

DARLING PHYSICS

- $F_m = \frac{k}{}(\frac{q_1q_2}{}) = \frac{1}{}(\frac{q_1q_2}{}) = \frac{1}{}(\frac{q_1q_2}{})$

- $F_m = \frac{k}{\varepsilon_r}(\frac{q_1q_2}{r^2}) = \frac{1}{4\pi\varepsilon_0\varepsilon_r}(\frac{q_1q_2}{r^2}) = \frac{1}{4\pi\varepsilon_m}(\frac{q_1q_2}{r^2})$
- F_e acts along line joining both point charges.
- F_{21}: F on q_2 by q_1
- F_{12}: F on q_1 by q_2
- $F_{21} = -F_{12}$ acts as mutual/action reaction pair
- Coulomb's law obeys inverse square law. $F = C/r^2$ ($C = Kq_1q_2$)
- Coulomb's law is applicable for point charge/spherical charge when distance b/w two charges ≥ 10-15m.
- It apply on macro/micro particles.
- Not apply inside of nucleus.
- Not apply on particles moving speed of light.

Electric Field:

- **Field of force**: Region around a charge in which it exert electric force on any other charge.
- It is a vector quantity and intrinsic property.
- For infinite extent EF remains uniform all over.
- Region b/w 2 opposite charges is field area.
- Region b/w 2 same charges is field free area. (neutral zone)
- Action at a distance theory about charge is rejected experimentally.

Electric Field Intensity:

- **Electric Field Strength**: Force on unit charge due to electric field. $E = F/q_o$
- N/C, V/m, $[MLT^{-2}C^{-1}]$, Vector, direction is towards force.
- E due to source charge: $E = \frac{Kq}{r^2}\hat{r}$
- E due to linear charge density: $E = \int \frac{K\lambda}{r^2} dl$
- E due to surface charge density: $E = \int \frac{K\sigma}{r^2} da$
- E due to volume charge density: $E = \int \frac{K\rho}{r^2} dv$
- E due to charged sphere (inside): $E = Kqr/R^3$
- E due to charged sphere (outside): $E = \rho R^3/3r^2\varepsilon_o$
- E on surface of charged sphere: $E = Kq/R^2$
- E just on outside of charged isolated conductor: $E = \sigma/\varepsilon_o$
- E due to infinite sheet of charge: $E = \sigma/2\varepsilon_o$
- E due to 2 parallel charged plates (capacitor): $E = \sigma/\varepsilon_o$
- E due to ring of +ve charge of radius R at distance r: $E = Kqr/(R^2+r^2)^{3/2}$
- E due to disk of +ve charge at distance r: $E = \frac{\sigma}{2\varepsilon_0}[1 - \frac{r}{\sqrt{R^2+r^2}}]$
- E due to dipole (P) at distance r: $E = KP/r^3$

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- E due to quadru-pole at distance r: $E = 3KQ/r^4$

- E due to quadru-pole at distance r: $E = 3KQ/r^4$
- E as potential gradient: $E = -\Delta V/\Delta r$
- Net E b/w two oppositely charged particles is maximum.

Electric Field Lines:

- **Electric Lines of Force**: Imaginary lines to represent electric field.
- Introduced by Faraday to show emergence of virtual photons.
- Start from +ve charge, end on –ve charge.
- Never cross each other.
- One line only pass through one point.
- Contract longitudinally, repel transversely.
- Not present inside conductor.
- Tangent to line show direction of E.
- EF is stronger where lines are closed.
- EF is weaker where lines are apart.
- +ve test charge move along line.
- In capacitor, start from +ve plate towards –ve plate.

Electric Flux:

- No of electric lines of force passing perpendicular through an area.
- $\phi_e = E.A\cos\theta$
- Scalar, Nm^2/C
- $\phi_e = E.A$ $\theta = 0°$ (surface ⊥ E)
- $\phi_e = 0$ $\theta = 90°$ (surface II E)
- $\phi_e = \oint E.da$ (for close surface)
- **Electric Displacement/Electric Flux Density**: Charge per unit area that would be displaced across a layer of conductor placed across an electric field. Vector, C/m^2
- Electric flux through a closed surface: $\phi = Q/\varepsilon_o$
- Flux depend upon intensity of charge Q and permittivity of medium ε_o.

Gauss's Law:

- Electric flux through any closed surface is equal to $1/\varepsilon_o$ times charge enclosed in it. $\phi = Q/\varepsilon_o$
- Integral Form for EF: $\oint E.da = \frac{1}{\varepsilon_0}\int \rho dV$
- Differential Form for EF: $\nabla.E = \rho/\varepsilon_o$
- Integral Form for MF: $\oint B.da = 0$
- Differential Form for MF: $\nabla.B = 0$
- Integral form for dielectric: $\oint E.da = \frac{Q}{k_e \varepsilon_o} \Rightarrow \int D.\hat{n}da = \int \rho\, dv$

- Differential form for dielectric: $\nabla.D = \rho$
- Point charges in closed surface must be distributed arbitrarily.
- Gauss's law is a form of one of maxwell's four equations.
- Gauss's law can be used to derive coulomb's law and vice versa.
- Electric charge enclosed by gaussian surface is zero.
- **Gaussian Surface**: On which gauss's law can be apply.
- If no charge at sphere no flux produced.
- If +ve charge is spread over the surface of a sphere then interior will be field free zone bcz all field lines going outside. (faraday cages)
- It is used to find E due to any surface having charge distribution.
- **1st Shell Theorem**: A uniform spherical charged shell behaves as a point charge and exert E at distance r. $E = Kq/r^2$
- It acts as all its charge is concentrated at its center.
- **2nd Shell Theorem**: A uniform spherical charged shell exert no electric force on a charge enclosed in it.

Electric Potential:

- Strength of charge at any point in electric field.
- +ve charge produces +ve potential: $V = +Kq/r$
- -ve charge produces -ve potential: $V = -Kq/r$
- Absolute potential at distance r from source: $V = Kq/r$
- Potential due to uniform EF: $V = -\int_a^b E.ds$
- Potential due to linear charge density: $V = \int \frac{K\lambda}{r} dl$
- Potential due to surface charge density: $V = \int \frac{K\sigma}{r} da$
- Potential due to volume charge density: $V = \int \frac{K\rho}{r} dv$
- Potential due to ring of +ve charge of radius R at distance r: $V = \frac{Kq}{\sqrt{R^2+r^2}}$
- Potential due to disk of +ve charge at distance r: $V = \frac{\sigma}{2\varepsilon_0}[\sqrt{R^2 + r^2} - z]$
- Potential due to dipole (P) at distance r: $V = KP\cos\theta/r^2$
- Potential due to mono-pole at distance r: $V = KQ/r$
- Potential due to quadru-pole at distance r: $V = KQ/r^3$
- Net electric potential b/w two oppositely charged particles is zero.
- **Equipotential Surfaces**: Any surface with same electric potential at every point. Hollow charge sphere containing point charge at its center.
- Electric field is always perpendicular to an equipotential surface.
- Work done in moving a charge b/w 2 points on equipotential surface is 0.

DARLING PHYSICS

- ECG records voltage b/w different points on skin, generated by electrical process in heart.

Potential Difference:

- Difference of electric potential b/w two points in electric field.
- Work done by F_e on unit +ve charge in moving it against EF: $\Delta V = W/q_o$
- Change of electric PE per unit charge: $\Delta V = \Delta U/q_o$
- Volt: 1J work is done on 1C charge.
- $\Delta V = Kq[\frac{1}{r_h} - \frac{1}{r_l}]$ ($r_h \rightarrow$ high potential, $r_l \rightarrow$ low potential)
- pd may be +ve, -ve, zero.
- Potential and potential difference are two different quantities.
- In the region where E = 0, electric potential is always constant.
- Energy supplied by charge: $W = q(V_h - V_l)$
- Electric potential energy: $U_r = kq_1q_2/r$
- Electric PE → +ve F_e will be repulsive.
- Electric PE → -ve F_e will be attractive.
- Unit of electric PE (W = Vq): J = VxC eV = Vxe
- **Potential Gradient**: Max rate of increase in electric potential in a particular direction.
- Rate of change of potential difference wrt displacement. $E = -\Delta V/\Delta r$
- N/C, V/m, -ve means direction of E is along decreasing potential.
- Gradient means rate of max change.
- $\Delta V \rightarrow$ grad$V = -\nabla|V| = -[(\delta V/\delta x)\hat{i} + (\delta V/\delta y)\hat{j} + (\delta V/\delta z)\hat{k}]$
- $E_x = -\delta V/\delta x$ $E_y = -\delta V/\delta y$ $E_z = -\delta V/\delta z$

Capacitor:

- Charge storing device. Q = CV
- **Capacitance**: Ability of a capacitor to store charge. C = Q/V
- **Farad**: Capacitance of a capacitor when pd = 1V and it store 1C charge.
- $C \propto$ area $\propto$ medium $\propto$ 1/distance $C_m > C_v$
- Parallel plate capacitor with vacuum: $C_v = A\varepsilon_o/d$
- Parallel plate capacitor with dielectric: $C_m = A\varepsilon_m/d = A\varepsilon_o\varepsilon_r/d$
- Cylindrical capacitor: $C = 2\pi\varepsilon_o L/\ln(R_o/R_i)$
- Spherical Capacitor: $C = 4\pi\varepsilon_o[R_oR_i/R_o-R_i]$
- **Electrical Elastance**: Reciprocal of capacitance.
- Old name of capacitor is condenser.
- Net charge on capacitor is zero bcz both plates contain equal amount of charges with opposite polarity.
- Power dissipated in a pure capacitor is zero.

- Capacitor provide uniform EF and allow to pass AC.
- Capacitor acts as blocking element when applied signal is DC.

Combination of Capacitors:

Parallel Combination	*Series Combination*
Many paths for current	One path for current
Current is different in all	Current is same in all
Voltage is same on all	Voltage is different on all
Ceq is larger than smallest one	Ceq is smaller than largest one
$C_{eq} = C_1 + C_2 + C_3$	$1/C_{eq} = 1/C_1 + 1/C_2 + 1/C_3$
$C_{eq} = \Sigma C_i$ (inc)	$1/C_{eq} = \Sigma 1/C_i$ (dec)

Types of Capacitor:

- **Parallel Plate Capacitor**: Has 2 plates.
- **Spherical Capacitor**: Cylindrical shape.
- **Miniature Capacitor**: Small shape.
- **Tubular Capacitor**: Long shape.
- **Paper Capacitor**: Paper used as dielectric.
- **Variable Capacitor**: Capacitance can be changed.
- **Electrolytic Capacitor**: Used only for DC. It has least value of breakdown voltage. Layer of metal oxide form on foil acts as dielectric.
- **Ceramic Capacitor**: Used for temperature compensation.
- **Mica Capacitor**: Usually preferred for closer tolerances.
- **Air Capacitor**: Used for radio frequency tuning.

Energy Store in a Capacitor:

- Capacitor has electrical PE bcz work is done to deposit charge on plates.
- Electrical energy stored in electric field b/w plates.
- Energy stored on plate: $W = ½QV$
- Energy stored in parallel plate capacitor: $W = ½CV^2 = ½Q^2/C$
- Energy in form of EF: $W = ½CE^2d^2 = ½\varepsilon_o E^2(Ad)$
- **Energy Density**: Energy per unit volume. $u_e = ½\varepsilon_o E^2$
- Scalar, J/m^3
- Energy density for vacuum: $u_e = ½\varepsilon_o E^2$
- Energy density for medium: $u_e = ½\varepsilon_m E^2$

Charging and Discharging of Capacitor:

- DC supplies store charge on plates of capacitor.
- AC supplies do not store charge on plates of capacitor.
- Capacitor behaves as open circuit for DC
- Capacitor behaves as closed circuit for AC
- Charging of a capacitor is due to induction phenomenon.

- **Charging Transient**: Variation of charge/voltage across capacitor.

- **Charging Transient**: Variation of charge/voltage across capacitor.
- **Growth Transient**: Equation of charging of capacitor.
- $Q = Q_o(1 - e^{-t/RC})$
- $V = V_o(1 - e^{-t/RC})$
- $I = I_o e^{-t/RC}$
- **Decay Transient**: Equation for discharging of capacitor.
- $Q = Q_o e^{-t/RC}$
- $V = V_o e^{-t/RC}$
- $I = I_o e^{-t/RC}$
- **Time Constant**: Time in which capacitor charges to 63% of its maximum value of charge. Time in which a capacitor discharges to 36% of its maximum value.
- Capacitive time constant: $\tau = RC$
- Charging and discharging depend on product of R & C.
- Wipers of car work due to charging and discharging of capacitor.

Effect of Polarization of Dielectric in Capacitor:

- Dielectric get polarized due to opposite polarity of EF in capacitor.
- EF separate +ve and –ve charge of dielectric material.
- Pole charge of dipoled dielectric, attracts some of charge from plates of capacitor, so charge per unit area on plates of capacitor decreased. $\sigma/\varepsilon_o = E \rightarrow E(dec)$ and $E = \Delta V/\Delta t \rightarrow pd(dec)$
- When dielectric is inserted b/w plates of capacitor, capacitance inc and voltage dec to keep charge constant. $Q = CV$
- Dielectric reduces EF by a factor $\kappa_e(\varepsilon_r)$ b/w both plates of capacitor.
- $\kappa_e = C_m/C_v = \varepsilon_m/\varepsilon_o$
- When dielectric is homogeneous, then potential gradient is uniform.

Comparison of F_e and F_g: $F_e/F_g = 1038$, $F_e > F_g$

Gravitational Force	*Electrostatic Force*
$F_g = Gm_1m_2/r^2$	$F_e = Kq_1q_2/r^2$
$G = 6.67x10^{-11}\ Nkg^2/m^2$	$K = 9x10^9\ Nm^2/C^2$
always attractive	attractive or repulsive
medium independent	medium dependent

ELECTRODYNAMICS

ELECTRODYNAMICS

Current Electricity: Study of charges in motion.
Conductor: Conduct electricity and heat. Has free electrons.
Insulator: Not conduct electricity and heat.

- Good conductor of heat are also good conductor of electricity.
- $I = -\sigma A(\Delta V/L)$ -ve: charge flow from high to low potential
- $H = -kA(\Delta T/L)$ -ve: energy flow from high to low temperature

Circuit: Closed path for flow of current.

- Open Circuit: R = max/∞ $I = 0$
- Short Circuit: R = 0 I = max/∞
- Close Circuit: I/R has some values.

Current:

- Rate of unidirectional flow of charge. $I = Q/t$
- DC is a scalar quantity while AC is a phasor (vector).
- Electrons only oscillate to & fro in AC, while electronic influence is transmitted at nearly speed of light.
- Steady current flow when constant pd is maintained.
- **Ampere**: 1C charge flow in 1S. Current due to 6×10^{18} electrons per sec.
- **Alternating Current/AC**: Which change its direction after some time.
- **Direct Current/DC**: Which not change its direction.
- **Conventional Current**: Current due to +ve charges. Flow from higher potential to lower along E. I_c
- **Electronic Current**: Current due to -ve charges. Flow from lower potential to higher against the E. I_e
- **Drift Current**: Current due to drift velocity of electrons.
- **Diffusion Current**: Current due to charge density gradient. Thermocouples & semiconductors show diffusion current.
- **Displacement Current**: Current due to varying electric/magnetic flux.
- **Current Density**: Current flowing per unit area. $J = I/A$
- Vector, A/m^2, direction of J is along E
- **Drift Velocity**: Speed of electrons in opposite direction of applied EF. Its direction is opposite J and E. $V_d = -J/ne$
- If both current are flowing: $I_{total} = I_c + I_e$

Source of Current:

- **Cell**: Convert chemical energy into electrical energy.
- **Primary Cell**: Non rechargeable cell.
- **Secondary Cell**: Rechargeable cell.

- **Voltaic Cell**: Convert chemical energy into electrical energy.
- **Generator**: Convert mechanical energy into electrical energy.
- **Solar Cell**: Convert light energy into electrical energy.
- **Thermocouple**: Convert heat energy into electrical energy.

Effect of Current:

- Heating Effect: $H = I^2Rt$ as in heater.
- Chemical Effect: Cu^{+2} deposit on cathode.
- Magnetic Effect: As in motor and transformer.

Ohm's Law:

- Macroscopic form: $V \propto I$ $V = IR$
- Microscopic form: $J \propto E$ $E = \rho J$
- **Ohmic Material**: Which obeys ohm's law. VI-graph is straight line.
- **Non-Ohmic Material**: Which not obeys ohm's law. VI-graph is not straight line. Bulb filament, diode, thermistor.
- All metals obeys ohm's law bcz their resistivity is constant. $\rho = m/\tau ne^2$

Resistance/Conductance:

- Hindrance to flow of electrons in a wire. $R = V/I$
- **Ohm:** 1A current flow when pd is 1V. Ω
- Resistance is due to collision b/w electrons and vibrating ions.
- Mean Free Path: Average distance covered by electron b/w collisions. λ
- Mean Free Time: Average time taken by electron b/w collisions. τ
- **Temperature Coefficient of Resistance**: Variance in value of resistance per degree change in temperature.
- $\alpha = \Delta R/R_o\Delta T = R_t\text{-}R_o/R_o\Delta T$
- $R_t = R_o(1 + \alpha\Delta T)$
- K^{-1}, $^oC^{-1}$
- **Conductance**: Reciprocal of resistance. $G = 1/R$
- Siemen, mho, Ω^{-1}

Combination of Resistance:

Parallel Combination	*Series Combination*
Different path for current flow	One path for current flow
Current is diff in all R	Current is same in all R
Voltage is same in all R	Voltage is diff in all R
R_{eq} is smaller than smallest one	R_{eq} is larger than largest one
$1/R_{eq} = 1/R_1 + 1/R_2 + 1/R_3$	$R_{eq} = R_1 + R_2 + R_3$
$1/R_{eq} = \Sigma 1/R_i$ (dec)	$R_{eq} = \Sigma R_i$ (inc)

Color Coding for Resistors:

Black	Brown	Red	Orange	Yellow	Green	Blue	Violet	Gray	White

B	B	R	O	Y	G	B	V	G	W
0	1	2	3	4	5	6	7	8	9

- BB Roy good BV is good woman.
- 1st Color Band: 1st digit, Left side of resistor.
- 2nd Color Band: 2nd digit.
- 3rd Color Band: No of zeros.
- 4th Color Band: Value of tolerance, Right side of resistor.
- Tolerance for gold color: T = 5%
- Tolerance for silver color: T = 10%
- Tolerance for no color: T = 20%
- Numerical value for tolerance = RT/100

Thermistor:
- Highly heat sensitive non-metallic resistor which convert change in temperature into electrical voltage.
- It has –ve temperature coefficient. $R \propto 1/T$

Resistivity/Conductivity:
- Resistance of one cubic meter material. $\rho = E/J$
- **Law of Resistance**: $R \propto LT/A$
- $\rho = RA/LT$, Ωm
- **Temperature Coefficient of Resistivity**: Variance in value of resistivity per degree change in temperature.
- $\alpha = \Delta\rho/\rho_o\Delta T = \rho_t\text{-}\rho_o/\rho_o\Delta T$
- $\rho_t = \rho_o(1 + \alpha\Delta T)$
- K^{-1}, $^oC^{-1}$
- Ge and Si have –ve temperature coefficient bcz semiconductor $\alpha \propto 1/T$
- **Conductivity**: Reciprocal of resistivity. $\sigma = 1/\rho$
- mho/m, $(\Omega m)^{-1}$

Super Conductor:
- Conductors that has mini resistance/resistivity at low temperature.
- R/ρ cannot be made zero bcz ions has oscillations even at 0K
- **Critical Temperature**: Temp at which superconductor almost lose all its resistance. T_c
- 1st super conductor (Hg) discovered 1911 by Kmaerlingornes.
- Yttrium barium copper oxide ($YBa_2Cu_3O_7$) become superconductor at 163K discovered by Yao Lians Lee at Cambridge.
- Al = 1.18K, Sn = 3.72K, Pb = 7.2K
- Superconductivity is a quantum mechanical phenomenon.

- Used in MRI, MLT, CPU, small electric motors.

Electromotive Force/emf:

- pd of a source on its output terminals when either its internal resistance is zero or no current is drawn from it. ε
- **Terminal Potential**: Difference in voltages of output terminals of an emf source when current is drawn from it (Ir) and not (ε). $V_t = \varepsilon - Ir$
- $V_t = \varepsilon$ if I=0/r=0 (open circuit)
- **Internal Resistance**: Resistance in source of emf due to electrolyte. r
- emf is also called strength of source of emf/seat of emf.
- emf is start from +ve terminal of source in circuit. •→
- **emf**: Energy supplied to unit charge by cell. $\varepsilon = W/q$
- Scalar, Volt

Electrical Power:

- Rate of electrical work. $P = W/t = VI = I^2R = V^2/R$
- **Watt**: 1J electrical energy is consumed/wasted in 1s. W, AV, J/s
- **Kilowatt-hours**: 1000 watt is consumed in 1 hour.
- $1KWh = 3.6\times10^6 J = 3.6MJ$ $1J = 2.7\times10^{-7} KWh$
- Electrical energy wasted as heat: $W = Pt$
- P represent power dissipation (wastage of power).
- **Joule Thomson's Effect**: Current transfer some of its energy to ions, so increase their vibrations which rise temperature.
- Heat produced due to power dissipation: $H = Pt = VIt = I^2Rt = V^2t/R$
- **Power Dissipation**: $P = E^2/4r = E^2R/(R-r)^2+4Rr$
- Max power is delivered when r = R

Kirchhoff's Law:

- **1st Law**: Sum of all currents going to a junction is equal to sum of currents going out of it. $\Sigma I = 0$
- **2nd Law**: Sum of voltage rise in a closed loop is equal to sum of voltage drop in it. $\Sigma V = 0$
- Currents entering into node → +ve
- Currents leaving node → -ve
- emf is taken along direction of I_c in loop.
- Potential drop across a resistor wrt ε: $-IR$
- Moving from low to high potential point: $+\varepsilon$
- Moving from high to low potential point: $-\varepsilon$

Wheatstone Bridge:

- It has 4 resistors connected in loop.

DARLING PHYSICS

- When G show no deflection, then WSB is balanced. Zero current is flowing and same voltage is across the galvanometer.
- Principle: $R_1/R_2 = R_3/R_4$
- Used in post office box, slide wire bridge, meter bridge.

Rheostat:

- A device used to alter current in a circuit.
- **Rheo**: Stream/flow of charge, **Stat**: Regulating device.
- Principle: $R \propto L$
- Output Voltage: $V_{BC} = Vr/R$
- Used as variable resistor and potential divider.
- Dimmer in fan, volume in radio.

Potentiometer:

- Used to find unknown emf in a circuit without drawing any current from circuit.
- Principle: $V \propto L$
- Used to compare two source of emf.
- Its wire is about 4m long, made of eureka.

DARLING PHYSICS

ELECTROMAGNETISM

Lodestone: 600 B.C, a magnetic ore (Fe_3O_4) was found from magnesia in Turkey.

- Named lodestone meaning "leading stone"

Magnet: A material having directional properties.

Properties of a Magnet:

- It has 2 poles. 1st north pole and 2nd south pole.
- Magnetism at poles are greater than at middle.
- Like poles attract while unlike poles repel each other.
- If a magnet is cut into many pieces, every part has both N & S poles.
- North pole of magnet coincides with south pole of earth and vice versa.
- Any magnet can be magnetized by passing strong DC.
- Any magnet can be de-magnetized by passing strong AC, by heating, by hammering or by striking.

Magnetic Field: Region around a magnet within which it can exert its influence upon a magnetic material. Vector, B

- ⊗ → field into paper (•) → field out of paper

Magnetic Lines of Force: Imaginary lines to represent magnetic field.

- All lines are curved, never end or cut.
- Never cross each other.
- Fill whole surface around a magnet.
- Lines tend to shorten their length longitudinally. It explains attraction b/w poles.
- Lines repel each other transversely. It explains repulsion b/w poles.
- Moving charges produced magnetic lines.

Magnetic Dipole Moment: Magnetization is due to spin and orbital motion of elementary particles (p^+,e^-,n) that is represented by mag dipole moment.

- It is smallest fundamental unit (tiny magnet) of magnetism.
- Product of current produced by particle and area of orbit. $\mu = IA$
- Vector, J/T, Am^2
- By RHR, curled fingers is along direction of rotation (I), thumb show μ
- Resultant effect of all mag dipole moments makes a material magnet.
- **Magnetic dipole moment due to electron**:
- Orbital motion of $\bar{e}$ produces orbital mag dipole moment. $\mu_o = -e\vec{L}/2m_e$
- Spin motion of $\bar{e}$ produces spin mag dipole moment. $\mu_s = -e\vec{S}/m_e$
- **Magnetic dipole moment due to proton**:
- Orbital motion of p^+ produces orbital mag dipole moment. $\mu_o = -e\vec{L}/2m_p$
- Spin motion of p^+ produces spin mag dipole moment. $\mu_s = -e\vec{S}/m_p$

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- **Magnetic dipole moment due to neutron**:

- **Magnetic dipole moment due to neutron**:
- Orbital motion of n produces orbital mag dipole moment. $\mu_o = -e\vec{L}/2m_n$
- Spin motion of n produces spin mag dipole moment. $\mu_s = -e\vec{S}/m_n$
- **Bohar Magneton**: Natural unit to measure atomic mag dipole moment.
- Atomic magneton: $\mu = e\hbar/2m_e = 9.27\times10^{-24}$ J/T
- Nuclear magneton: $\mu = e\hbar/2m_p = 5.02\times10^{-27}$ J/T
- atomic magneton = 10^{-3} (nuclear magneton)
- L → orbital angular momentum, S → spin/intrinsic angular momentum
- **Magnetization**: Net mag dipole moments per unit volume. $M = \Sigma\mu_i/V$

Curie's Law: $M \propto B_o$ $M \propto 1/T$ $M = CB_o/T$

Magnetic Substances: 3 types of substances can show magnetism.

- **Ferromagnetic**: Spin and orbital motion of electrons support each other.
- Has permanent μ_o & μ_s, so show magnetization.
- Strongly attracted by magnet. Fe, Co, Ni, Al, Pa
- **Paramagnetic**: Spin and orbital motion of electrons support each other.
- Has randomly oriented permanent μ_o & μ_s, so magnetization is zero.
- External applied filed (B_o) induced filed ($\mu_o M$) in them.
- Weakly attracted by magnet. K, Cu, Bi, Sb, Hg, Na, H_2, O_2
- Curie temperature: Temperature for ferromagnetic above which it become paramagnetic. FM < T_C > PM
- **Diamagnetic**: Spin and orbital motion of $\bar{e}$ support strongly each other.
- Weakly repelled by magnet. Cu, Co, Zn, Au, Ag
- **Domain**: Groups of atoms/small regions in a magnetic material.
- Each domain has 10^{12}-10^{16} atoms, size = 0.01mm
- Each domain behaves as small tiny magnet with its own N/S poles.
- **Soft Magnetic Material**: Its domains easily magnetize and demagnetize by external magnetic field. Iron
- **Hard Magnetic Material**: After removal of external magnetic field, all domains not come to their original state. Steel, Co, alnico

Electromagnet: Iron rod inside solenoid behaves as strong magnet.
Magnetism: Study of magnetic properties.
Electromagnetism: Study of magnetic properties associated with electricity.
Hysteresis Loop:

- Graph b/w magnetizing current and magnet flux density plotted by CRO.
- Magnetization lags behind magnetizing current, is called hysteresis.
- **Saturation**: Magnet flux density increases from zero to max and material is magnetized fully. It is called magnetically saturated.

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- **Remance/Retantivity**: Tendency of some domains to stay partially in line and keep material still strongly magnetized even if magnetizing current reduced to zero.
- **Coercivity**: Magnetizing current (coercive current) increased in reverse direction to demagnetize material.
- Coercivity of steel is more than iron, so it needs more I to demagnetize.
- **Hysteresis Loss**: Area of hysteresis loop is equal to energy (work) needed to magnetize and demagnetize the material, used to remove internal friction of domains. It dissipated as heat.
- Material with high retentively and large coercive force will be best to make permanent magnet.

Magnetic Field due to Current in a Conductor:

- Ampere: If current is pass through long straight wire then magnetic field is produces around wire in form of co-center circles.
- By RHR, if thumb is along I_c then curled fingers show field.
- **Orested Experiment**: He proved ampere experimentally by pass a wire through cardboard and keep needles on it.

Magnetic Force on Current Carrying Conductor:

- When a conductor is placed on iron rails and current is pass through it. It feels a magnetic force due to interaction b/w external MF and MF produced by current around conductor.
- $F_m \propto \sin\alpha$ $\qquad F_m \propto I$ $\qquad F_m \propto L$ $\qquad F_m \propto B$
- $F_m = IBL\sin\alpha$
- $F_m = \overrightarrow{IL} \times \vec{B} = \int_0^L I(dl \times B)$ $\qquad (F_m \perp L \perp B)$
- By RHR, curl of fingers is along rotation of L and B then thumb show direction of F_m.
- By Fleming LHR, thumb, 1st and 2nd fingers kept $\perp$ with each other.
- **Magnetic Induction**: Strength of magnetic field. $B = F_m/IL$
- **Tesla**: 1N force act on 1m long conductor through which 1A current is passing. $T = N/Am = 10^4$ Gauss
- Two parallel conductors with current (same direction) attract each other.
- Two anti-parallel conductors with current (opposite dir) repel each other.

F_m on a Charge moving in Current carrying Conductor placed in MF:

- Actually magnetic force exerts force on moving charges with velocity V, due to which conductor experiences force.
- Force on a charged particle: $F_m = q(\vec{V} \times B) = qVB\sin\theta$
- If $\theta = 0^\circ$ or 180° the charge will perform rectilinear motion. ($F_m \rightarrow$ mini)
- If $\theta = 90^\circ$ then charge will perform circular motion. ($F_m \rightarrow$ max)

- If $0^\circ<\theta<90^\circ$ then charge will perform helical or spiral motion

- If $0^\circ<\theta<90^\circ$ then charge will perform helical or spiral motion.
- Force on an electron: $F_m = -e(V \times B)$
- Force on an proton: $F_m = +e(V \times B)$
- By Fleming LHR, thumb, 1st and 2nd fingers kept ⊥ with each other.

Force on a Charge due to MF and EF:

- Force due to EF: $F_e = qE$
- Force due to MF: $F_m = q(V \times B)$
- **Lorentz Force**: $F = qE + q(V \times B)$
- EF does work on charge while MF not do work.
- **Velocity Selector**: Device in which cross fields (EF ⊥ MF) are so adjusted that a particle entering in it, move with a specific velocity. $V = E/B$
- By this method particles are separated from each other.

Magnetic Flux:

- No of magnet lines of force crossing any surface normally.
- Dot product of MF and area. $\phi_B = B.A = BA\cos\theta$
- Web, Nm/A, Maxwell = 10^{-8}Wb
- Maximum flux: Plane of surface is ⊥ to B. $\theta = 0$
- Minimum flux: Plane of surface is II to B. $\theta = 90^\circ$
- **Magnetic Flux Density**: Magnetic flux per unit area. $B = \phi/A$
- Wb/m^2, N/Am, T

Gauss's Law: Net magnetic flux through a closed surface is zero. $\Sigma\phi_m = 0$

- total inward flux = total outward flux
- No magnet mono-pole exist.
- Integral form: $\oint B.da = 0$
- Differential form: $\nabla.B = 0$

Ampere's Law:

- Magnetic field around a current carrying conductor is directly proportional to current and inversely proportional to radius made around it.
- $B \propto I$ $B \propto 1/r$ $2\pi rB = \mu_o I$
- $Bl = \mu_o I$ ($l \rightarrow$ circumference of circle)
- Integral form: $\oint B.dr = \mu_o \oint J.da$
- Differential form: $\nabla \times B = \mu_o J$
- Ampere circuital law: Generalized form of ampere law. $\Sigma(B.\Delta l) = \mu_o I$
- **Permeability:** Measure of ability of a material to support formation of a magnetic field within itself. Ability of a material to allow magnetic lines of force to pass through it.
- Permeability of free space: $\mu_o = 4\pi \times 10^{-7}$ Wb/Am = $4\pi \times 10^{-7}$ Tm/A
- Permeability of medium: $\mu_m = \mu_o \mu_r$

DARLING PHYSICS