CHAPTER AT A GLANCE

WORK, ENERGY AND POWER

Work (W)
Work done by a constant force
$W = Fs\cos\theta = \vec{F}.\vec{s}$
Work done by a variable force
$W = \int_{s_1}^{s_2} Fds\cos\theta = \int_{s_1}^{s_2} \vec{F}d\vec{s}$

Types of work

Positive work
When force (F) and displacement (s) are in same direction
$W_{positive}$ when $0 < \theta < \pi/2$

Negative work
When force (F) and displacement (s) are in opposite direction
$W_{(Negative)}$ when $\pi/2 < \theta < \pi$

Zero work
When force and displacement (s) are perpendicular to each other
W_{Zero} when $\theta = \pi/2$

- Work done, if a body raised through height h, $W = mgh$
- Work done, if a body moves up a plane inclined at an angle θ with a constant speed then $W = mg \sin\theta \times s$
- Work done W = area under the force – displacement curve

Conservative force
If work done by the force is path independent and depends on position only e.g., spring force

For conservative force
$F = -\dfrac{du}{dx}$

Non-conservative force
If the work done by the force is path dependent e.g., force of friction, drag force, etc.

Power (P) $= \dfrac{\text{work (w)}}{\text{time (t)}}$
Instantaneous power
$P_{inst} = \vec{F}\cdot\dfrac{d\vec{s}}{dt} = \vec{F}\cdot\vec{v} = Fv\cos\theta$
1 hp = 746 watt
1 kilowatt hour (1 kwh) = 3.6×10^6 J

Energy
Capacity of doing work

Work-energy theorem
Change in kinetic energy
$(K_f - K_i) = W$ (work done)

Types of mechanical energy

Potential energy
$E_P = mgh$

Potential energy of a spring stretched through distance x
$W = u = \dfrac{1}{2}kx^2$
Force constant, $k = \dfrac{F}{x}$

Kinetic energy
$E_K = \dfrac{1}{2}mv^2 = \dfrac{p^2}{2m}$

Relation between K.E. and momentum P
$P = \sqrt{2mK}$

Law of Conservation of Energy
It can neither be created nor destroyed only be transformed from one from to another.
Total energy in an isolated system remains constant.

Perfectly elastic collision
Total mechanical/kinetic energy conserved
Momentum conserved, $e = 1$
$(KE)_{final} = (KE)_{initial}$

Perfectly inelastic collision
Total energy and linear momentum conserved. Kinetic energy not conserved,
coefficient of restitution, $e = 0$

Inelastic collision
In this case kinetic energy after collision is not equal to kinetic energy before collision.
Coefficient of restitution $0 < e < 1$

Types of Collision

Coefficient of restitution

$$e = \frac{v_2 - v_1}{u_1 - u_2} = \frac{\text{velocity of separation}}{\text{velocity of approach}}$$

For a ball rebounding from a floor, $e = \frac{v}{u}$

Collision
When exchange of momentum takes place between two physical bodies due to their mutual interaction.

Head on elastic collision

- If projectile and target are of same mass *i.e.*, $m_1 = m_2$

  Since $\upsilon_1 = \left(\frac{m_1 - m_2}{m_1 + m_2}\right)u_1 + \frac{2m_2}{m_1 + m_2}u_2$ and $\upsilon_2 = \left(\frac{m_2 - m_1}{m_1 + m_2}\right)u_2 + \frac{2m_1u_1}{m_1 + m_2}$

  i.e., $\upsilon_1 = u_2$ and $\upsilon_2 = u_1$

- If massive projectile collides with a light target *i.e.*, $m_1 >> m_2$

  Since $\upsilon_1 = \left(\frac{m_1 - m_2}{m_1 + m_2}\right)u_1 + \frac{2m_2u_2}{m_1 + m_2}$ and $\upsilon_2 = \left(\frac{m_2 - m_1}{m_1 + m_2}\right)u_2 + \frac{2m_1u_1}{m_1 + m_2}$

  i.e., $\upsilon_1 = u_1$ and $\upsilon_2 = 2u_1 - u_2$

- If light projectile collides with a very heavy target *i.e.*, $m_1 << m_2$

  Since $\upsilon_1 = \left(\frac{m_1 - m_2}{m_1 + m_2}\right)u_1 + \frac{2m_2u_2}{m_1 + m_2}$ and $\upsilon_2 = \left(\frac{m_2 - m_1}{m_1 + m_2}\right)u_2 + \frac{2m_1u_1}{m_1 + m_2}$

  i.e., $\upsilon_1 = -u_1 + 2u_2$ and $\upsilon_2 = u_2$

Stable equilibrium	Unstable equilibrium	Neutral equilibrium
• If a particle is displaced slightly from its present position, then a force acting on it brings it back to the initial position.	If a particle is displaced slightly from its present position, then a force acting on it tries to displace the particle further away from the equilibrium position.	If a particle is slightly displaced from its position, then it does not experience any force acting on it and continues to be in equilibrium in the displaced position.
• Potential energy is minimum.	Potential energy is maximum.	Potential energy is constant.
• $F = -\frac{dU}{dx} = 0$	$F = -\frac{dU}{dx} = 0$	$F = -\frac{dU}{dx} = 0$
• $\frac{d^2U}{dx^2}$ = positive	$\frac{d^2U}{dx^2}$ = negative	$\frac{d^2U}{dx^2} = 0$
i.e., rate of change of $\frac{dU}{dx}$ is positive	*i.e.*, rate of change of $\frac{dU}{dx}$ is negative	*i.e.*, rate of change of $\frac{dU}{dx}$ is zero

CHAPTER AT A GLANCE

MECHANICAL PROPERTIES OF FLUIDS

Fluids – Liquids and Gases that can flow

Pressure $P = \dfrac{\text{thrust }(F)}{\text{area }(A)} = \lim\limits_{\Delta A \to 0} \dfrac{\Delta F}{\Delta A} = \dfrac{dF}{dA}$

Pressure exerted by a liquid column of height h, density ρ, $P = h\rho g$

Atmospheric pressure (P)
Pressure (atm) exerted by the atmosphere.
At sea-level, 1 atm = pressure exerted by 0.76 m of Hg = h ρg
$= 0.76 \times 13.6 \times 10^3 \times 9.8$
$= 1.013 \times 10^5$ Nm^{-2} = 101.3 kPa
Barometer is used to measure atmospheric pressure

Absolute pressure (P_{abs})
The total or actual pressure (P) at a point.
Absolute pressure
= atmospheric pressure
+ gauge pressure
Most of the pressure measuring device measure the absolute pressure.
$\rho_{abs} = r_o + h\rho g$

Gauge pressure (P_g)
Difference between the absolute pressure (P_{abs}) at a point and the atmospheric pressure (Pa)
Gauge pressure (P_g)
= absolute pressure (P_{abs})
– atmospheric pressure (Pa)
Gauge pressure is always measured by manometer.

Pascal's law
The pressure exerted at any point on an enclosed liquid is transmitted equally in all directions. Hydraulic lift and hydraulic brakes are based on Pascal's law.
For a hydraulic lift,
$P = \dfrac{F}{A} = \dfrac{f}{a}$

Density $(\rho) = \dfrac{\text{mass }(M)}{\text{volume }(V)}$
Density of water at 4°C
i.e., maximum density of water
$= 1.0 \times 10^3$ kg/m^3

Relative density or specific gravity
$= \dfrac{\text{density of substance}}{\text{density of water at 4°C}}$

Flow of fluids
Streamline : When the liquid flow velocity is less than critical velocity, each particle of the liquid passing through a point travels along the same path and same velocity as the preceding particles passing. Reynold's number $R_e = 0 – 2000$
Turbulent : When velocity of liquid flow greater than critical velocity and particles follow zig-zag path. Reynold's number $R_e > 3000$

- For a solid body volume and density will be same as that of its constituent substance of equal mass.
  i.e. $M_{body} = M_{sub}$ then $V_{body} = V_{sub}$ and $\rho_{body} = \rho_{sub}$.
  But for a hollow body or body with air gaps
  $M_{body} = M_{sub}$ and $V_{body} > V_{sub}$ then $\rho_{body} < \rho_{sub}$
- If m_1 mass of liquid of density ρ_1 and m_2 mass of liquid of density ρ_2 are mixed then,
  $$M_{mix} = m_1 + m_2 \text{ and } V_{mix} = V_1 + V_2 = \frac{m_1}{\rho_1} + \frac{m_2}{\rho_2} \qquad \therefore \ \rho_{mix} = \frac{M_{mix}}{V_{mix}} = \frac{m_1 + m_2}{\dfrac{m_1}{\rho_1} + \dfrac{m_2}{\rho_2}}$$
  If *same masses are mixed*, *i.e.*, $m_1 = m_2 = m$ then $\rho_{mix} = \dfrac{2\rho_1\rho_2}{\rho_1 + \rho_2}$
  (harmonic mean of individual densities)
- If V_1 volume of liquid of density ρ_1 and V_2 volume of liquid of density ρ_2 are mixed then
  $$V_{mix} = V_1 + V_2 \text{ and, } M_{mix} = m_1 + m_2 = \rho_1 V_1 + \rho_2 V_2$$
  $$\therefore \ \rho_{mix} = \frac{M_{mix}}{V_{mix}} = \frac{\rho_1 V_1 + \rho_2 V_2}{V_1 + V_2}$$
  If same volumes are mixed, *i.e.*, $V_1 = V_2 = V$ then $\rho_{mix} = \dfrac{\rho_1 + \rho_2}{2}$, (arithmetic mean of individual densities)

Viscosity
Opposing force between different layers of fluid in relative motion.
Viscous drag $F = -\eta A \frac{dV}{dx}$ η = coefficient of viscosity

Stoke's law $F = 6\pi\eta vr$

Terminal velocity
Maximum constant velocity attained by a spherical body while falling through a viscous medium.
$$V_T = \frac{2}{9}\frac{r^2}{\pi}(\rho - \sigma)g$$

Surface tension, $S = \frac{f}{\ell}$
Surface energy
$= \frac{\text{Work done in increasing surface area}}{\text{increase in surface area}}$

Capillary rise or fall, $h = \frac{2S\cos\theta}{r\rho g}$
JURIN's Law, $h \propto \frac{1}{r}$

Excess pressure inside a drop (liquid)
$P_{excess} = \frac{2S}{R}$ (1 surface area)
Excess pressure inside a bubble (soap)
$P_{excess} = \frac{4S}{R}$

Equation of continuity,
$m = a_1 v_1 \rho_1 = a_2 v_2 \rho_2$
For an incompressible liquid, $\rho_1 = \rho_2$ then
$a_1 v_1 = a_2 v_2$ or av = constant

Bernoulli's Principle
For an incompressible, non-viscous streamline, irrotational flow of fluid,
$$P + \frac{1}{2}\rho v^2 + \rho g h = \text{constant}$$
$$\frac{P}{\rho g} + h + \frac{1}{2}\frac{v^2}{g} = \text{constant}$$

Applications of Bernoulli's Principle

Venturimeter
A device used to measure rate of flow of liquid. Volume of liquid flowing per second
$$Q = a_1 a_2 \sqrt{\frac{2h\rho_m g}{\rho(a_1^2 - a_2^2)}}$$

Torricelli's law
Velocity of efflux of liquid through an orifice,
$$V = \sqrt{2gh}$$

- Lift of an aircraft wing.
- Sprayer or atomizer.
- Blowing off the roofs during windstorm.

Poiseuille's formula
Volume of a liquid flowing per second through a horizontal capillary tube, under a pressure difference 'P' across its two ends
$$Q = \frac{v}{t} = \frac{\pi \rho r^4}{8\eta\ell}$$

Reynold's Number
$$R_e = \frac{\rho V D}{\eta}$$
ρ = diameter of pipe through which fluid is flowing

Critical velocity
$$V_c = \frac{K\eta}{\rho D}$$

- If a drop of water of radius R is broken into n identical drops, the work done in the process is $4\pi R^2 S(n^{1/3} - 1)$.
- The ratio of surface energy of the big drop to that of one smaller drop in the above case is $n^{2/3}$.
- When n drops each of radius r coalesce, generally the radius of the resulting drop will be $n^{1/3} r$.
- Rise in temperature (i) when bigger drops splits into smaller droplets, $\Delta\theta = \frac{3T}{J\rho s}\left[\frac{1}{r} - \frac{1}{R}\right]$

  (ii) When smaller droplets combine to form a bigger drop $\Delta\theta = \frac{3T}{J\rho s}\left[\frac{1}{r} - \frac{1}{R}\right]$;

  J = mechanical equivalent of heat ; s = specific heat and T = surface tension

CHAPTER AT A GLANCE

WAVES
Information and energy propagate in the form of signal or disturbances without actual transfer of matter

Types of waves

Matter Waves
Waves associated with particles like - electrons, protons, neutrons, atoms, molecules, etc.

Electromagnetic Waves
Do not require any material medium for their propagation e.g., light waves

Mechanical Waves
Require material medium for their propagation

Essential Properties for propagation
- Elasticity
- Inertia
- Minimum friction

Transverse waves
Individual particles of the medium oscillate perpendicular to the direction of wave propagation

Longitudinal waves
Individual particles of the medium oscillate along the direction of wave propagation

Relation b/w wave velocity (v), wavelength (λ) and frequency (ν)

Wave velocity $v = \nu\lambda$

Time period $(T) = \dfrac{1}{\text{frequency}}$

Angular frequency $(\omega) = 2\pi\nu$

Wave number $(\bar{v}) = \dfrac{1}{\text{wavelength}}$

Speed of longitudinal wave

Speed of sound, $V = \sqrt{\dfrac{B}{\rho}}$

$= \sqrt{\dfrac{Y}{\rho}} = \sqrt{\dfrac{P}{\rho}} = \sqrt{\dfrac{\gamma P}{\rho}} = \sqrt{\dfrac{\gamma RT}{M}}$

for air $\gamma = 7/5$

Elasticity of solids maximum and of gases-minium

Displacement relation in a plane progressive wave

$y(x, t) = A\sin(\omega t - kx + \phi_0)$

$y(x, t) = A\sin 2\pi\left(\dfrac{t}{T} - \dfrac{x}{\lambda}\right)$

velocity amplitude $v_0 = A\omega$

Acceleration amplitude $a_0 = A\omega^2$

Speed of transverse wave in a stretched string :

$V = \sqrt{\dfrac{T}{M}}$ T = tension

and M = mass/length

- **Phase** $\phi = 2\pi\left(\dfrac{t}{T} - \dfrac{x}{\lambda}\right) + \phi_0$

  ϕ_0 - initial phase
- Phase change with time $\Delta\phi = \dfrac{2\pi}{T}\Delta t$
- Phase change with position,

  $\Delta\phi = -\dfrac{2\pi}{\lambda}\Delta x$

- If string is stretched by some weight then speed of transverse wave,

  $V = \sqrt{\dfrac{Mg}{m}}$
- If suspended weight attached to the string is immersed in a liquid of density σ,

  $V = \sqrt{Mg\dfrac{1 - \sigma/\rho}{m}}$

Speed of sound in case of extended solid

$V = \sqrt{\dfrac{B + \frac{4}{3}\eta}{\rho}}$

B = bulk modulus.
η = rigidity modulus

Intensity of wave
Average energy flow in medium per unit time and per unit its corss-sectional area

$I = \dfrac{\text{Energy}}{\text{Area} \times \text{Time}} = 2\pi^2 n^2 a^2 \rho v$

$I \propto a^2$

$I \propto \dfrac{\rho}{4\pi r^2} \Rightarrow I \propto \dfrac{1}{r^2}$

Factors affecting velocity of sound in gaseous medium

(i) Temperature, $V \propto \sqrt{T}$

(ii) Density, $V \propto \dfrac{1}{\sqrt{\rho}}$

(iii) Humidity-speed of sound increases with humidity.

(iv) Pressure-at constant temperature speed of sound is independent of pressure

Relation between velocity of sound and RMS speed

$\dfrac{V_{rms}}{V_{sound}} = \sqrt{\dfrac{3}{\gamma}}$

$V_{solid} > V_{liquid} > V_{gas}$

Velocity of sound in air
$V_{air} = 332$ m/s

Principle of superposition of waves: $Y = Y_1 + Y_2 + \ldots\ldots + Y_n$

- If the prong of a tuning fork is slightly loaded with wax, its frequency of vibration decreases.
- If the prong of a tuning fork is filled slightly, its frequency of vibration increases.

Stationary waves

(I) **In string :** Fundamental frequency, $\nu = \frac{1}{2l}\sqrt{\frac{T}{m}}$

(ii) **In organ pipe :**

(a) Open at both ends **(open organ pipe)** fundamental frequency or first harmonic $\nu = \frac{v}{2l}$

(b) Closed at one end **(closed organ pipe)** $\nu = \frac{v}{4l}$ Fundamental frequency or first harmonic

In open organ pipe- All (even and odd) harmonics are formed $n_1 : n_2 : n_3$ - 1 : 2 : 3 .....
Ratio of overtones = 2 : 3 : 4 : 5 .....
Maximum possible wavelength = 2ℓ

In closed organ pipe-
Only odd harmonics are present only odd. $n_1 : n_3 : n_5$ ..... 1 : 3 : 5
Ratio of overtones = 3 : 5 : 7
Maximum possible wavelength = 4ℓ

End correction: Distance of antinode from the open end.
$e = 0.6\,r$; r = radius of pipe
- Effective length in open organ pipe $\ell' = (\ell + 2e)$
- Effective length in closed organ pipe, $\ell' = (\ell + e)$

Resonance tube: Used to determine velocity of sound in air with the help of a tuning fork of known frequency,
$V = 4v(L_1 + 0.3D)$; $V = 2v(L_2 - L_1)$
End correction = 0.3 D = $\frac{L_2 - 3L_1}{2}$
L_1 & L_2 first and second resonance lengths and
D = internal diameter of the resonance tube

Characteristics of a musical sound.
(i) ***Pitch.*** Distinguishing a shrill note from a grave (flat or dull) one. It depends on frequency.
(ii) ***Quality.*** Distinguishes between two sounds of same pitch and loudness from one another. It depends on the number or intensity of overtones.
(iii) ***Loudness.*** The sensation of hearing which enables us to distinguish between a loud and a faint sound. It depends on intensity.
The unit of loudness of a sound is ***bel***. The loudness of a sound of intensity I is given by $L = \ell og_{10}\frac{1}{I_0}$ where I_0 is threshold of hearing. It is called *Weber-Fechner law.*

Doppler Effect in Sound
The change in apparent pitch of sound due to relative motion between the source of sound(s) and the observer (o).

- When the source moves towards the stationary observer,
$$v' = \frac{v}{v - v_s} \times v \qquad (v' > v)$$
- When the source moves away from the stationary observer,
$$v' = \frac{v}{v + v_s} \times v \qquad (v' < v)$$
- When the observer moves towards the stationary source,
$$v' = \frac{v + v_0}{v} \times v \qquad (v' > v)$$
- When the observer moves away from the stationary source,
$$v' = \frac{v - v_0}{v} \times v \qquad (v' < v)$$
- When both source and observer move towards each other,
$$v' = \frac{v + v_0}{v - v_s} \times v \qquad (v' > v)$$
- When both source and observer move away from each other,
$$v' = \frac{v - v_0}{v + v_s} \times v \qquad (v' < v)$$
- When source moves towards observer and observer away from the source,
$$v' = \frac{v - v_0}{v - v_s} \times v$$
- When source moves away from observer and observer towards the source,
$$v' = \frac{v + v_0}{v + v_s} \times v$$

Beats
Regular variation in intensity of sound with time at a particular position. Difference in frequencies of two superposing waves, $v_{beat} = v_1 - v_2$

CHAPTER AT A GLANCE

Current Electricity

Series grouping of resistances
Equivalent resistance, $R_s = R_1 + R_2 + ... + R_n$
In this case same current flows through each resistance but potential difference distributes in the ratio of resistance

Parallel grouping of resistances
Equivalent resistance,
$$\frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2} + ... + \frac{1}{R_n}$$
In this case same potential across each resistance but current distributes in the reverse ratio of their resistances

After stretching, if length increases by n times then resistance will increase by n^2 times i.e., $R_2 = n^2 R_1$. Similarly if radius be reduced to $\frac{1}{n}$ times then area of cross-section decreases $\frac{1}{n^2}$ times so the resistance becomes n^4 times i.e., $R_2 = n^4 R_1$.
After stretching, if length of a conductor increases by x%, then resistance will increase by $2x$% (valid only if $x < 10$%).

Grouping of resistances

Resistance (R) Obstruction offered to flow of electrons

On length (ℓ) and area of cross-section (A)
$$\left.\begin{array}{l} R \propto l \\ \propto \frac{1}{A} \end{array}\right\} R = \rho \frac{l}{A}$$
ρ = resistivity
Resistivity depends on the material of the conductor only.

Resistance, $R \propto \frac{\ell^2}{m}$
ℓ = length and
m = mass of conducting wire

Dependence of resistance

Ohm's law If the physical conditions remain same, current $I \propto V \Rightarrow V = IR$
R-electric resistance
Substances which obey Ohm's law called ohmic and that do not obey called non-ohmic substances.

Colour coding of Resistance
$R = AB \times C \pm D\%$ A, B – First two significant figures of resistance C-multiplier D-tolerance to remembers the sequence of colour code
B B Roy Great Britain Very Good Wife

On temperature
$R_t = R_0(t + \alpha t)$
α = temperature coefficient of resistance

Current density (J)
Current per unit cross sectional area
(A) $\vec{J} = \frac{I}{A} = \frac{\vec{E}}{\rho}$

Conductivity (σ)
Reciprocal of resistivity $\sigma = \frac{1}{\rho}$
Conductance, $C = \frac{1}{\text{resistance}}$

Electric Current (I) The time rate of flow of charge (Q) through any cross-section
$$I = \frac{Q}{t}\,;\; I = \lim_{\Delta t \to 0} \frac{\Delta Q}{\Delta t} = \frac{dQ}{dt}$$

Drift velocity (V_d)
Average uniform velocity acquired by free electrons $V_d = \frac{i}{neA} = \frac{J}{ne} = \frac{V}{\rho \ell ne}$
$$V_d = \frac{E}{\rho ne}$$
Direction of drift velocity for electrons in a metal is opposite to that of applied electric field.

Mobility (μ)
Drift velocity per unit electric field $\mu = \frac{V_d}{E}$

- Using n conductors of equal resistance, the number of possible combinations is 2^{n-1}.
- If the resistances of n conductors are totally different, then the number of possible combinations will be 2^n.
- If n identical resistances are first connected in series and then in parallel, the ratio of the equivalent resistance is given by $\frac{R_s}{R_p} = \frac{n^2}{1}$.
- If a wire of resistance R is cut in n equal parts and then these parts are collected to form a bundle, then equivalent resistance of combination will be $\frac{R}{n^2}$.
- If equivalent resistance of R_1 and R_2 in series and parallel be R_s and R_p respectively, then $R_1 = \frac{1}{2}\left[R_s + \sqrt{R_s^2 - 4R_sR_p}\right]$ and $R_2 = \frac{1}{2}\left[R_s - \sqrt{R_s^2 - 4R_sR_p}\right]$.

Electric cell Source of energy that maintains continuous flow of charge in a circuit

Electrical energy
$H \propto I^2$, $\propto R$, $\propto t$ — **Jule's heating law** $H = I^2Rt$; Electrical power $P = \frac{V^2}{R}$

In series combination, power consumed $P_{total} = \frac{P}{n}$
Brightness ∝ power ∝ V ∝ R ∝ $\frac{1}{P_{rated}}$
In parallel combination
$P_{total} = nP$
Brightness ∝ power ∝ I ∝ $\frac{1}{R}$

Kirchhoff's laws

Ist law/Junction law Algebraic sum of all the current meeting at a junction is zero i.e. $\Sigma I = 0$

2nd law/Loop rule Algebraic sum of changes in potential around any closed loop is zero. $\Sigma V = 0$

Meter bridge Based on Wheatstone bridge
$\frac{P}{Q} = \frac{R}{S} \Rightarrow \frac{l}{100 - l} = \frac{R}{S}$

Balanced condition of wheatstone bridge
$\frac{P}{Q} = \frac{R}{S}$

Potentiometer used to
(i) Compare emfs
$\frac{E_1}{E_2} = \frac{l_1}{l_2}$
(ii) Find internal resistance of cell
$r = \left(\frac{E}{V} - 1\right)S$

Groupings of cells

Cells in series Current in the circuit, $I = \frac{n\varepsilon}{R + nr}$
n = no. of cells
m = no. of rows

Cells in parallel Current in the circuit current $I = \frac{\varepsilon}{R + \frac{r}{m}}$

Cells in series and parallel i.e. mixed Current in the circuit, $I = \frac{n\varepsilon}{\frac{nr}{m} + R}$

- **When cell is discharging:** When cell is discharging current inside the cell is from cathode to anode. Current $I = \frac{E}{r + R}$
or $E = IR + Ir = V + Ir$ or $V = E - Ir$
When current is drawn from the cell potential difference is less than emf of cell. Greater is the current drawn from the cell smaller is the terminal voltage. When a large current is drawn from a cell its terminal voltage is reduced.
- **When cell is charging:** When cell is charging current inside the cell is from anode to cathode. Current $I = \frac{V - E}{r}$ or $V = E + Ir$
During charging terminal potential difference is greater than emf of cell.

When cell is in open circuit: In open circuit
$R = \infty \quad \therefore \quad I = \frac{E}{R + r} = 0$ So $V = E$
In open circuit terminal potential difference is equal to emf and is the maximum potential difference which a cell can provide.

- **When cell is short circuited:** In short circuit
$R = 0$ so $I = \frac{-E}{(R + r)}$ and $V = IR = 0$
In short circuit current from cell is maximum and terminal potential difference is zero.

Power transferred to load by cell:
$P = I^2R = \frac{E^2R}{(r + R)^2}$ so, $P = P_{max}$
if $\frac{dP}{dR}$ and $P = P_{max}$ if $r = R$
Power transferred by cell to load is maximum when r = R and
$P_{max} = \frac{E^2}{4r} = \frac{E^2}{4R}$

Potential gradient (x)
Potential difference per unit length of wire $x = \frac{V}{L} = \frac{\text{volt}}{\text{m}}$
where $V = iR = \left(\frac{e}{R + R_h + r}\right)R$ So,
$x = \frac{V}{L} = \frac{iR}{L} = \frac{i\rho}{A} = \frac{e}{(R + R_h + r)} \cdot \frac{R}{L}$
(I) Potential gradient directly depends upon
(a) The resistance per unit length (R/L) of potentiometer wire.
(b) The radius of potentiometer wire (i.e., Area of cross-section)
(c) The specific resistance of the material of potentiometer
(d) The current flowing through potentiometer wire (i)
(ii) potential gradient indirectly depends upon
(a) The emf of battery in the primary circuit
(b) The resistance of rheostat in the primary circuit

Sensitivity of potentiometer
A potentiometer is more sensitive, if it measures a small potential difference more accurately.
(i) The sensitivity of potentiometer is assessed by its potential gradient. The sensitivity is inversely proportional to the potential gradient.
(ii) In order to increase the sensitivity of potentiometer.
(a) The resistance in primary circuit will have to be decreased.
(b) The length of potentiometer wire will have to be increased

CHAPTER AT A GLANCE

RAY OPTICS AND OPTICAL INSTRUMENTS

Ray optics
Optics - branch of study of light (EM waves wavelength 400 nm to 750 nm). The path of light (always travel in straight line) is ray of light

Refraction of light Bending of light ray while passing from one medium to another medium
- A ray of light bends towards the normal, while going from rarer to denser medium
- And bends away from the normal while going from denser to rarer medium
- Refraction of light takes place because the speed of light is different in the two media

Laws of refraction

Snell's law $\mu = \frac{\sin i}{\sin r}$

For two media

$${}_1\mu_2 = \frac{\mu_2}{\mu_1} = \frac{\sin i}{\sin r}$$

The incident ray, the normal and the refracted ray all lie in the same plane

Refractive index,

$$\mu = \frac{c}{v} = \frac{\text{real depth}}{\text{apparent depth}}$$

Total internal Reflection Ray totally reflected back to denser medium

Phenomena based on TIR
- Mirage - optical illusion in deserts
- Looming - optical illusion in cold countries
- optical fibre
- Brilliance of diamond

Necessary conditions for TIR
(i) ray of light must travel from denser to rarer medium
(ii) $\angle i > \angle c$ for two media

Critical angle (c) Angle *i* in denser medium for which angle of refraction in rarer medium is 90° $\mu = \frac{1}{\sin c}$

Reflection of light Turning back of light in the same medium after striking the reflecting surface or mirror
- After reflection, velocity, frequency and wavelength of light remains same but intensity decreases
- If reflection takes place from denser medium then phase change 'π'

Laws of reflection
- The incident ray, the normal and the reflected ray all lie in the same plane
- The angle of incidence (i) is always equal to angle of reflection (r) i.e., $\angle i = \angle r$

Mirror formula $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$

When two plane mirrors are held at an angle θ with their reflecting surfaces facing each other and an object is placed between them, images are formed by successive reflections.

$f_{concave}$ = negative

f_{convex} = positive

and $f_{plane} = \infty$

Relation between focal length (f) and radius of curvature, R

$$f = \frac{R}{2}$$

Magnification

$$m = -\frac{v}{u} = \frac{\text{height of image}}{\text{height of object}}$$

$$m = \frac{f}{f-u} = \frac{f-v}{f}$$

Refraction at a single spherical surface $\frac{\mu_2}{v} - \frac{\mu_1}{u} = \frac{\mu_2 - \mu_1}{R}$

(A) In case, the object (real or virtual) is situated in rarer medium so that the incident ray travels in rarer medium and the refracted ray travels in denser medium, then the relation between *u, v*, R, μ_1 and μ_2 is

$$-\frac{\mu_1}{u} + \frac{\mu_2}{v} = \frac{\mu_2 - \mu_1}{R}$$

(B) In case, the object (real or virtual) is situated in denser medium, so that the incident ray travels in denser medium and refracted ray travels in rarer medium then the relation between *u, v,* R, μ_1 and μ_2 is

$$-\frac{\mu_2}{u} + \frac{\mu_1}{v} = \frac{\mu_1 - \mu_2}{R}$$

(C) The factor $\frac{\mu_2 - \mu_1}{R}$ is called power of the spherical refracting surface. It gives the measure of the degree to which the refracting surface can converge or diverge the rays of light passing through it.

Optical Instruments

Microscope Forms large image of tiny objects

Magnification produced by simple microscope

Image formed at near point $M = 1 + \frac{D}{f}$, D = 25 cm

Image formed at infinity $M = \frac{D}{f}$

Telescope provide angular magnification of distant objects.

Magnification by compound microscope

When final image is formed at infinity

$$M = -\frac{v_0}{u_0}\frac{D}{f_e}$$

Length of the microscope

$$L = |v_0| + f_e$$

When final image is formed at near point

$$M = -\frac{v_0}{u_0}\left(1 + \frac{D}{f_e}\right)$$

Length of the microscope

$$L = |v_0| + |u_e|$$

Dispersion Without Deviation (Direct Vision Spectroscope)

- To produce dispersion without mean deviation we use a combination of two prisms of different materials such that

$$A' = -\left(\frac{\mu - 1}{\mu' - 1}\right)A \text{ or } \frac{A'}{A} = \frac{(\mu - 1)}{(\mu' - 1)}$$

- Net dispersion caused

$$= (\mu_v - \mu_R)A - (\mu'_v - \mu'_R)A'$$

$$= (\mu - 1)A(\omega - \omega') = \delta(\omega - \omega')$$

Deviation Without Dispersion (Achromatic Prism)

- To produce deviation without dispersion we use a combination of two prisms of different materials such that $A' = \left[\frac{\mu_V - \mu_R}{\mu'_V - \mu_R}\right]A$

When final image is formed at near point

$$M = -\frac{f_0}{f_e}\left(1 + \frac{f_e}{D}\right)$$

Length of the telescope,

$$L = f_0 + |u_e|$$

When final image is formed at infinity

$$M = -\frac{f_0}{f_e}$$

Length of the telescope,

$$L = f_0 + f_e$$

Power of a lens

$$P = \frac{1}{f(\text{in metre})}$$

Unit of power of lens is diopter (D)

$P_{convex} \rightarrow$ Positive
$P_{concave} \rightarrow$ Negative
and $P_{plane} \rightarrow$ Zero

Focal length of lens-**Lens maker's formula**

$$\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

When one face of a lens is silvered, it behaves as a mirror. If f_e is the effective focal length of the lens, then $\frac{1}{f_e} = \frac{2}{f_\ell} + \frac{1}{f_m}$

f_m is the focal length of the mirror

(i) Plano-convex lens silvered at plane surface, then

$$f_e = \frac{R}{2(\mu - 1)}$$

(ii) Plano-convex lens silvered at curved surface, then

$$f_e = \frac{R}{2\mu}$$

Dispersive power

$$\omega = \left(\frac{\mu_v - \mu_r}{\mu_y - 1}\right)$$

Angle of deviation $\delta = A(\mu - 1)$

- When prism is thin, then value of A will be small ($\leq 10°$) $\delta_m = (\mu - 1)A$
- Condition for maximum deviation i_1 or $i_2 = 90°$.

Prism Formula

$$\mu = \frac{\sin\left(\frac{A + \delta_m}{2}\right)}{\sin A/2}$$

Lens formula $\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$

$f_{concave}$ = negative
f_{convex} = positive
and $f_{plane} = \infty$

Refraction by lens

Refraction through Prism