CHAPTER-1: UNITS AND MEASUREMENTS

1. Measurement

Definition

Measurement is the comparison of an unknown physical quantity with a standard unit of the same kind.

$$\boxed{Physical\ Quantity = Magnitude + Unit}$$

2. SI Base Quantities and Units

Physical Quantity	SI Unit	Symbol
Length	metre	m
Mass	kilogram	kg
Time	second	s
Electric Current	ampere	A
Thermodynamic Temperature	kelvin	K
Amount of Substance	mole	mol
Luminous Intensity	candela	cd

3. Common SI Prefixes

Prefix	Symbol	Factor
tera	T	10^{12}
giga	G	10^{9}
mega	M	10^{6}
kilo	k	10^{3}
centi	c	10^{-2}
milli	m	10^{-3}
micro	µ	10^{-6}
nano	n	10^{-9}
pico	p	10^{-12}
femto	f	10^{-15}

4. Scientific Notation

General form:

Scientific notation expresses numbers in the form

$$\boxed{a \times 10^{n}}$$

where:

- $1 \leq a < 10$
- n is an integer.

5. Dimensional Formulae (Most Important)

Quantity	Formula	Dimensions
Length	—	[L]
Mass	—	[M]
Time	—	[T]
Area	$l \times b$	$[L^2]$
Volume	$l \times b \times h$	$[L^3]$
Velocity	s/t	$[LT^{-1}]$
Acceleration	v/t	$[LT^{-2}]$
Momentum	mv	$[MLT^{-1}]$
Force	ma	$[MLT^{-2}]$
Work/Energy	Fs	$[ML^2T^{-2}]$
Power	W/t	$[ML^2T^{-3}]$
Pressure	F/A	$[ML^{-1}T^{-2}]$
Density	m/V	$[ML^{-3}]$
Frequency	$1/T$	$[T^{-1}]$

6. Principle of Dimensional Homogeneity

For every correct physical equation,
In any correct physical equation, the dimensions of all terms must be the same. Any equation may be separated by +, >, <, + or - , will have same dimensions both sides.

$$\boxed{Dimensions\ of\ LHS = Dimensions\ of\ RHS}$$

7. Error Formulae

Mean Value

$$\boxed{\bar{x} = \frac{x_1 + x_2 + x_3 \pm - - - - x_n}{n}}$$

Absolute Error

$$\boxed{\Delta x = |x_i - \bar{x}|}$$

Mean Absolute Error

$$\boxed{\Delta \boldsymbol{x}_{\boldsymbol{mean}} = \frac{\Delta \boldsymbol{x}_1 + \Delta \boldsymbol{x}_2 + \Delta \boldsymbol{x}_3 + - - - - - - - \Delta \boldsymbol{x}_n}{\boldsymbol{n}}}$$

Relative Error

$$\boxed{Relative\ Error = \frac{\Delta x_{mean}}{\bar{x}}}$$

Percentage Error

$$\boxed{\%Error = Relative\ Error\ \times 100}$$

8. Propagation of Errors

Addition / Subtraction

If Z = A ± B, then

$$\boxed{\Delta Z = \Delta A \pm \Delta B}$$

Multiplication / Division

If Z = AB / C, then

$$\boxed{\frac{\Delta Z}{Z} = \frac{\Delta A}{A} + \frac{\Delta B}{B} + \frac{\Delta C}{C}}$$

Relative errors are added.

Power Rule

If Z = A^n, then

$$\boxed{\frac{\Delta Z}{Z} = n\frac{\Delta A}{A}}$$

General Formula

If

$$Z = \frac{A^m B^n}{C^p}$$

Then

$$\boxed{\frac{\Delta Z}{Z} = m\frac{\Delta A}{A} + n\frac{\Delta B}{B} + p\frac{\Delta C}{C}}$$

9. Unit Conversion Formula

For dimensions

If the dimensional formula of a quantity is

$$[M^a L^b T^c]$$

then, during unit conversion,

$$n_2 = n_1 \left(\frac{M_1}{M_2}\right)^a \left(\frac{L_1}{L_2}\right)^b \left(\frac{T_1}{T_2}\right)^c$$

This formula is especially useful for **JEE Advanced** problems.

10. Standard Unit Conversions

Quantity	Standard Form
1 km	$10^3 m$
1 mm	$10^{-3} m$
1 µm	$10^{-6} m$
1 nm	$10^{-9} m$
1 pm	10^{-12}

Speed Conversion

$$1ms^{-1} = 3.6kmh^{-1}$$

$$1kmh^{-1} = \frac{5}{18} ms^{-1}$$

11. Significant Figures – Quick Rules

1. All non-zero digits are significant.
2. Zeros between non-zero digits are significant.
3. Leading zeros are **not** significant.
4. Trailing zeros after the decimal point are significant.
5. Trailing zeros in whole numbers without a decimal point are generally **not** significant.

12. Rounding-Off Rules

- Digit < 5 → Leave unchanged.
- Digit > 5 → Increase previous digit by 1.
- Digit = 5 followed by non-zero digits → Round up.
- Digit = 5 only:
  - Previous digit even → Leave unchanged.
  - Previous digit odd → Increase by 1.

13. Important Dimensionless Quantities

- Plane angle
- Solid angle
- Strain
- Relative density
- Refractive index
- Coefficient of friction

14. Frequently Asked Values

Quantity	Value
Speed of light (c)	$3.0 \times 10^{8} m/s$
Planck constant (h)	$6.626 \times 10^{-34} Js$
Avogadro constant (N_A)	$6.022 \times 10^{23} mol^{-1}$
Elementary charge (e)	$1.602 \times 10^{-19} C$

CHAPTER-2: MOTION IN A STRAIGHT LINE

1. Important Definitions

Motion
Changing the position of an object with time is called Motion.

Rest
When the position of an object does not change with time, is said to be in rest.

Reference Frame
To measure the relative position of an object with respect to a point or coordinate is called Reference Frame.

Position
The stae of an object with respect to reference point is called position.

$$\boxed{x}$$

SI Unit: $\boxed{metre\ (m)}$

2. Distance and Displacement

Distance
It is the actualpath length covered by an object.
Formula:

$$\boxed{Distance = Total\ Path\ Length}$$

Nature:

- Scalar quantity
- Always positive

SI Unit: $\boxed{m\ (metre)}$

Displacement
The shortest distance covered between initial position and final position with direction is called displacement.
Formula:

$$\boxed{\Delta x = x_f - x_i}$$

Nature:

- Vector quantity
- Positive, negative or zero

SI Unit: $\boxed{m\ (metre)}$

---

3. Speed

Definition

Distance travelled per unit time is called speed.

Formula:

$$\boxed{Speed = \frac{distance}{time}}$$

SI Unit: $\boxed{m/s}$

Average Speed

$$\boxed{\boldsymbol{Average\ Speed = \frac{Total\ Distance}{Total\ Time}}}$$

Instantaneous Speed

The speed of a particle at particular instant of time is called instantanous speed.

---

4. Velocity

Definition

Displacement per unit time is called velocity.

Formula:

$$\boxed{velocity = \frac{displacement}{time}}$$

SI Unit: $\boxed{m/s}$

Average Velocity

$$\boldsymbol{Average\ velocity = \frac{Total\ displacement}{Total\ time}}$$

Instantaneous Velocity

$$\boldsymbol{v = \frac{dx}{dt}\ OR\ \frac{dy}{dt}\ OR\ \frac{ds}{dt}\ OR\ \frac{dr}{dt}}$$

5. Acceleration

Definition

Rate of change in velocity is called acceleration.
Formula:

$$a = \frac{\Delta v}{\Delta t} = \frac{v_f - v_i}{t_f - t_i} = \frac{v - u}{t}$$

where:

- u = Initial velocity
- v = Final velocity

SI Unit: $\boxed{ms^{-2}}$

Dimensions: $\boxed{[a] = [LT^{-2}]}$

Instantaneous Acceleration

$$a = \frac{dv}{dt}$$

6. Equations of Motion (SUVAT Equations)

Condition:

Uniform acceleration

First Equation

$$\boldsymbol{v = u + at}$$

Second Equation

$$\boldsymbol{s = ut + \frac{1}{2}at^2}$$

Third Equation

$$\boxed{v^2 = u^2 + 2as}$$

7. Motion under Gravity

Acceleration due to gravity: $\boxed{9.8\ ms^{-2}}$

Falling Body

$$\boxed{v = u + gt}$$

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

$$\boxed{v^2 = u^2 + 2gh}$$

Body Thrown Upward

$$\boxed{v = u - gt}$$

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

$$\boxed{v^2 = u^2 - 2gh}$$

8. Maximum Height

$$\boxed{h = \frac{u^2}{2g}}$$

9. Time of Ascent

$$\boxed{t = \frac{u}{g}}$$

10. Total Time of Flight

$$\boxed{T = \frac{2u}{g}}$$

11. Relative Motion

Relative velocity of A with respect to B:

$$\boxed{v_{AB} = V_A - v_B}$$

Relative acceleration:

$$\boxed{\boldsymbol{a_{AB} = a_A - a_V}}$$

12. Graph Formulae

Position–Time Graph

Slope gives velocity:

$$\boxed{Slope = v = \frac{\Delta x}{\Delta t}}$$

Velocity–Time Graph

Slope gives acceleration:

$$\boxed{Slope = Acceleration = \frac{\Delta v}{\Delta t}}$$

Area gives displacement:

$$\boxed{Area = displacement}$$

Acceleration–Time Graph

Area gives change in velocity:

$$\boxed{Area = Change\ in\ velocity\ (\Delta V)}$$

13. SI Units Summary Table

Physical Quantity	Symbol	SI Unit
Position	x	metre (m)
Distance	d	metre (m)
Displacement	Δx or s	metre (m)
Time	t	second (s)
Speed	v	m s^{-1}
Velocity	v	m s^{-1}
Acceleration	a	m s^{-2}
Gravity	g	m s^{-2}

14. Dimensional Formula Summary

Quantity	Dimension
Distance	[L]
Velocity	$[LT^{-1}]$
Acceleration	$[LT^{-2}]$

15. Calculus:

From calculus, we find rate of change or slope by Differentiation and to find area, we use Integration.

Some important Differential formulae

$$\boxed{\frac{d(t^n)}{dt} = nt^{n-1}}$$

Hence, $\frac{d(any\ constant)}{dt} = 0, \frac{d(t)}{dt} = 1, \frac{d(t^2)}{dt} = 2t, ---$

We read $\frac{d(t^n)}{dt}$ as differentiating t^n with respect to t.

$$\boxed{\frac{d(\sin t)}{dt} = \cos t, and\ \frac{d(\cos t)}{dt} = -\sin t}$$

Some Important Integral Formula:

$$\boxed{\int t^n dt = \frac{t^{n+1}}{n+1}}$$

Note: In Physics, we use mostly the definite integration, so no need to put a constant plus in the above integration formula.

$$\boxed{\int_{1}^{2} t^2 dt = \left(\frac{t^3}{3}\right)_1^2 = \left(\frac{8}{3} - \frac{1}{3}\right) = \frac{7}{3}}$$

16. When we use differentiation and Integration in order to get displacement, velocity or acceleration?

(1) From displacement-time equation ($x - t\ equation, or, y - t\ equation\ or, s - t\ equation, or\ r - t\ equation$) to velocity-time equation (v-t) , (differentiation), use,

$$v = \frac{dx}{dt}$$

(2) From velocity-time equation (v-t) to acceleration time equation (a-t) , (differentiation), use,

$$a = \frac{dv}{dt}$$

(3) From acceleration-time (a-t) to velocity-time equation (v-t), (Integration), use,

$$\boxed{\int_{v_i}^{v_f} dv = \int_{t_i}^{t_f} a dt}$$

(4) From velocity-tine equation (v-t equation) to displacement-time (s-t) equation, (Integration), use,

$$\boxed{\int_{s_i}^{s_f} ds = \int_{t_i}^{t_f} v dt}$$

CHAPTER-3: MOTION IN A PLANE

Vectors

1. Scalars and Vectors

Scalar Quantity

Only Magnitude

Examples

- Mass
- Time
- Distance
- Speed
- Temperature

Vector Quantity

Magnitude + Direction

Examples

- Displacement
- Velocity
- Acceleration
- Force
- Momentum

2. Position Vector

A particle located at point **P(x, y)** has position vector,

$$\boxed{\vec{r} = x\hat{\imath} + y\hat{\jmath}}$$

where

x = x-coordinate

y = y-coordinate

3. Unit Vector

Magnitude of unit vector = 1

$$\boxed{|\hat{\imath}| = |\hat{\jmath}| = |\hat{k}| = 1}$$

If $\vec{r}$ is given, then

$$\boxed{\breve{r} = \frac{\vec{r}}{|\vec{r}|}}$$

4. Magnitude of a Vector

For

A→=Axi^+Ayj^

$$\boxed{\vec{A} = A_x\hat{\imath} + A_y\hat{\jmath}}$$

Magnitude

$$|\vec{A}| = \sqrt{{A_x}^2 + {A_y}^2}$$

5. Direction of Vector

If θ is angle with x-axis

$$\tan\theta = \frac{A_y}{A_x}$$

6. Addition of Two Vectors

If

$\vec{R} = \vec{A} + \vec{B}$

Then

$$R_x = A_x + B_x$$

$$R_y = A_y + B_y$$

Magnitude

$$|\vec{R}| = \sqrt{{R_x}^2 + {R_y}^2}$$

We can also write by law of Parallelogram method when two vectors are acting at a point,

$$R = \sqrt{A^2 + B^2 + 2AB\cos\theta}$$

7. Subtraction of Vectors

$\vec{R} = \vec{A} - \vec{B}$

Components

$$R_x = A_x - B_x$$

$$R_y = A_y - B_y$$

And its magnitude can also be written as

$$R = \sqrt{A^2 + B^2 - 2AB\cos\theta}$$

8. Resolution of Vector

Horizontal Component

$$A_x = A\cos\theta$$

Vertical Component

$$A_y = A\sin\theta$$

10. Dot Product (Scalar Product)

$$\boxed{\vec{A} \cdot \vec{B} = AB \cos \theta}$$

Special Cases
θ = 0°

$$\vec{A} \cdot \vec{B} = AB$$

θ = 90°

$$\vec{A} \cdot \vec{B} = 0$$

Note: If two vectors are perpendicular to each other, then their dot product is zero.

11. Cross Product (Vector Product)

$$\boxed{\vec{A} \times \vec{B} = AB \sin \theta \, \hat{n}}$$

$$\boxed{|\vec{A} \times \vec{B}| = AB \sin \theta}$$

Magnitude of $|\hat{n}| = 1$

Note: If two vectors are parallel with each other then their cross product is zero.
Direction
Right Hand Rule

12. Kinematics in Vector Form

Position Vector

$$\boxed{\vec{r} = \vec{r}_0 + \vec{v}t}$$

Velocity

$$\boxed{\vec{v} = \frac{d\vec{r}}{dt}}$$

Acceleration

$$\boxed{\vec{a} = \frac{d\vec{v}}{dt}}$$

13. First Equation of Motion (Vector Form)

$$\boxed{\vec{v} = \vec{u} + \vec{a}t}$$

In component form,
In x-direction,

$$\boxed{v_x = u_x + a_x t}$$

In y-direction,

$$\boxed{v_y = u_y + a_y t}$$

14. Second Equation of Motion (Vector Form)

$$\vec{s} = \vec{u}t + \frac{1}{2}\vec{a}t^1$$

In component form,
In x-direction,

$$s_x = u_x t + \frac{1}{2}a_x t^2$$

In y-direction,

$$s_y = u_y t + \frac{1}{2}a_y t^2$$

15. Third Equation of Motion

$$\boldsymbol{v^2 = u^2 + 2\vec{a} \cdot \vec{s}}$$

In component form,
In x-direction,

$$\boldsymbol{v^2 = u^2 + 2a_x s_x}$$

In y-direction,

$$\boldsymbol{v^2 = u^2 + 2a_y s_y}$$

Quick Revision Formulae

✔ Position Vector

$$\boldsymbol{\vec{r} = \vec{r}_0 + \vec{v}t}$$

✔ Magnitude

$$A^2 = {A_x}^2 + {A_y}^2$$

✔ Components
Horizontal Component

$$A_x = A\cos\theta$$

Vertical Component

$$A_y = A\sin\theta$$

✔ Dot Product

$$\vec{A} \cdot \vec{B} = AB\cos\theta$$

✔ Cross Product

$$\boldsymbol{|\vec{A} \times \vec{B}| = AB\sin\theta}$$

✔ Motion Equation

$$\boldsymbol{\vec{v} = \vec{u} + \vec{a}t}$$

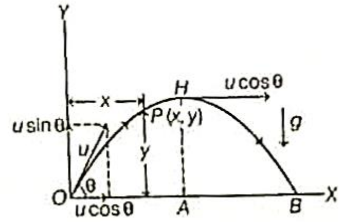
$$\vec{s} = \vec{u}t + \frac{1}{2}\vec{a}t^1$$

$$\boldsymbol{v^2 = u^2 + 2\vec{a} \cdot \vec{s}}$$

Projectile Motion & Circular Motion

1. Horizontal and Vertical Components

For a projectile projected with velocity u at angle θ , ($\theta \neq 0^{0}, 90^{0} or 180^{0}$), the path is parabola.



Horizontal Component

$$\boxed{u_x = u\cos\theta}$$

Vertical Component

$$\boxed{u_y = u\sin\theta}$$

2. Horizontal Velocity

$$\boxed{\boldsymbol{v_x = u\cos\theta}}$$

(Constant)

3. Vertical Velocity

$$\boxed{v_y = u_y\sin\theta - gt}$$

At the maximum height,

$$\boxed{v_y = 0}$$

Note: Horizontal component $u_x = u\cos\theta$ is same everywhere on the path of projectile motion.

4. Resultant Velocity

When particle is thrown with initial velocity; $\vec{u} = u_x\hat{\imath} + u_y\hat{\jmath}$

$$\boxed{u = \sqrt{{u_x}^2 + {u_y}^2}}$$

5. Angle of projection

$$\boxed{\tan\theta = \frac{u_y}{u_x}}$$

6. Time of Flight

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

7. Maximum Height

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

8. Horizontal Range

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

9. Equation of Trajectory

$$\boxed{y = x \tan\theta - \frac{1}{2}\frac{gx^2}{u^2 cos^2\theta}}$$

In terms of Range ® and angle of projection θ,

$$\boxed{y = x \tan\theta \left(1 - \frac{x}{R}\right)}$$

10. Greatest Range

For

$$\boxed{\theta = 45^0}$$

Maximum Range

$$\boxed{R_{max} = \frac{u^2}{g}}$$

Range will be maximum for complementary angles, $\theta\ and\ 90^0 - \theta$,

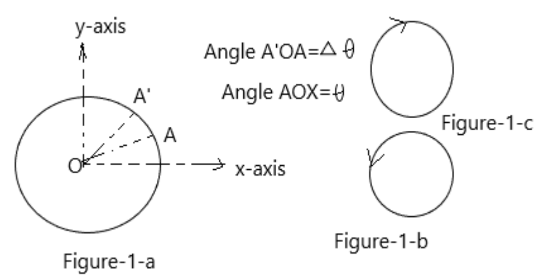
$$\boxed{R_\theta = R_{90^0 - \theta}}$$

Circular Motion:

In circular motion, the particle has two velocities, (i) Angular velocity and Linear velocity.
Acceleration is also is of two types, (i) Angular acceleration and (ii) Linear acceleration

11. Angular Velocity

$$\boxed{\omega = \lim_{\Delta t \to 0} \frac{\Delta\theta}{\Delta t} = \frac{d\theta}{dt}}$$



Where θ is angular displacement.
SI Unit
rad/s

12. Linear Velocity

$$\boxed{v = \frac{ds}{dt} = r\omega}$$

Here, $ds = rd\theta$

13. Centripetal Acceleration or Radial Acceleration

$$\boxed{a_c = \frac{v^2}{r} = r\omega^2}$$

14. Centripetal Force

$$\boxed{F_C = \frac{mv^2}{r} = mr\omega^2}$$

15. Period of Revolution

$$\boxed{T = \frac{2\pi}{\omega}}$$

16. Frequency

$$\boxed{f = \frac{I}{T}}$$

17. Relation between Angular Velocity and Frequency

$$\boxed{\omega = 2\pi f}$$

18. Centrifugal Force

Pseudo Force

Magnitude

$$\boxed{F = m\frac{v^2}{r}}$$

Direction

Away from Centre

19. Banking of Roads (Without Friction)

$$\boxed{\tan\theta = \frac{v^2}{rg}}$$

20. Angular Acceleration:

$$\boxed{\alpha = \frac{d\omega}{dt}}$$

If angular acceleration and angular velocity are in same direction, Speed increases and if both are in opposite direction, speed decreases.

21. Linear Acceleration:

It is of two types, (i) Tangential acceleration and (ii) Centripetal acceleration.

Tangential Acceleration:

$$\boxed{a_t = \frac{dv}{dt} = r\alpha}$$

22. Resultant Linear Acceleration in Circular Motion:

$$\boxed{\boldsymbol{a} = \sqrt{\boldsymbol{a_c}^2 + \boldsymbol{a_t}^2}}$$

$$\boxed{\tan\theta = \frac{a_c}{a_t}}$$

23. In Uniform Circular Motion,

$$\boxed{Linear\ Speed = constant}$$

$$\boxed{Angular\ speed = constant}$$

$$\boxed{Tangential\ Acceleration\ (a_{t)} = 0}$$

$$\boxed{Angular\ Acceleration\ (\alpha) = 0}$$

Exam Tips

Students are often confused in **Dot Product** and **Cross Product**.

Remember:

- Dot Product → **Scalar**
- Cross Product → **Vector**
- Maximum Range is at **45°**.
- Equal Range for complementary angles θ and (90^0−θ).
- Velocity is always tangent in Circular Motion.
- Centripetal Acceleration and Force always **act towards Centre.**

CHAPTER-4: LAWS OF MOTION

Part–1 : Newton's Laws & Friction

1. Newton's First Law

With no forces acting on it, the ball keeps moving at the same speed in the same direction, or will remain be in rest.

Law of Inertia

A body continues in its state of rest or uniform motion unless acted upon by an external unbalanced force.

2. Momentum

$$\vec{p} = m\vec{v}$$

SI Unit

kg m s^{-1}

3. Newton's Second Law

$$\boxed{F_{net} = ma}$$

For constant mass

$$\vec{F} = m\vec{a}$$

Force related with linear momentum as:

$$\vec{F} = \frac{d\vec{P}}{dt}$$

4. SI Unit of Force

Newton

$$1N = 1kgms^{-2}$$

5. Impulse

$$\vec{J} = \vec{F}\Delta t = \Delta\vec{P}$$

6. Newton's Third Law

Force of person on box and force of box on person are equal in magnitude, opposite in direction, and act on different objects

Contact example

Pushing a box, Colliding balls, Box on table

For every action, there is an equal and opposite reaction.

7. Weight

$$\boxed{W = mg}$$

Where

- M = Mass
- g= 9.8 m/s^2

8. Normal Reaction

For horizontal surface

$$\boxed{N = mg}$$

9. Static Friction

$$\boxed{f_s \leq \mu_s N}$$

Maximum Static Friction

$$\boxed{f_{s,\max} = \mu_s N}$$

10. Kinetic Friction

$$\boxed{f_k = \mu_k N}$$

11. Coefficient of Friction

$$\boxed{\mu = \frac{f}{N}}$$

12. Angle of Friction

$$\boxed{\tan\phi = \mu}$$

13. Angle of Repose

$$\boxed{\tan\theta = \mu}$$

14. Motion on Smooth Horizontal Surface

$$\boxed{a = \frac{F}{m}}$$

15. Motion with Friction

$$\boxed{a = \frac{F - f}{m}}$$

Part–2 : Inclined Plane • Pulley • Elevator • Circular Motion Applications

1. Motion on a Smooth Inclined Plane

Inclined Plane Acceleration

2. Components of Weight

Parallel to Plane

$$\boxed{w = mgsin\theta}$$

Perpendicular to Plane

$$\boxed{w = mgcos\theta}$$

3. Normal Reaction

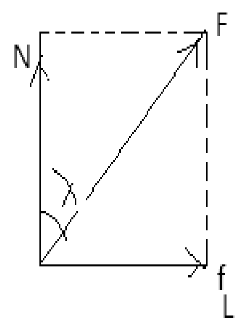
Smooth Plane

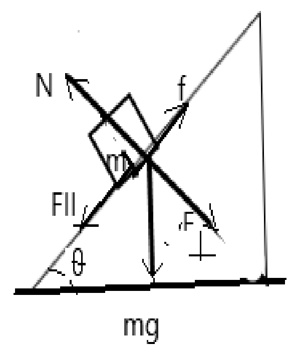
$$\boxed{N = mg\cos\theta}$$

4. Friction on Inclined Plane

Limiting Friction

$$\boxed{f = \mu N}$$





$$\boxed{f_L = \mu_s N = \mu N}$$

Therefore

$$\boxed{f = \mu mg\cos\theta}$$

Angle of Friction (λ)

$$\boxed{\lambda = tan^{-1}\mu}$$

Angle of Repose (α)

$$\boxed{\alpha = tan^{-1}\mu}$$

Driving Force (Down the Plane),

$$\boxed{F = mg\sin\theta}$$

Note:

1. **If $\boldsymbol{\theta < \alpha, the\ block\ is\ stationary}$.**
2. **If $\boldsymbol{\theta = \alpha, the\ block\ is\ about\ to\ slide}$**
3. **If $\boldsymbol{\theta > \alpha, F > f_{L,} the\ block\ slides\ down\ with\ acceleration}$.**
   And, the acceleration is,

$$\boldsymbol{a = \frac{F - f_L}{m} = g(\sin\theta - \mu\cos\theta)}$$

5. Acceleration with Friction

Moving Down the Plane

$$\boxed{a = g(\sin\theta - \mu\cos\theta)}$$

Moving Up the Plane

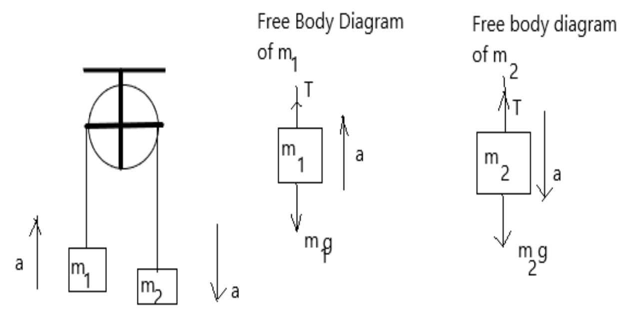
$$a = g(\sin\theta + \mu\cos\theta)$$

6. Connected Bodies

For two masses
 (Ideal Pulley)

$$a = \frac{(m_2 - m_1)g}{m_1 + m_2}$$

7. Tension in String



For Mass m_1

$$T = m_1(a + g)$$

For Mass m_2

$$T = m_2(g - a)$$

8. Elevator

Moving Upward

Normal Reaction

$$N = m(g + a)$$

Moving Downward

$$N = m(g - a)$$

Free Fall

$$\boxed{N = 0}$$

9. Apparent Weight

$$\text{Apparent Weight} = N$$

10. Banking of Roads

Ideal Banking

$$\boxed{\tan\theta = \frac{v^2}{rg}}$$

11. Circular Motion

Centripetal Force

$$\boxed{F = \frac{mv^2}{r}}$$

12. Centripetal Acceleration

$$\boxed{a = \frac{v^2}{r}}$$

13. Uniform Circular Motion

Angular Velocity

$$\boxed{\omega = \frac{v}{r}}$$

In Vector Form,

$$\boxed{\vec{v} = \vec{\omega} \times \vec{r}}$$

14. Linear Velocity

$$\boxed{v = r\omega}$$

Exam Tips

□ **Impulse = Change in Momentum**

□ **Static Friction is always greater than Kinetic Friction.**

□ Make Free Body Diagram (FBD) of a body first and then write equations of forces acting on it.

□ Resolve weight of a mass placed on inclined plane in two components_ Horizontal and Vertical

□ Check first in Elevator Problems

- Upward Acceleration
- Downward Acceleration
- Free Fall

CHAPTER 5: WORK, ENERGY & POWER

Work • Kinetic Energy • Potential Energy

1. Work Done by Constant Force

If the force makes an angle θ with the displacement, then

$$W = Fs\cos\theta$$

$$\boxed{W = Fs\cos\theta}$$

In vector form,

$$\boxed{W = \vec{F}\cdot\vec{s}}$$

Where

- W = Work (Joule)
- F = Force (Newton)
- s = Displacement (metre)
- θ = Angle between Force and Displacement

---

2. Special Cases

(i) θ = 0°

$$\boxed{W = Fs}$$

(ii) θ = 90°

$$\boldsymbol{W = 0}$$

(iii) θ = 180°

$$\boxed{\boldsymbol{W = -Fs}}$$

---

3. SI Unit of Work

$$\boxed{1\,J = 1\,Nm}$$

4. Kinetic Energy

Definition

Energy possessed due to motion.

$$\boxed{KE = \frac{1}{2}mv^2}$$

---

5. Relation between Work and Kinetic Energy

$$\boxed{W = \Delta KE}$$

This is known as the **Work-Energy Theorem**.

---

6. Change in Kinetic Energy

$$\boxed{W = \frac{1}{2}m(v^2 - u^2)}$$

7. Potential Energy

Gravitational Potential Energy

$$\boxed{PE = mgh}$$

8. Change in Potential Energy

$$\boxed{\Delta PE = mg(h_2 - h_1)}$$

9. Mechanical Energy

$$\boxed{E = KE + PE}$$

10. Law of Conservation of Mechanical Energy

$$\boxed{KE + PE = \text{Constant}}$$

(Only when non-conservative forces are absent.)

11. Conservative Force

Examples

- Gravitational Force
- Spring Force

For Conservative Force

$$\boxed{W = -\Delta PE}$$

12. Non-Conservative Force

Examples

- Friction
- Air Resistance

Mechanical Energy is **not conserved**.

Power • Spring Energy • Variable Force • Energy Graphs

13. Power

Power = Rate of doing work

$$P = \frac{W}{t}$$

SI Unit

$$1 Watt = 1 J/s$$

14. Average Power

The ratio of total work done to the total time taken is called average power.

$$P_{av} = \frac{Total\ Work}{Total\ Time\ Taken}$$

Average Power between the given time interval can also be calculated, if Power is a function of time or constant power as:

$$P_{av} = \frac{\int_{t_1}^{t_2} p\,dt}{\int_{t_1}^{t_2} dt}$$

15. Instantaneous Power

$$P = \vec{F} \cdot \vec{v}$$

Special Case

If Force and Velocity are in same direction,

$$P = Fv$$

16. Horse Power

$$1HP = 746W$$

17. Spring Potential Energy

Using Hooke's Law

Spring Energy

$$F = -kx$$

$$U = \frac{1}{2}kx^2$$

where

- K = Spring Constant

- x = Extension/Compression

18. Variable Force

Work done by a variable force equals the **area under the Force–Displacement (F–x) graph**.

$$\boxed{W = \int F\,dx}$$

19. Spring Work

For a spring,

$$\boxed{W = \frac{1}{2}kx^2}$$

20. Mechanical Energy

$$\boxed{E = \frac{1}{2}mv^2 + mgh}$$

21. Conservation of Mechanical Energy

$$\boxed{\frac{1}{2}mv_1^2 + mgh_1 = \frac{1}{2}mv_2^2 + mgh_2}$$

22. Efficiency

$$\boxed{\eta = \frac{\text{Useful Output}}{\text{Input}} \times 100\%}$$

23. Energy Conversion

Gravitational PE → KE
Spring PE → KE
Electrical Energy → Mechanical Energy

24. Energy Graphs

Force–Displacement Graph

Area under graph = Work Done

Potential Energy–Position Graph

Slope of curve

$$\boxed{F = -\frac{dU}{dx}}$$

25. Equilibrium Position: Stable, Unstable & Neutral Positions

For Equilibrium Position,

$$\boxed{F = 0}$$

For Stable Equilibrium Position,

$$\boxed{U \text{ should be Minimum}}$$

To find Minimum Position,

$$\boxed{\frac{d^2U}{dt^2} > 0}$$

Then, the point at which unstable equilibrium can be obtained by putting

$$\boxed{F = -\frac{dU}{dx} = 0}$$

For Unstable Equilibrium Position,

$$\boxed{U \text{ should be Maximum}}$$

And to find maximum position,

$$\boxed{\frac{d^2U}{dt^2} < 0}$$

Then, the point at which unstable equilibrium can be obtained by putting

$$\boxed{F = -\frac{dU}{dx} = 0}$$

Exam Tips

- If force and displacement are in same direction→ Work Positive
- If both are in opposite direction→ Work Negative
- If both are perpendicular → Work Zero
- **Area under F–x graph = Work Done**
- **Slope of U–x graph = Force**
- For conservative force only, mechanical energy is always conserved.

CHAPTER-6: SYSTEM OF PARTICLE & ROTATIONAL MOTION

Part–1: Centre of Mass • Torque • Angular Momentum

1. Position of Centre of Mass (Two Particles)

For two masses m_1 and m_2,

$$x_{CM} = \frac{m_1 x_1 + m_2 x_2}{m_1 + m_2}$$

Similarly,

$$y_{CM} = \frac{m_1 y_1 + m_2 y_2}{m_1 + m_2}$$

2. Centre of Mass (n Particles)

$$\vec{r}_{CM} = \frac{\sum m_i \vec{r}_i}{\sum m_i}$$

3. Velocity of Centre of Mass

$$\vec{V}_{CM} = \frac{\sum m_i \vec{v}_i}{\sum m_i}$$

4. Acceleration of Centre of Mass

$$\vec{a}_{CM} = \frac{\sum m_i \vec{a}_i}{\sum m_i}$$

5. Linear Momentum of a System

$$\vec{P} = \sum m_i \vec{v}_i$$

6. Newton's Second Law for System

$$\vec{F}_{ext} = \frac{d\vec{P}}{dt}$$

7. Torque (Moment of Force)

Vector Form

$$\vec{\tau} = \vec{r} \times \vec{F}$$

Magnitude

$$\boxed{\tau = rF\sin\theta}$$

SI Unit: Newton metre (N-m)

8. Special Cases of Torque

Maximum Torque

$$\boxed{\theta = 90^0}$$

$$\boxed{\tau = rF}$$

Zero Torque

$$\boxed{\theta = 0^\circ}$$

9. Couple

Torque produced by a couple

$$\boxed{\tau = Fd}$$

where
d = Perpendicular distance between forces

10. Angular Momentum

Definition
Moment of Linear Momentum

$$\boxed{\vec{L} = \vec{r} \times \vec{p}}$$

Magnitude

$$\boxed{L = mvr\sin\theta}$$

11. Relation between Torque and Angular Momentum

$$\boxed{\tau = \frac{dL}{dt}}$$

12. Conservation of Angular Momentum

If

$$\boxed{\tau_{ext} = 0}$$

Then

$$\boxed{L = \text{Constant}}$$

Part–2: Moment of Inertia • Rotational Dynamics • Rolling Motion

13. Angular Displacement

$$\theta = \frac{s}{r}$$

SI Unit: radian (rad)

14. Angular Velocity

$$\omega = \frac{d\theta}{dt}$$

Uniform Motion

$$\omega = \frac{2\pi}{T} = 2\pi f$$

15. Angular Acceleration

$$\alpha = \frac{d\omega}{dt}$$

16. Rotational Equations of Motion

First Equation

$$\omega = \omega_0 + \alpha t$$

Second Equation

$$\theta = \omega_0 t + \frac{1}{2}\alpha t^2$$

Third Equation

$$\omega^2 = \omega_0^2 + 2\alpha\theta$$

17. Moment of Inertia

Definition
Resistance offered by a body to rotational motion.

$$I = \sum mr^2$$

SI Unit: kg m²

18. Radius of Gyration

$$I = Mk^2$$

Therefore

$$k = \sqrt{\frac{I}{M}}$$

19. Standard Moments of Inertia

Thin Ring

$$I = MR^2$$

Solid Disc

$$I = \frac{1}{2}MR^2$$

Solid Sphere

$$I = \frac{2}{5}MR^2$$

Hollow Sphere

$$I = \frac{2}{3}MR^2$$

Thin Rod (Through Centre)

$$I = \frac{1}{12}ML^2$$

Rod (Through End)

$$I = \frac{1}{3}ML^2$$

20. Parallel Axis Theorem

$$I = I_{CM} + Md^2$$

21. Perpendicular Axis Theorem

(For Plane Lamina)

$$I_z = I_x + I_y$$

22. Rotational Kinetic Energy

$$\boxed{KE = \frac{1}{2} I\omega^2}$$

23. Relation Between Torque and Angular Acceleration

$$\boxed{\tau = I\alpha}$$

24. Angular Momentum

$$\boxed{L = I\omega}$$

25. Rolling Motion

For Pure Rolling

$$\boxed{v = r\omega}$$

26.Total Kinetic Energy

$$\boxed{KE = \frac{1}{2} Mv^2 + \frac{1}{2} I\omega^2}$$

Standard MOI Table (NEET Favourite)

Body	Moment of Inertia
Thin Ring	MR^2
Solid Disc	$\frac{1}{2} MR^2$
Solid Sphere	$\frac{2}{5} MR^2$
Hollow Sphere	$\frac{2}{3} MR^2$
Rod (Centre)	$\frac{1}{12} ML^2$
Rod (End)	$\frac{1}{3} ML^2$

Exam Tips

- Centre of Mass always tends to higher mass.
- Torque and Angular Momentum both are **Vector Quantities**.
- If External Torque zero then Angular Momentum is conserved.
- Moment of inertia of **Ring** is greater for same mass and same radius.
- Always Remember $v = r\omega$ in **Pure Rolling**
- Parallel Axis Theorem and Standard MOI questions are important.

CH-7: GRAVITATION

Part–1: Universal Law of Gravitation • Gravitational Field • Potential

1. Universal Law of Gravitation

Gravitational force between two masses m_1 and m_2

$$\boxed{F = G\frac{m_1 m_2}{r^2}}$$

Where

- G = Universal Gravitational Constant
- r = distance between centres of two masses

2. Universal Gravitational Constant

$$\boxed{G = 6.67\times10^{-11}\,Nm^2kg^{-2}}$$

SI Unit: Nm^2/kg^2
Dimensions:

$$\boxed{[M^{-1}L^3T^{-2}]}$$

3. Newton's Law (Vector Form)

The direction of force at a mass is towards other mass along the line joining the centre of these two masses.

$$\boxed{\vec{F} = -G\frac{m_1 m_2}{r^2}\hat{r}}$$

4. Acceleration Due to Gravity

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

Where

- M = Mass of earth
- R = Radius of earth

5. Weight

$$\boxed{W = mg}$$

6. Gravitational Field Intensity

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

Or

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

SI Unit: N/kg

7. Relation Between g and Gravitational Field

$$\boxed{g = E}$$

8. Gravitational Potential

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

SI Unit: J/kg

9. Gravitational Potential Energy

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

10. Relation Between Potential and Potential Energy

$$\boxed{U = mV}$$

11. Escape Condition

Total mechanical energy to free a body from gravitation

$$\boxed{E = 0}$$

12. Variation of g with Height

$$\boxed{g_h = \frac{g}{\left(1+\frac{h}{R}\right)^2}}$$

If $h \ll R$

$$\boxed{g_h = g\left(1 - \frac{2h}{R}\right)}$$

Exam Tips

- Gravitaiona force is always **Attractive**
- Gravitational Potential and Potential Energy both are **Negative**.
- g and Gravitational Field Intensity has same Numerical value.

Part–2: Escape Velocity • Satellites • Kepler's Laws

13. Escape Velocity

Escape Velocity is the minimum velocity required to leave the gravitational field of Earth permanently.

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

Using

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

$$\boxed{v_e = \sqrt{2gR}}$$

For Earth

$$\boxed{v_e = 11.2 km/s}$$

14. Orbital Velocity

Velocity of a satellite near Earth's surface

$$\boxed{v_o = \sqrt{\frac{GM}{R}}}$$

Or

$$\boxed{v_o = \sqrt{gR}}$$

For Earth

$$\boxed{v_o = 7.9 km/s}$$

15. Relation between Escape Velocity and Orbital Velocity

$$\boxed{v_e = \sqrt{2}\, v_o}$$

16. Time Period of Satellite

Using orbital velocity

$$\boxed{T = \frac{2\pi r}{v}}$$

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

17. Geostationary Satellite

Conditions

- Time Period = 24 hours
- Circular Orbit
- Equatorial Plane
- Same Direction as Earth's Rotation

Height above Earth

$$\boxed{h = 3.6\times10^7 m}$$

Approx.

$$\boxed{35800km}$$

18. Variation of g with Depth

At depth d

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

19. Variation of g with Height

$$\boxed{g_h = g\left(1-\frac{2h}{R}\right)}$$

For h << R

20. Kepler's First Law

Every planet moves in an elliptical orbit with the Sun at one focus.

21. Kepler's Second Law

The line joining the planet and the Sun sweeps equal areas in equal intervals of time.

22. Kepler's Third Law

$$\boxed{T^2 \propto r^3}$$

or

$$\boxed{\frac{T^2}{r^3} = Constant}$$

23. Total Energy of Satellite

$$\boxed{E = -\frac{GMm}{2r}}$$

---

24. Kinetic Energy of Satellite

$$\boxed{KE = \frac{GMm}{2r}}$$

---

25. Potential Energy of Satellite

$$\boxed{PE = -\frac{GMm}{r}}$$

Exam Tips

□ Remember

- Escape Velocity = **11.2 km/s**
- Orbital Velocity = **7.9 km/s**
- PE=−2KE
- E=−KE

In Satellite Questions

CHAPTER-8: MECHANICAL PROPERTIES OF SOLIDS (ELASTICITY)

Part–1: Stress • Strain • Hooke's Law

1. Elasticity

Definition

The property of a material by virtue of which it regains its original shape and size after the deforming force is removed.

---

2. Plasticity

The property of a material to retain its deformed shape after removing the external force.

---

3. Deforming Force

External force which changes the shape or size of a body.

---

4. Stress (σ)

Stress is the restoring force acting per unit area.

$$\boxed{\sigma = \frac{F}{A}}$$

Where

- F = Restoring Force
- A = Cross-sectional Area

SI Unit

$$\boxed{N/m^2 = Pascal(Pa)}$$

---

5. Types of Stress

(i) Longitudinal Stress

$$\boxed{\sigma = \frac{F}{A}}$$

(ii) Shearing Stress

Force acts parallel to the surface.

$$\boxed{\tau = \frac{F}{A}}$$

(iii) Hydraulic (Bulk) Stress

Pressure applied equally in all directions.

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

6. Strain

Strain is the ratio of change in dimension to original dimension.
It is **dimensionless**.

(i) Longitudinal Strain

$$\boxed{\text{Longitudinal Strain} = \frac{\Delta L}{L}}$$

(ii) Volumetric Strain

$$\boxed{\frac{\Delta V}{V}}$$

(iii) Shear Strain

$$\boxed{\theta}$$

(in radians)

7. Hooke's Law

Within elastic limit,

$$\boxed{\text{Stress} \propto \text{Strain}}$$

or

$$\boxed{\sigma \propto \varepsilon}$$

8. Elastic Limit

Maximum value of stress up to which Hooke's Law is obeyed.

9. Stress–Strain Curve

Important Points

- Proportional Limit
- Elastic Limit
- Yield Point
- Ultimate Strength
- Breaking Point

10. Factor of Safety

$$\boxed{\text{Factor of Safety} = \frac{\text{Ultimate Stress}}{\text{Working Stress}}}$$

Part–2: Elastic Moduli • Poisson's Ratio • Elastic Energy

11. Young's Modulus (Y)

Young's Modulus is the ratio of longitudinal stress to longitudinal strain.

$$\boxed{Y = \frac{\text{Longitudinal Stress}}{\text{Longitudinal Strain}}}$$

or

$$\boxed{Y = \frac{FL}{A\Delta L}}$$

SI Unit

$$\boxed{Pa(N/m^2)}$$

12. Bulk Modulus (K)

Bulk Modulus is the ratio of bulk stress to volumetric strain.

$$\boxed{K = \frac{\text{Bulk Stress}}{\text{Volume Strain}}}$$

Or

$$\boxed{K = -\frac{P}{\Delta V/V}}$$

(The negative sign indicates decrease in volume.)

13. Compressibility

Compressibility is the reciprocal of Bulk Modulus.

$$\boxed{\beta = \frac{1}{K}}$$

14. Shear Modulus (Modulus of Rigidity)

$$\boxed{G = \frac{\text{Shearing Stress}}{\text{Shearing Strain}}}$$

15. Poisson's Ratio

$$\boxed{\mu = \frac{\text{Lateral Strain}}{\text{Longitudinal Strain}}}$$

For most solids

$$\boxed{0 < \mu < 0.5}$$

16. Relation Between Young's Modulus and Shear Modulus

$$\boxed{Y = 2G(1+\mu)}$$

17. Relation Between Young's Modulus and Bulk Modulus

$$\boxed{Y = 3K(1-2\mu)}$$

18. Relation Among Three Elastic Constants

$$\boxed{Y = \frac{9KG}{3K+G}}$$

19. Elastic Potential Energy

Stored Elastic Energy

$$\boxed{U = \frac{1}{2}F\Delta L}$$

Also

$$\boxed{U = \frac{1}{2}kx^2}$$

20. Energy Density

Elastic Energy per Unit Volume

$$\boxed{u = \frac{1}{2}(\text{Stress})(\text{Strain})}$$

Exam Tips

- Young's Modulus → Stretching Problems
- Bulk Modulus → Liquids & Compression
- Shear Modulus → Shape Change
- **Elastic Constants all three relations Relations** are important every year
- **Stress: SI Unit = Pascal**
- **Strain: No SI Unit (Dimensionless)**
- Hooke's Law applicable only up to **Elastic Limit**

CHAPTER-9: MECHANICAL PROPERTIES OF FLUIDS

Part–1: Pressure • Pascal's Law • Buoyancy • Archimedes' Principle

---

1. Pressure

Pressure is the normal force acting per unit area.

Formula

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

Where

- P = Pressure
- F = Normal Force
- A = Area

SI Unit: Pascal or N/m^2

$$\boxed{1Pa = 1N/m^2}$$

---

2. Atmospheric Pressure

Standard Atmospheric Pressure

$$\boxed{P = 1.013 \times 10^5 Pa}$$

or

$$\boxed{1atm = 760mmHg}$$

---

3. Density

Density is mass per unit volume.

Formula

$$\boxed{\rho = \frac{m}{V}}$$

SI Unit: kg/m^3

---

4. Relative Density (Specific Gravity)

$$\boxed{RD = \frac{\rho_{substance}}{\rho_{water}}}$$

Dimensionless Quantity

---

5. Pascal's Law

Pressure applied to a confined fluid is transmitted equally in all directions.

---

6. Hydraulic Lift

$$\boxed{\frac{F_1}{A_1} = \frac{F_2}{A_2}}$$

Mechanical Advantage

$$\boxed{F_2 = F_1 \frac{A_2}{A_1}}$$

7. Hydrostatic Pressure

Pressure at depth h

$$\boxed{P = \rho g h}$$

Total Pressure

$$\boxed{P = P_0 + \rho g h}$$

8. Thrust

Force acting normally on a surface.

$$\boxed{F = PA}$$

9. Buoyant Force (Upthrust)

According to Archimedes' Principle

$$\boxed{F_B = \rho V g}$$

Where

- ρ = Density of Fluid
- V = Volume of Fluid Displaced

10. Archimedes' Principle

The buoyant force acting on a body immersed in a fluid is equal to the weight of the displaced fluid.

11. Floatation Condition

A body floats when

$$\boxed{F_B = W}$$

That is,

$$\boxed{\rho_{fluid} V g = mg}$$

12. Fraction of Volume Submerged

$$\boxed{\frac{V_{sub}}{V} = \frac{\rho_{body}}{\rho_{fluid}}}$$

Exam Tips

 Pressure depends on **Area** as well as **Force**.
 Hydrostatic Pressure depends only on **Depth**, not on the shape of the container.
 Floating Body → **Buoyant Force = Weight**.

Part–2 : Surface Tension • Viscosity • Bernoulli's Theorem

13. Surface Tension (T)

Surface tension is the force acting per unit length on the free surface of a liquid.

Formula

$$\boxed{T = \frac{F}{L}}$$

SI Unit: N/m

14. Surface Energy

Surface Energy = Work done per unit surface area.

$$\boxed{E = TA}$$

Or

$$\boxed{E = \frac{W}{A}}$$

Where

- T = Surface Tension
- A = Surface Area

15. Capillary Rise

Height of liquid in a capillary tube

$$\boxed{h = \frac{2T\cos\theta}{\rho rg}}$$

Where

- r = Radius of Capillary
- θ = Angle of Contact

16. Excess Pressure inside a Liquid Drop

$$\boxed{\Delta P = \frac{2T}{R}}$$

17. Excess Pressure Inside a Soap Bubble

$$\boxed{\Delta P = \frac{4T}{R}}$$

18. Coefficient of Viscosity

According to Newton's Law of Viscosity

$$\boxed{F = \eta A \frac{dv}{dx}}$$

Where

- η = Coefficient of Viscosity

SI Unit: Pa·s

19. Stokes' Law

Viscous Force

$$\boxed{F = 6\pi\eta r v}$$

Where

- r = Radius of Sphere
- v = Velocity

20. Terminal Velocity

$$\boxed{v_t = \frac{2r^2(\rho - \sigma)g}{9\eta}}$$

Where

- ρ = Density of Sphere
- σ = Density of Liquid

21. Streamline Flow

Fluid particles move in smooth, parallel paths.

22. Turbulent Flow

Fluid particles move irregularly.

23. Equation of Continuity

$$\boxed{A_1 v_1 = A_2 v_2}$$

24. Bernoulli's Theorem

Pressure + Kinetic Energy per unit volume + Potential Energy per unit volume = Constant

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

25. Venturimeter Principle

Venturimeter works on Bernoulli's Principle.

Exam Tips

- Soap Bubble → Excess Pressure always double of **Liquid Drop**
- Bernoulli's Theorem→ increase in **Velocity, Pressure decreases**
- Continuity Equation → applicable for **Incompressible Fluid**

CHAPTER-10: THERMAL PROPERTIES OF MATTER

Part–1: Temperature • Thermal Expansion • Calorimetry

1. Temperature Scales

Celsius Scale

$$\boxed{0^\circ C \to 100^\circ C}$$

Kelvin Scale

$$\boxed{0\,K = -273.15^\circ C}$$

Relation

$$\boxed{K = {}^\circ C + 273}$$

Fahrenheit Scale

$$\boxed{{}^\circ F = \frac{9}{5}({}^\circ C) + 32}$$

Relation Between Three Scales

$$\boxed{\frac{C}{5} = \frac{F-32}{9} = \frac{K-273}{5}}$$

---

2. Thermal Expansion

Increase in dimensions of a body due to increase in temperature.

---

3. Linear Expansion

Increase in Length

$$\boxed{\Delta L = \alpha L \Delta T}$$

Final Length

$$\boxed{L = L_0(1 + \alpha \Delta T)}$$

Where

- α = Coefficient of Linear Expansion

SI Unit: K^{-1}

---

4. Area Expansion

Increase in Area

$$\boxed{\Delta A = \beta A \Delta T}$$

Final Area

$$\boxed{A = A_0(1 + \beta \Delta T)}$$

Relation

$$\boxed{\beta = 2\alpha}$$

5. Volume Expansion

Increase in Volume

$$\boxed{\Delta V = \gamma V \Delta T}$$

Final Volume

$$\boxed{V = V_0(1+\gamma \Delta T)}$$

Relation

$$\boxed{\gamma = 3\alpha}$$

6. Thermal Stress

If expansion is prevented,

$$\boxed{\sigma = Y\alpha \Delta T}$$

Where

- Y = Young's Modulus
- $\sigma = Thermal\ Stress$

7. Specific Heat Capacity

Heat required to raise temperature of unit mass by 1^0 or 1K

$$\boxed{Q = mc\Delta T}$$

Or

$$\boxed{c = \frac{Q}{m\Delta T}}$$

SI Unit:$Jkg^{-1}K^{-1}$

8. Heat Capacity

$$\boxed{C = mc}$$

SI Unit:J/K

9. Water Equivalent

$$\boxed{W = \frac{ms}{c_w}}$$

where

- c_W = Specific Heat Capacity of Water

10. Principle of Calorimetry

Heat Lost = Heat Gained

$$\boxed{m_1 c_1 (T_1 - T) = m_2 c_2 (T - T_2)}$$

Exam Tips

 हमेशा **Kelvin Scale** का प्रयोग Thermodynamics में करें।
 Expansion के तीनों गुणांक याद रखें:

- Linear → α
- Area → β=2α
- Volume → γ=3α

 In Calorimetry, **Heat Lost = Heat Gained**

Part–2: Latent Heat • Heat Transfer • Thermal Radiation

11. Latent Heat

Heat absorbed or released during change of state without change in temperature.

(i) Latent Heat of Fusion

$$\boxed{Q = mL_f}$$

Where

- L_f = Latent Heat of Fusion

(ii) Latent Heat of Vaporisation

$$\boxed{Q = mL_v}$$

Where

- L_V = Latent Heat of Vaporisation

12. Heat Required for Complete Process

When temperature changes as well as state changes,

$$\boxed{Q = mc\Delta T + mL}$$

13. Modes of Heat Transfer

There are **three modes**:

- Conduction
- Convection
- Radiation

14. Conduction

Heat transfer without actual motion of particles.

15. Rate of Heat Conduction (Fourier's Law)

$$\boxed{\frac{Q}{t} = \frac{kA(T_1 - T_2)}{L}}$$

Where

- k = Thermal Conductivity
- A = Cross-sectional Area
- L = Length

---

16. Thermal Resistance

$$\boxed{R = \frac{L}{kA}}$$

---

17. Convection

Heat transfer due to actual movement of fluid particles.
Examples

- Sea Breeze
- Land Breeze
- Chimney

---

18. Radiation

Heat transfer without any material medium.
Travels through vacuum.

---

19. Stefan–Boltzmann Law

Rate of radiation

$$\boxed{P = e\sigma AT^4}$$

Where

- e = Emissivity
- σ = Stefan Constant

$$\boxed{\sigma = 5.67 \times 10^{-8} Wm^{-2}K^{-4}}$$

---

20. Wien's Displacement Law

$$\boxed{\lambda_m T = 2.898 \times 10^{-3} mK}$$

---

21. Newton's Law of Cooling

For small temperature difference,

$$\boxed{\frac{dT}{dt} \propto (T - T_s)}$$

or

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

We can also say it as:

$$\boxed{\frac{T_1 - T_2}{t} = k\left[\frac{T_1 + T_2}{2} - T_s\right]}$$

Where

- Ts = Surrounding Temperature

Important Constants

Stefan Constant

$$\boxed{5.67 \times 10^{-8} Wm^{-2} K^{-4}}$$

Wien Constant

$$\boxed{2.898 \times 10^{-3} mK}$$

Exam Tips

 Conduction → Solids
 Convection → Liquids & Gases
 Radiation → Possible in Vacuum
 Black Body→ Best **Emitter** and Best **Absorber**

CHAPTER-11: THERMODYNAMICS

Part–1 : Basic Concepts • Internal Energy • First Law of Thermodynamics

1. Thermodynamic System

A specified quantity of matter or a region under study is called a **Thermodynamic System**.

Types

- Open System
- Closed System
- Isolated System

2. Surroundings

Everything outside the thermodynamic system is called the **Surroundings**.

3. Thermodynamic Equilibrium

A system is said to be in equilibrium when

- Thermal Equilibrium
- Mechanical Equilibrium
- Chemical Equilibrium

exist simultaneously.

4. State Variables

The variables which define the state of a system are:

- Pressure (P)
- Volume (V)
- Temperature (T)

5. Equation of State (Ideal Gas)

$$\boxed{PV = nRT}$$

Where

- P = Pressure
- V = Volume
- n = Number of moles
- R = Universal Gas Constant
- T = Absolute Temperature

6. Universal Gas Constant

$$\boxed{R = 8.314 J\ mol^{-1} K^{-1}}$$

7. Internal Energy

Internal Energy is the total kinetic and potential energy of all molecules of a system.

Symbol:U

8. Change in Internal Energy

$$\boxed{\Delta U = U_2 - U_1}$$

9. Heat (Q)

Heat is the energy transferred due to temperature difference.
SI Unit:Joule

10. Work Done

For constant pressure,

$$\boxed{W = P\Delta V}$$

Where

$$\boxed{\Delta V = V_2 - V_1}$$

11. Sign Convention

Heat

- Heat Supplied to System → **Positive (+Q)**
- Heat Given by System → **Negative (−Q)**

Work

- Work Done by System → **Positive (+W)**
- Work Done on System → **Negative (−W)**

12. First Law of Thermodynamics

$$\boxed{\Delta U = Q - W}$$

Equivalent form

$$\boxed{Q = \Delta U + W}$$

This law is based on the **Law of Conservation of Energy**.

13. Cyclic Process

For a complete cycle,

$$\boxed{\Delta U = 0}$$

Therefore,

$$\boxed{Q = W}$$

Exam Tips

□ **Temperature in Kelvin**
□ Fix Sign Convention in First Law related questions
□ Cyclic Process→ Internal Energy Change: **Zero**

Part–2 : Thermodynamic Processes • Heat Capacities • Adiabatic Equation

14. Isothermal Process

Temperature remains constant.

$$\boxed{\Delta T = 0}$$

Hence,

$$\boxed{\Delta U = 0}$$

Work Done

$$\boxed{W = nRT \ln\left(\frac{V_2}{V_1}\right)}$$

Also,

$$\boxed{Q = W}$$

15. Isochoric (Constant Volume) Process

$$\boxed{\Delta V = 0}$$

Therefore,

$$\boxed{W = 0}$$

From First Law,

$$\boxed{W = 0}$$

16. Isobaric (Constant Pressure) Process

$$\boxed{P = \text{Constant}}$$

Work Done

$$\boxed{W = P(V_2 - V_1)}$$

17. Adiabatic Process

No heat exchange takes place.

$$\boxed{Q = 0}$$

From First Law,

$$\boxed{\Delta U = -W}$$

18. Adiabatic Equation

$$\boxed{PV^{\gamma} = \text{Constant}}$$

Also,

$$\boxed{TV^{\gamma-1} = \text{Constant}}$$

and

$$\boxed{T^{\gamma}P^{1-\gamma} = \text{Constant}}$$

---

19. Heat Capacity

At Constant Volume

$$\boxed{Q = nC_v\Delta T}$$

At Constant Pressure

$$\boxed{Q = nC_p\Delta T}$$

---

20. Mayer's Relation

$$\boxed{C_p - C_v = R}$$

---

21. Ratio of Heat Capacities

$$\boxed{\gamma = \frac{C_p}{C_v}}$$

For Monoatomic Gas

$$\boxed{\gamma = \frac{5}{3}}$$

For Diatomic Gas

$$\boxed{\gamma = \frac{7}{5}}$$

---

22. Internal Energy of Ideal Gas

$$\boxed{U = \frac{f}{2}nRT}$$

where f = Degrees of Freedom.

---

23. Work Done in Adiabatic Process

$$\boxed{W = \frac{P_1V_1 - P_2V_2}{\gamma - 1}}$$

Thermodynamic Processes Summary

Process	Constant	Heat	Work	Internal Energy
Isothermal	Temperature	Q =W	✔	ΔU=0
Isochoric	Volume	Q = ΔU	0	✔
Isobaric	Pressure	✔	PΔV	✔
Adiabatic	No Heat	0	✔	ΔU = −W

Exam Tips

- Isothermal Process→Internal Energy does not change
- Adiabatic Process→Heat Transfer: Zero
- Remember

$$\boxed{C_p > C_v}$$

CHAPTER-12: KINETIC THEORY OF GASES

Part–1: Ideal Gas • Kinetic Theory • Gas Pressure • RMS Speed

1. Ideal Gas

An ideal gas is a hypothetical gas which obeys the gas laws at all temperatures and pressures.

Ideal Gas Equation

$$\boxed{PV = nRT}$$

Where

- P = Pressure
- V = Volume
- n = Number of moles
- R = Universal Gas Constant
- T = Absolute Temperature (Kelvin)

---

2. Assumptions of Kinetic Theory

- Gas consists of a large number of molecules.
- Molecules are point masses.
- Molecules move randomly in all directions.
- Collisions are perfectly elastic.
- Molecular volume is negligible compared to the container volume.
- No intermolecular force acts except during collisions.

---

3. Pressure of an Ideal Gas

From Kinetic Theory,

$$\boxed{P = \frac{1}{3}\rho c_{\text{rms}}^2}$$

Where, ρ = Density of gas and c_{rms} = Root Mean Square Speed

---

4. Kinetic Energy of One Molecule

$$\boxed{KE = \frac{1}{2}mv^2}$$

---

5. Average Translational Kinetic Energy

$$\boxed{\frac{3}{2}kT}$$

Where, k = Boltzmann Constant

$$\boxed{k = 1.38 \times 10^{-23} J/K}$$

---

6. Total Kinetic Energy of n Moles

$$\boxed{KE = \frac{3}{2} nRT}$$

7. Root Mean Square (RMS) Speed

$$\boxed{c_{\text{rms}} = \sqrt{\frac{3RT}{M}}}$$

Where, M = Molar Mass (kg/mol)

8. Relation with Pressure

$$\boxed{c_{\text{rms}} = \sqrt{\frac{3P}{\rho}}}$$

9. Most Probable Speed

$$\boxed{c_p = \sqrt{\frac{2RT}{M}}}$$

10. Average Speed

$$\boxed{c_{avg} = \sqrt{\frac{8RT}{\pi M}}}$$

11. Relation Among Speeds

$$\boxed{c_p < c_{avg} < c_{rms}}$$

Important Constants

Universal Gas Constant

$$\boxed{R = 8.314 J\, mol^{-1} K^{-1}}$$

Boltzmann Constant

$$\boxed{k = 1.38 \times 10^{-23} J/K}$$

Exam Tips

- RMS Speed greater than **Average Speed**
- RMS Speed increases upon increasing the temperature
- Kinetic Energy depends only on **Absolute Temperature (Kelvin)**

Part–2: Degrees of Freedom • Equipartition of Energy • Specific Heat

12. Degrees of Freedom (f)

The number of independent ways in which a molecule can possess energy is called **Degrees of Freedom**.

Monoatomic Gas

$$\boxed{f = 3}$$

(Only Translational at all temperature)

Diatomic Gas (Ordinary Temperature)

$$\boxed{f = 5}$$

(3 Translational + 2 Rotational)

Diatomic Gas (High Temperature)

$$\boxed{f = 7}$$

(3 Translational + 2 Rotational + 2 Vibrational)

Polyatomic Gas

$$\boxed{f = 6}$$

or more (depending on molecular structure and temperature)

13. Law of Equipartition of Energy

According to this law,
Each degree of freedom contributes an average energy of

$$\boxed{\frac{1}{2}kT}$$

per molecule.

14. Total Average Energy per Molecule

$$\boxed{E = \frac{f}{2}kT}$$

15. Total Internal Energy of n Moles

$$\boxed{U = \frac{f}{2}nRT}$$

16. Molar Specific Heat at Constant Volume

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

17. Molar Specific Heat at Constant Pressure

$$\boxed{C_P = C_V + R}$$

or

$$\boxed{C_P = \frac{f+2}{2}R}$$

18. Ratio of Specific Heats

$$\boxed{\gamma = \frac{C_P}{C_V}}$$

Monoatomic Gas

$$\boxed{\gamma = \frac{5}{3} = 1.67}$$

Diatomic Gas

$$\boxed{\gamma = \frac{7}{5} = 1.40}$$

19. Mean Free Path

Average distance travelled by a molecule between two successive collisions.

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

Where

- d = Molecular Diameter
- n = Number Density

20. Avogadro Number

$$\boxed{N_A = 6.022 \times 10^{23} mol^{-1}}$$

21. Universal Gas Constant Relation

$$\boxed{R = N_A k}$$

CHAPTER-13: OSCILLATIONS

Part–1: Simple Harmonic Motion (SHM) – Basic Formulae

1. Periodic Motion

A motion which repeats itself after equal intervals of time is called **Periodic Motion**.

---

2. Oscillatory Motion

A body moving to and fro about its mean position repeatedly is said to perform **Oscillatory Motion**.

---

3. Simple Harmonic Motion (SHM)

A motion in which the restoring force (or acceleration) is directly proportional to the displacement from the mean position and always directed towards the mean position.
Mathematically,

$$\boxed{F \propto -x}$$

Or

$$\boxed{F = -kx}$$

---

4. Restoring Force

According to Hooke's Law,

$$\boxed{F = -kx}$$

Where, k = Force Constant ; x = Displacement

---

5. Acceleration in SHM

Using Newton's Second Law,

$$\boxed{a = -\omega^2 x}$$

This is the **fundamental equation of SHM**.

---

6. Displacement Equation

$$\boxed{x = A\sin(\omega t + \phi)}$$

Or

$$\boxed{x = A\cos(\omega t + \phi)}$$

Where,A = Amplitude ; ω = Angular Frequency ; ϕ = Initial Phase

---

7. Amplitude

Maximum displacement from the mean position.
Symbol: A

---

8. Angular Frequency

$$\boxed{\omega = \frac{2\pi}{T}}$$

Also,

$$\boxed{\omega = 2\pi f}$$

Unit: rad/s

9. Time Period

Time taken for one complete oscillation.

$$\boxed{T = \frac{2\pi}{\omega}}$$

Unit: second

10. Frequency

Number of oscillations per second.

$$\boxed{f = \frac{1}{T}}$$

Unit: Hertz (Hz)

11. Phase

Phase at any instant

$$\boxed{\theta = \omega t + \phi}$$

12. Relation between Frequency and Angular Frequency

$$\boxed{\omega = 2\pi f}$$

Part–2 : Velocity • Energy • Spring–Mass System • Simple Pendulum

13. Velocity in SHM

Velocity is the rate of change of displacement.

$$\boxed{v = \omega\sqrt{A^2 - x^2}}$$

Also,

$$\boxed{v = \pm\omega\sqrt{A^2 - x^2}}$$

14. Maximum Velocity

At Mean Position (x = 0)

$$\boxed{v_{max} = A\omega}$$

15. Acceleration in SHM

$$\boxed{a = -\omega^2 x}$$

16. Maximum Acceleration

At Extreme Position

$$\boxed{a_{max} = A\omega^2}$$

17. Kinetic Energy in SHM

$$\boxed{KE = \frac{1}{2} m\omega^2 (A^2 - x^2)}$$

18. Potential Energy in SHM

$$\boxed{PE = \frac{1}{2} m\omega^2 x^2}$$

19. Total Energy

Total Mechanical Energy remains constant.

$$\boxed{E = \frac{1}{2} m\omega^2 A^2}$$

Also,

$$\boxed{E = KE + PE}$$

20. Spring–Mass System

Time Period

$$\boxed{T = 2\pi\sqrt{\frac{m}{k}}}$$

Angular Frequency

$$\boxed{\omega = \sqrt{\frac{k}{m}}}$$

Frequency

$$\boxed{f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}}$$

21. Simple Pendulum

Time Period

$$\boxed{T = 2\pi\sqrt{\frac{L}{g}}}$$

Frequency

$$\boxed{f = \frac{1}{2\pi}\sqrt{\frac{g}{L}}}$$

22. Conditions for Simple Pendulum Formula

The formula $T = 2\pi\sqrt{\frac{L}{g}}$

is valid only if

- Oscillations are small.
- String is massless.
- Bob is treated as a point mass.
- Air resistance is neglected.

23. Energy Variation

At Mean Position

- Velocity = Maximum
- Kinetic Energy = Maximum
- Potential Energy = Zero

At Extreme Position

- Velocity = Zero
- Potential Energy = Maximum
- Kinetic Energy = Zero

Exam Tips

□ SHM Important Formula

$$\boxed{a = -\omega^2 x}$$

□ Negative Sign→Acceleration Towrads Mean Position
□ If Time Period given, then find ω
□ Total Energy→ **Constant**
□ Mean Position→**Speed greatest**
□ Extreme Position →**Acceleration greatest**
□ Simple Pendulum→Time Period depends on **Mass**

CHAPTER-14:WAVES

Part–1: Wave Motion • Wave Equation • Wave Parameters

1. Wave Motion

Wave motion is the propagation of a disturbance from one point to another without the actual transfer of matter.

---

2. Types of Waves

(i) Mechanical Waves

Require a material medium.

Examples

- Sound Waves
- Water Waves
- Waves on a String

(ii) Electromagnetic Waves

Do not require any material medium.

Examples

- Light
- Radio Waves
- X-rays

---

3. Transverse Waves

Particles vibrate **perpendicular** to the direction of wave propagation.

Examples

- Waves on a stretched string
- Electromagnetic Waves

---

4. Longitudinal Waves

Particles vibrate **parallel** to the direction of propagation.

Examples

- Sound Waves
- Compression Waves

---

5. Important Wave Parameters

Amplitude

Maximum displacement of particles.

$$\boxed{A}$$

Wavelength

Distance between two consecutive particles in the same phase.

$$\boxed{\lambda}$$

SI Unit: m

Time Period
Time taken to complete one oscillation.

$$\boxed{T}$$

Frequency
Number of oscillations per second.

$$\boxed{f = \frac{1}{T}}$$

Unit: Hz

Angular Frequency

$$\boxed{\omega = 2\pi f}$$

6. Wave Speed
The speed of propagation of a wave is

$$\boxed{v = f\lambda}$$

7. Wave Number

$$\boxed{k = \frac{2\pi}{\lambda}}$$

Unit: rad/m

8. Phase
Phase of a wave

$$\boxed{\phi = \omega t - kx}$$

9. Progressive Wave Equation
For a wave travelling in the positive x-direction,

$$\boxed{y = A\sin(\omega t - kx)}$$

For a wave travelling in the negative x-direction,

$$\boxed{y = A\sin(\omega t + kx)}$$

10. Phase Difference

$$\boxed{\Delta\phi = \frac{2\pi x}{\lambda}}$$

11. Relation Between Phase Difference and Path Difference

$$\boxed{\Delta\phi = \frac{2\pi}{\lambda}\Delta x}$$

Part–2: Standing Waves • Harmonics • Organ Pipes • Doppler Effect

12. Principle of Superposition

When two or more waves travel simultaneously through a medium, the resultant displacement is the algebraic sum of individual displacements.

$$\boxed{y = y_1 + y_2}$$

13. Standing (Stationary) Waves

Standing waves are formed by the superposition of two waves of the same frequency, amplitude and speed travelling in opposite directions.

Equation

$$\boxed{y = 2A\sin kx\cos\omega t}$$

14. Node (N)

A point where displacement is always zero.
Distance between two consecutive nodes

$$\boxed{\frac{\lambda}{2}}$$

15. Antinode (A)

A point where displacement is maximum.
Distance between two consecutive antinodes

$$\boxed{\frac{\lambda}{2}}$$

16. Distance Between Node and Adjacent Antinode

$$\boxed{\frac{\lambda}{4}}$$

17. Fundamental Frequency

Lowest possible frequency of vibration.

Also called First Harmonic

18. Harmonics

Frequency of nth Harmonic

$$\boxed{f_n = nf_1}$$

19. Vibrating String

For a stretched string,
Fundamental Frequency

$$\boxed{f = \frac{1}{2L}\sqrt{\frac{T}{\mu}}}$$

Where

- L = Length
- T = Tension
- μ = Mass per Unit Length

20. Open Organ Pipe

Fundamental Frequency

$$\boxed{f = \frac{v}{2L}}$$

nth Harmonic

$$\boxed{f_n = \frac{nv}{2L}}$$

All harmonics are present.

21. Closed Organ Pipe

Fundamental Frequency

$$\boxed{f = \frac{v}{4L}}$$

Only Odd Harmonics are present.

$$\boxed{f_n = \frac{(2n-1)v}{4L}}$$

22. Beats

Beat Frequency

$$\boxed{f_b = | f_1 - f_2 |}$$

23. Doppler Effect (Basic Formula)

Observed Frequency

$$\boxed{f' = f\left(\frac{v \pm v_o}{v \mp v_s}\right)}$$

Where

- v_0 = Observer Speed
- v_s = Source Speed
- v = Speed of Sound

Exam Tips

 Wave Speed→ depends on Medium
 Frequency→ is determined by Source
 Changing Medium→**Frequency does not change** whereas **Speed and Wavelength changes**
 Open Organ Pipe → Odd & Even Harmonics
 Closed Organ Pipe → only Odd Harmonics
 Distance between Node and Antinode

$$\boxed{\frac{\lambda}{4}}$$
