Physical World

Classical physics deals with **macroscopic** domain (**everyday and laboratory)**
egs: Mechanics, Optics, Thermodynamics
Microscopic domain includes atomic, molecular and nuclear phenomena

Units and Measurement

SI Units

Fundamental Units

Mass – kilogram (**kg**)	Electric Current – ampere (**A**)	**Supplementary Units**
Length ---- metre (**m**)	Temperature – kelvin (**K**)	
Time ----- seconds (**s**)	Amount of Substance – mole (**mol**)	Angle – radian (**rad**)
	Luminous Intensity – candela (**cd**)	Solid Angle – steradian (**sr**)

Derived Units

$$Velocity = \frac{Displacement}{Time}$$ **m/s** or **ms^{-1}**

$$Speed = \frac{Total\ path\ length}{Time\ interval}$$ **m/s** or **ms^{-1}**

$$Acceleration = \frac{Change\ \text{in}\ velocity}{Time}$$ **m/s^2** or **ms^{-2}**

Acceleration due to gravity **m/s^2** or **ms^{-2}**

Momentum = mass x velocity **kgms^{-1}**

$$Force = \frac{Change\ \text{in}\ momentum}{Time} = ma$$ **kgms^{-2} or newton (N)**

Energy or Work = Force x displacement **kgm^{2}s^{-2} or newton (Nm) or joule (J)**

Dimensions

Fundamental Quantities

Mass – [M]
Length ---- [L]
Time ----- [T}

Derived Units

$$Velocity = \frac{Displacement}{Time}$$ **LT^{-1}**

$$Speed = \frac{Total\ path\ length}{Time\ interval}$$ **LT^{-1}**

$$Acceleration = \frac{Change\ in\ velocity}{Time} \quad \mathbf{LT^{-2}}$$

Acceleration due to gravity **LT^{-2}**

Momentum = mass x velocity **MLT^{-1}**

$$Force = \frac{Change\ in\ momentum}{Time} = ma \quad \mathbf{MLT^{-2}}$$

Energy or Work = Force x displacement **ML^2T^{-2}**

Homogeneity Principle

The dimensions of the each term on both sides of an equation must be same

Q. Check the dimensional consistancy (Check the correctness) of an equation **F = ma**

[F] = **MLT^{-2}**
[ma] **= M x LT^{-2} = MLT^{-2}**
According to homogeneity principle equation **F=ma** is correct

Limitations of Dimensional Analysis

1. **Dimensionless** constants (trigonometric) can't be obtained
2. It checks only **dimensional** correctness **not exact** correctness

Motion in a Straight line

Path Length (Distance Travelled)

The total length of the path travelled by an object is called Path Length.
It is a scalar quantity. It is always positive.

Displacement

Dispalcement is the change in position of the object.
It is a vector quantity. It can be positive, zero and negative values

Distance (path length) is always greater or equal to displacement.
For a straight line motion, diatance and displacement are equal.

$$Average\ speed = \frac{Total\ path\ length}{Time\ interval}$$

$$Average\ Velocity = \frac{Displacement}{Time\ interval} = \frac{x_2 - x_1}{t_2 - t_1} = \frac{\Delta x}{\Delta t}$$

$$Instantaneous\ velocity = velocity = \frac{\lim}{\Delta t \dashrightarrow 0} \quad \frac{\Delta x}{\Delta t} = \frac{dx}{dt}$$

Velocity is the time rate of change of the displacement

Velocity – time relation

$$acceleration\ a = \frac{change\ in\ velocity}{time} = \frac{v-u}{t}$$

cross multiplying **at = v-u**

or **v = u + at**

Displacement – time relation

Displacement = average velocity x time

$$s = \frac{u+v}{2}t$$

using **v = u + at**

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

Velocity – displacement relation

we have

$$a = \frac{v-u}{t} \quad \text{and} \quad s = \frac{u+v}{2}t$$

multiplying $as = \frac{v-u}{t}\frac{u+v}{2}t = \frac{v^2-u^2}{2}$

cross multiplying $2as = v^2 - u^2$ or $v^2 = u^2 + 2as$

Area under **velocity – time** graph gives **displacement**

Slope of **velocity – time** graph gives **acceleration**

Motion in a Plane

A **scalar quantity** has only magnitude and no direction

It can have zero or positive values

Eg. distance, speed, mass , temperature, time, work, power

A **vector quantity** has both magnitude and direction

It can have **negative**, **zero** or **positive** values

Eg.displacement, velocity, acceleration, force, momentum, torque

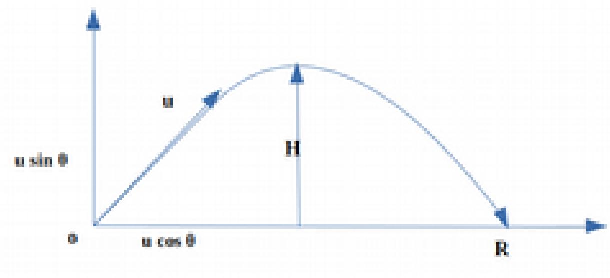
Projectile Motion

A body projected in air and moves under the **influence of gravity** alone is called projectile

It is a **two** dimensional motion

Vertical motion is **non-uniform** motion, **horizontal** motion is **uniform** motion

Vertical and horizontal motions are **completely independent**



Maximum height (H)

(draw above fig)

Consider **vertical** motion of the projectile

Final velocity **v = 0** at maximum height and **a = -g**

initial velocity u --> u sin θ

and s = H = ?

then the equation $v^2 = u^2 + 2as$ becomes

$0 = (u \sin\theta)^2 - 2gH$ or $H = \frac{u^2 \sin^2\theta}{2g}$

Time of Flight (T)

(draw above fig)

Consider **vertical** motion of the projectile

a = -g, s =0 (no vertical displacement)

initial velocity u --> u sin θ t = T = ?

then the equation $s = ut + \frac{1}{2}at^2$ becomes

$$0 = u \sin\theta T - \frac{1}{2} g T^2$$

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

Horizontal Range (R)

(draw above fig)

Consider **horizontal** motion of the projectile (it is a uniform motion)

Displacement = velocity x Time

velocity = u cos θ

$$Time = \frac{2u \sin\theta}{g}$$

$$Displacement\ R = u \cos\theta \frac{2u \sin\theta}{g} = \frac{u^2 2 \sin\theta \cos\theta}{g} = \frac{u^2}{g} \sin 2\theta$$

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

Maximum range R_{max}

Range is maximum at **sin2θ =1** (maximum value)

ie **2θ = 90** **0r** **θ = 45 degree**

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

Trajectory is a Parabola

Path of the projectile is called trajectory and it is a parabola, since its equation is in the form of

$$y = ax + bx^2$$

Laws of Motion

Momentum

p = m v

Momentum is a vector quantity.

Unit = kgm/s

Dimensions [p] = ML T^{-1}

Newton's Second Law's of Motion

Rate of change of momentum with respect to time is directional proportional to applied force

$$F = \frac{dp}{dt}$$

Proof of **F = ma**

According to Newto's second law $F = \frac{dp}{dt}$

But momentum p = mv

$F = d\frac{(mv)}{dt} = m\frac{dv}{dt} = ma$ since $\frac{dv}{dt} = a$ is the acceleration

Law of Conservation of Momentum

The total momentum of an **isolated** system of interacting particles is conserved.

Or

Ttotal momentum of a system of particles remains constant if there is no external force is acting

Proof

According to second law $F = \frac{dp}{dt}$

For an isolated system F = 0

$\frac{dp}{dt} = 0$ or **dp = 0**

That means **P = a constant**

Friction - Friction is a necessary evil

Static friction

It **opposes** impending relative motion between two surfaces in contact

It is **independent** of the area of contact

The limiting value of static friction $(fs)_{max}$, varies with the normal force (N)

$(fs)_{max} = \mu_s N$

μ_s is the coefficient of static friction

Kinetic friction

It opposes relative motion between surfaces in contact

Kinetic friction is independent of the area of contact.

Kinetic friction is nearly independent of the velocity.

Kinetic friction , f k varies with the normal force(N) , $f_k = \mu_k N$

μ_k is the coefficient of kinetic friction

Disadvantages of friction

Friction causes energy loss (Heat ao Sound)

It produces wear and tear

Advantages of friction

Friction helps to walk or move a car

Breaks are applied due to Friction

Friction provides centripetal force for circular motion

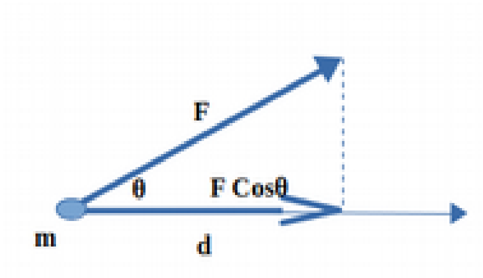
Methods to reduce friction

(1) Lubricants are a way of reducing kinetic friction in a machine.
(2) Another way is to use ball bearings between two moving parts of a machine.

Work , Energy and Power

WORK

Work is said to be done, if an object is **displaced** (d) on the application of **Force** (F).



F Cosθ is the effective Force in the direction of displacement

Work **W** = (F cos θ)d = F d Cos θ= **F.d**

So Work is a **Scalar Quantity**

It's unit is **Joule** (J) or $kgm^2 s^{-2}$

It's dimensional formula is $[ML^2T^{-2}]$

Work can be **positive , zero or negative** (even it is a **scalar**).

Energy

Energy is the **capacity to do work**
Energy is a Scalar Quantity
It's unit is Joule (J) or $kgm^2 s^{-2}$
It's dimensional formula is $[ML^2T^{-2}]$
(Same as that of work)

Kinetic Energy

It is the energy possessed by a moving body KE = ½ mv^2

Potential Energy It is a **stored energy**

Gravitational PE = mgh It is due to it's **position** (height = h)

Elastic PE, due to state of **strain** Eg: Energy stored in a stretched spring

Conservative Force

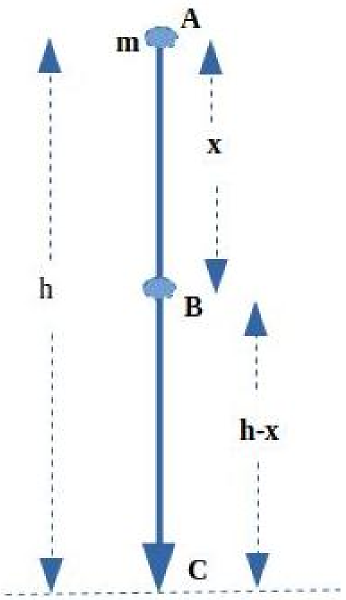
If force is conservative, work done is **independent** of the path

Work done depends only upon **initial** and **final** positions of the body

Eg: Work done by Gravity, EM force, Nuclear force, etc

Example of Non-conservative force: Friction, Viscous force, etc

Conservation of Mechanical Energy for a Freely Falling Body



At **position A**

KE = 0
PE = mgh
TE = KE + PE = 0+mgh = **mgh**

At **position B**
KE = mgx
PE = mg(h-x)
TE = KE + PE = mgx+mg(h-x) = **mgh**

At **position C**
KE = mgh
PE = 0
TE = KE + PE = mgh+0 = **mgh**
At any point, Total Energy **remains constant**.
So **total mechanical energy** is conserved during the free fall.

Power

Power is the **rate of doing** Work

$$Power = \frac{Work}{Time} \quad \text{0r} \quad Average\ Power = \frac{W}{t}$$

$$Instantaneous\ Power = \frac{dW}{dt} \quad \text{or} \quad Instantaneous\ Power = \vec{F}.\vec{v}$$

Power is a Scalar Quantity

It's unit is Watt (W) or Js^{-1}

It's dimensional formula is $[ML^2T^{-3}]$

Another unit of power is the horse-power (hp)

1 hp = 746 W

Commercial unit of power is kilowatt hour (kWh)

1kWh = 3.6 × 10^6 J

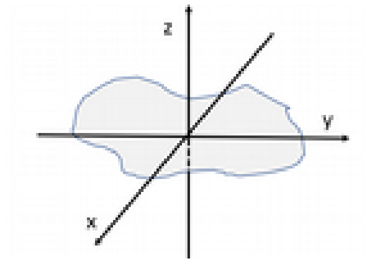
Systems of particle and Rotational Motion

Theorems of Perpendicular and Parallel Axes

Perpendicular Axes Theorem

$\mathbf{I_z = I_x + I_y}$

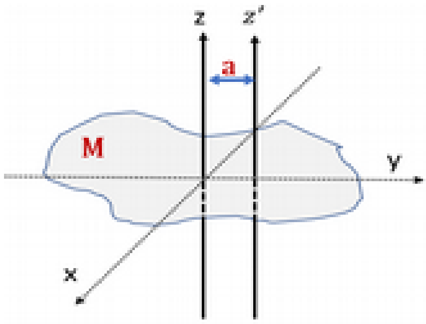
The moment of inertia of a plane lamina about z axis is equal to the sum of its moments of inertia about x-axis and y-axis, if the lamina lies in xy plane



Parallel Axes Theorem

$\mathbf{I_{z'} = I_z + Ma^2}$

The moment of inertia of a body about any axis is equal to the sum of the moment of inertia of the body about a parallel axis passing through its centre of mass and the product of its mass and the square of the distance between the two parallel axes.



Gravitation

Acceleration due to gravity of the Earth (g)

The acceleration gained by a body due to the gravitational force of earth is called acceleration due to gravity.

Expression for g

We know Gravitational force between **Earth (mass M)** and the **body (mass m)**

$|F| = G\frac{Mm}{R^2}$ and **F = mg**

Where R is the radius of Earth (size of the body is very small)

$g = \frac{GM}{R^2}$ is the acceleration due to gravity at the surface of the Earth ($g = 9.8\ ms^{-2}$)

Acceleration due to gravity at a height (h) above the surface of the earth

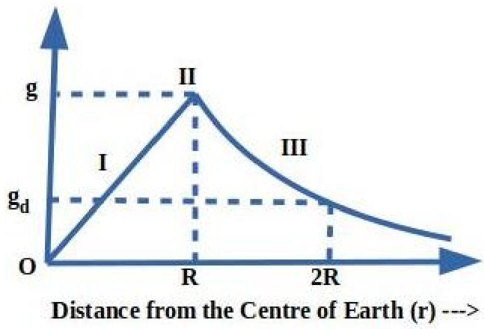
Acceleration due to gravity **decreases** with altitude (height)

$g(h) = \frac{GM}{(R+h)^2}$ and $g(h) = g\left(1-\frac{2h}{R}\right)$

Acceleration due to gravity at a depth d below the surface of the earth

Acceleration due to gravity **decreases** with depth

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



Acceleration due to gravity is **maximum** at the **surface** of the Earth

Mechanical Properties of Solids

Hooke's Law
For small deformations the stress is directly proportional to strain. This is known as Hooke's law.

Stress ∝ Strain

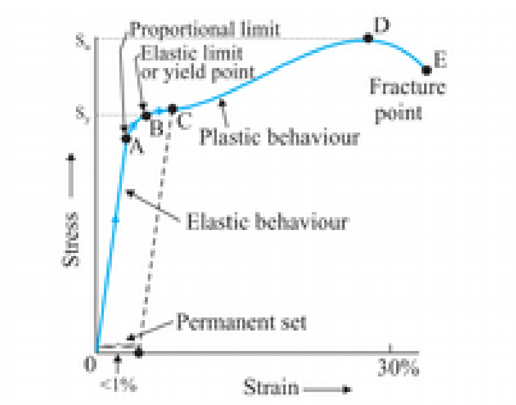
$$\frac{Stress}{Strain} = a\, constant = Modulus\ of\ Elasticity$$

The SI unit of modulus of elasticity is N m $^{-2}$ or pascal (Pa)

Dimensional formula is [$ML^{-1}T^{-2}$]

(same as that of stress,since strain is unitless)

Stress-Strain Curve



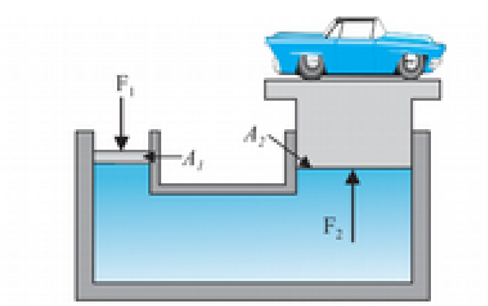
In the region from O to A
Hooke's law is obeyed (linear part of the curve)
In the region from A to B
The point B in the curve is known as yield point or elastic limit
In the region from B to D
The point D on the graph is the ultimate tensile strength (S u) of the material
In the region from D to E
Beyond this point D, additional strain is produced even by a reduced applied force and fracture occurs at point E.
The point E is called Fracture Point.

Mechanical Properties of Fluids

Pascal's law

Whenever **external pressure** is applied on any part of a fluid contained in a **vessel**, it is transmitted **undiminished** and **equally** in all directions.

Hydraulic lift



$$P_1 = \frac{F_1}{A_1} \quad \text{and} \quad P_2 = \frac{F_2}{A_2}$$

According to Pascal's law $\mathbf{P_1 = P_2}$

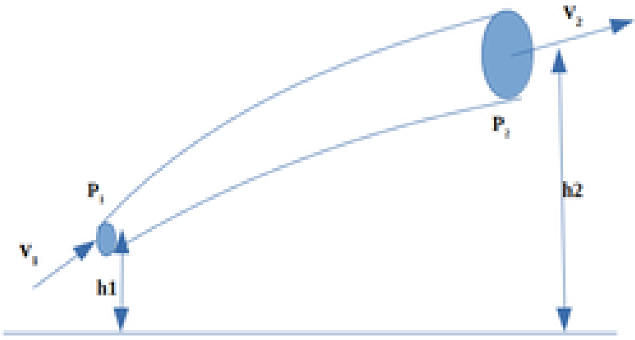
$$\frac{F_1}{A_1} = \frac{F_2}{A_2} \quad \text{or}$$

$$F_2 = F_1 \frac{A_2}{A_1}$$ Since $\mathbf{A_2 >> A_1}$, $\mathbf{F_2 >> F_1}$

Bernoulli's Principle
It is a consequence of **Conservation** of Energy

It is applied to **non viscous**, **incompressible** fluid motion in steady state

Pressure Energy + Kinetic Energy + Potential Energy = a constant



Proof: **ΔW = ΔKE + ΔPE**

For any two points

$$(P_1 - P_2)\Delta V = \frac{1}{2}m(v_2^2 - v_1^2) + mg(h_2 - h_1)$$

For **unit unit volume** of a fluid with density

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

Dividing throughout by **ΔV**

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g h_2$$ That is $$P + \frac{1}{2}\rho v^2 + \rho g h = a\ constant$$

P – Pressure head

$\frac{1}{2}\rho v^2$ – Velocity head

ρgg – Position head

Thermal Properties of Matter

Thermal Expansion

The increase in the dimensions of a body due to the increase in its temperature is called thermal expansion.

Three types of thermal expansions are

1.Coefficient of Linear expansion $\alpha_L = \frac{\Delta L}{L\ \Delta T}$

2. Coefficient of area expansion $\alpha_A = \frac{\Delta A}{A\ \Delta T}$

3. Coefficient of volume expansion $\alpha_V = \frac{\Delta V}{V\ \Delta T}$

Relation between α_L **and** α_A $\quad \alpha_A = 2\,\alpha_L$

Relation between α_L **and** α_V $\quad \alpha_V = 3\,\alpha_L$

Thermal Expansion of Water(Or) Anomalous Behavour of Water

Water **contracts** on heating from **0 °C to 4 °C.** That is water has **minimum volume** and hence **maximum density** at **4 °C** . When water is heated after 4 °C ,it expands like other liquids.

Thermodynamics

First law of Thermodynamics

The heat supplied to the system is partly used to increase the internal energy of the system and the rest is used to do work on the environment . **ΔQ = ΔU + ΔW**

Thermodynamic Processes

Isothermal process - at constant temperature **PV = constant**

Isobaric process - at constant pressure

Isochoric process – at constant volume

Adiabatic process - No heat flow between the system and the surroundings

PV^γ = constant

Heat Engine

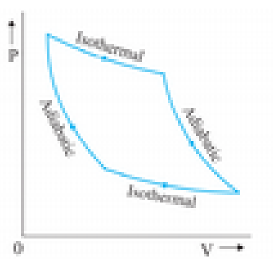
Processes in Carnot's cycle

Isothermal Expansion

Adiabatic Expansion

Isothermal Compression

Adiabatic Compression



Efficiencey of Heat Engine

$$\eta = \frac{Work}{Input\ Heat} = \frac{Q_1 - Q_2}{Q_1} = 1 - \frac{Q_2}{Q_1} = 1 - \frac{T_2}{T_1}$$

Kinetic Theory

- A given amount of gas is a collection of a large number of molecules that are in random motion.
- At ordinary pressure and temperature, the average distance between molecules is very large compared to the size of a molecule (2 Å).
- The interaction between the molecules is negligible.
- The molecules make elastic collisions with each other and also with the walls of the container .
- As the collisions are elastic , total kinetic energy and total momentum are conserved .
- The average kinetic energy of a molecule is proportional to the absolute temperature of the gas
-

Oscillations

For SHM,

F α x or **F = -kx**

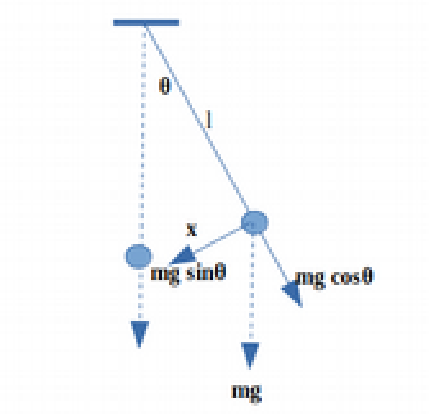
On solving we get $\omega = \sqrt{\frac{k}{m}}$ **is the angular velocity**

Period of Oscillations of a Simple Pendulum

We have F = -kx

or **-mg sin θ = -kx**

but from the figure sin θ = x/l



$$mg\frac{x}{l} = kx$$

$$\omega^2 = \frac{k}{m} = \frac{g}{l} \quad \text{or} \quad \omega = \sqrt{\frac{g}{l}}$$

$$\omega = 2\pi\nu = \sqrt{\frac{g}{l}}$$

or fregueny $\nu = \frac{1}{2\pi}\sqrt{\frac{g}{l}}$ and period $T = \frac{1}{\nu} = 2\pi\sqrt{\frac{l}{g}}$

Waves

Consider a wave propagating in **positive x** direction with initial phase φ = 0

y (x, t) = a sin (kx – ωt)

Consider a wave propagating in **negative x** direction with initial phase φ = 0

y (x, t) = a sin (kx + ωt)

Speed of a **Transverse** Wave on Stretched String $v = \sqrt{\frac{T}{\mu}}$

μ - the linear mass density and T - the tension

The speed of propagation of a **longitudinal** wave in a fluid $v = \sqrt{\frac{B}{\rho}}$

B= the bulk modulus of medium

ρ = the density of the medium