Editorial Board

PHYSICS

SMILE

PLUS ONE PHYSICS

TABLE OF CONTENT

CHAPTER 1

UNITS AND MEASUREMENTS

What are physical quantities?
All those quantities which can be measured directly or indirectly are called physical quantities.
Example:- length, mass, time, temperature, speed, force, electric current, etc.

Two types of physical quantities.

1. **fundamental physical quantities.**

The physical quantities which are not defined in terms of other physical quantities are called fundamental physical quantities.
(In physics we need a minimum of seven fundamental quantities .These are **mass, length, time, electric current, temperature, luminous intensity and amount of substance.)**

2. **derived physical quantities.**

The physical quantities derived from fundamental physical quantities are called derived physical quantities.
(All physical quantities other than the seven fundamental physical quantities are derived quantities.)
Example:- velocity, acceleration, force, momentum, etc.

The measurement of physical quantity
Measure of a physical quantity = numerical value(n) x unit.
The measure Q = nu , n is the numerical value and u is the unit.
Example length of a room = 5m= 500cm.
(smaller the unit size, the larger is the numerical value associated with the physical quantity.)

physical unit
The standard amount of a physical quantity chosen to measure the physical quantity of the same kind is called a *physical unit.*

Fundamental and derived units.
The units of fundamental quantities such as mass, length, etc. are fundamental units.
Physical units which can be expressed in terms of the fundamental units are called *derived units*.
Example: Consider the unit of speed,

$$speed = \frac{distance\,travelled}{time\,taken}$$

therefore, $unit\ of\ speed = \frac{unit\ of\ distance}{unit\ of\ time} = \frac{metre}{second} = ms^{-1}$

thus the unit of speed (ms^{-1})is a derived unit. Because it is expressed in the fundamental units of length and time.

Some commonly used system of units are

1. **cgs system**:- it is based on centimetre, gram and second as the fundamental units of length, mass and time respectively.
2. **fps system**:- it is based on foot ,pound and second as the fundamental units of length, mass and time respectively.
3. **mks system**:- it is based on metre ,kilogram and second as the fundamental units of length, mass and time respectively.

The cgs and mks systems were set up in France and the fps system is a British system.

S I System of units:-

In SI system, there are seven Fundamental units and two Supplementary units.

Fundamental units:-

Quantities	Units	Symbols
Mass	kilogram	kg
Length	metre	m
Time	second	s
Temperature	kelvin	K
Electric current	ampere	A
Luminous intensity	candela	cd
Amount of substance	mole	mol

Supplementary units:-

Quantities	Units	Symbols
Angle	radian	rad
Solid angle	steradian	sr

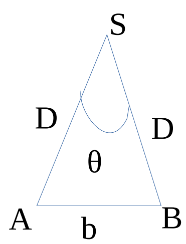
parallax method for measuring large distances.(Indirect length measurements.)

Parallax.

To measure the distance D of a far away planet S by the parallax method , we observe it from two different positions A and B on the earth as shown in the figure . The distance between A and B is the basis b.

We measure the angle θ between the two directions of observation, we get the distance D of the planet using the equation

$D=\frac{b}{\theta}$ (since $\theta=\frac{b}{D}$)



Dimensions and Dimensional analysis.

Dimensions are the powers of the fundamental quantities involved in a physical quantity.
using the square brackets [ ] round a quantity we represent 'the dimensions of' the quantity.
For example [area] is read as *dimensions of area*.

In mechanics, all the physical quantities can be written in terms of the dimensions [L], [M]and [T].
[area] = [length] x [breadth]=[L] x[L] = $[L]^2$ = $[L^2]$
Force = mass × acceleration
= mass x velocity/time
= mass x displacement/time/time
= mass x dispalcement /$(time)^2$
= mass × (length)/$(time)^2$
= $\frac{[[M]][L]}{[T]^2}$ = $[M]^1[L]^1[T]^{-2}$ = $[M^1L^1T^{-2}]$
Thus, the force has one dimension in mass, one dimension in length, and –2 dimensions in time.

Dimensional formula

The expression which shows how and which of the base quantities represent the dimensions of a physical quantity is called the dimensional formula of the given physical quantity.
Example :- the dimensional formula of area is $[M^0 L^2 T^0]$
the dimensional formula of volume is $[M^0 L^3 T^0]$.

Exercise

write the dimensional formulae of the following physical quantities.
1. mass density 4. force.
2. acceleration 5. work
3. linear momentum 6. kinetic energy

Dimensional equations

the dimensional equations are the equations, which represent the dimensions of a physical quantity in terms of the base quantities
the dimensional equations of volume[V] = $[M^0 L^3 T^0]$,
dimensional equations of speed [v] = $[M^0 L^1 T^{-1}]$,
dimensional equations of force [F] = $[M^1 L^1 T^{-2}]$ and
dimensional equations of mass density [ρ] = $[M^1 L^{-3} T^0]$

The principle of homogeneity of dimensions.

An equation in physics is dimensionally correct , only if the dimensions of all the term are same. This is the principle of homogeneity of dimensions.
If A = B + C is an equation in physics , it is dimensionally correct ,if [A] = [B] = [C] .

Dimensional analysis:- method of studying physical phenomena using dimensions

Applications of dimensional analysis.

1.To convert a physical quantity from one system of units to another:-

we use the relation $N_1 U_1 = N_2 U_2$

or $N_1 M_1^a L_1^b T_1^c = N_2 M_2^a L_2^b T_2^c$. That is

$$N_1 = N_2 \left(\frac{M_1}{M_2}\right)^a \left(\frac{L_1}{L_2}\right)^b \left(\frac{T_1}{T_2}\right)^c$$

Example :- the density of mercury is 13.6gcm^{-3} in CGS system. Find it's value in SI system.

Ans :- $13.6\,g\,cm^{-3} = ...kg\,m^{-3}$

$...= 13.6 \left(\frac{g}{kg}\right)^1 \left(\frac{cm}{m}\right)^{-3}$ = 13.6 x (g/1000g) x (cm/100cm)$^{-3}$ =13.6x 10^3

that is $13.6\,g\,cm^{-3} = 13.6 x 10^3 kg\,m^{-3}$

2.To check the dimensional correctness of a given physical relation:-

We use the principle of homogeneity of dimension.

Example :- Check the dimensional correctness of the following equations

1) $v = v_0 + at$ 2) $x - x_0 = v_0 t + \frac{1}{2} a t^2$

1) consider the equation $v = v_0 + at$. this equation is dimensionally correctness

if [v] = [v$_o$] = [at].

[v] = $L^1 T^{-1}$ ....(i) ,

[v$_o$] = $L^1 T^{-1}$ ....(ii) ,

[at] = [a][t] = $L^1 T^{-2} T^1 = L^1 T^{-1}$

[at] = $L^1 T^{-1}$. ...(iii)

from equation (i),(ii)and (iii) it is clear that [v] = [v$_o$] = [at] . Hence the equation $v = v_0 + at$ is dimensionally correct.

2) consider the equation $x - x_0 = v_0 t + \frac{1}{2} a t^2$ this equation is dimensionally correctness

$[x - x_0] = [v_0 t] = [\frac{1}{2} a t^2]$.

$[x - x_0] = L^1$ ......(i)

$[v_0 t] = (L^1 T^{-1}) T^1$ = $L^1 T^0$ = L^1 .....(ii)

$[\frac{1}{2} a t^2] = [a t^2]$ = $[a][t^2]$ = $(L^1 T^{-2})(T^2)$ = $L^1 T^0$ = L^1 .....(iii)

from eqns (i), (ii), and (iii) it is clear that $[x - x_0] = [v_0 t] = [\frac{1}{2} a t^2]$, hence the equation is dimensionally correct.

3. To derive a relationship between different physical quantities.

Example:- the centripetal force experienced by a body may depend on i) its mass(m) ii) its speed (v) and the radius (R) of its circular track. Using method of dimensions derive an expression for centripetal force(F).

Ans:- Let F ∞ m^a , F ∞ v^b ,F ∞ R^c
or F ∞ m^a v^b R^c that is
F = k $m^a v^b R^c$ ....(1)
where k is a dimensionless constant.
Now applying the principle of homogeneity of dimensions
we write [F] = [$m^a v^b R^c$]

$M^1 L^1 T^{-2}$ = [m^a] [v^b] [R^c]
= $M^a (L^1 T^{-1})^b L^c$
= $M^a (L^b T^{-b}) L^c$
$M^1 L^1 T^{-2}$ = $M^a L^{b+c} T^{-b}$ comparing the powers of similar terms we get
a = 1 , b + c = 1 and -b = -2 or b = 2 .
put b = 2 in the equation b+c = 1 we get c = -1 . substituting these values in equation (1) we get

F = k $m^1 v^2 R^{-1}$
F = k $\frac{mv^2}{R}$ it can be proved that k =1 so
F = $\frac{mv^2}{R}$

Exercise:- Suppose that the period of oscillation of a simple pendulum depends on (i) mass m of the bob ii) length of the pendulum l and iii) acceleration due to gravity g . Using the method of dimensions derive the expression for the time period of the simple pendulum .

CHAPTER 2
MOTION IN A STRAIGHT LINE

Motion in one , two and three dimensions
To describe the motion of an object if require a single position coordinate and time ,it is called **one dimensional motion** or **motion in a straight line**.
Eg :- 1) motion of a train along a straight track. 2) motion of a freely falling body.
To describe the motion of an object if require two position coordinates and time ,it is called **two dimensional motion** or **motion in a plane**.
Eg:- 1) motion of planets around the sun 2) motion of a carom coin
To describe the motion of an object if require all the three position coordinates and time ,it is called three dimensional motion or motion in a plane.
Eg:- a kite flying on a windy day. motion of a butterfly.

.Path length or distance travelled
Path length is defined as the total length of the path traversed by an object

.Displacement
Displacement is the change in position : $\Delta x = x_2 - x_1$.
Where x_2 and x_1 are the positions of the object at t_2 and t_1 ($t_2 > t_1$)
If $x_2 > x_1$ displacement is positive , If $x_2 < x_1$ displacement is negative
if $x_2 = x_1$ then displacement is zero.
Distance is a scalar quantity. Displacement is a vector.
Distance is always positive or zero.
Displacement may be positive , negative or zero.

.Speed
$$Speed = \frac{Distance}{time}$$
S I Unit: of speed is ms^{-1} it s dimensional formula is LT^{-1}
Uniform speed :- if an object covers equal distance in equal intervals of time ,it is said to be moving with uniform speed.

$$Average\ Speed = \frac{total\ Distance\ travelled}{Total\ time}$$
Instantaneous speed :- the speed of an object at an instant.

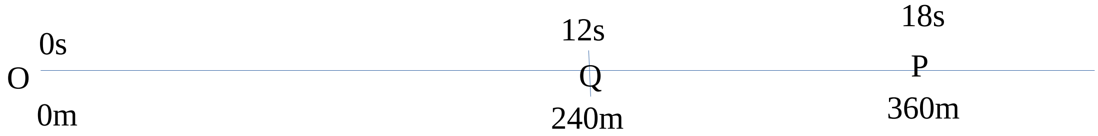
Velocity
$$Velocity = \frac{Displacement}{time}$$ S I Unit: of velocity is ms^{-1} it s dimensional formula is LT^{-1}
Uniform velocity:- if an object covers equal displacement in equal intervals of time ,it is said to be moving with uniform velocity. (Such a motion is called uniform motion)

$$Average\ velocity = \frac{Total\ displacement}{Total\ time} \qquad Average\ velocity,\ v_{av} = \frac{x_2 - x_1}{t_2 - t_1}$$

Instantaneous velocity:- the velocity if an object at an instant.
It is defined by the equation

$$\vec{v} = \lim_{\Delta t \to 0} \left(\frac{\Delta x}{\Delta t}\right)$$

Exercise:- A car is moving along X- axis as shown in figure. It moves from O to P in 18 s and then returns to Q in 6 seconds. What are the average velocity and average speed of the car in going from i) O to P and ii) O to P and back to Q ?



i) From O to P , $Average\ velocity = \frac{Total\ displacement}{Total\ time}$ = +360 m/ 18s = +20ms^{-1}

$Average\ Speed = \frac{total\ Distance\ travelled}{Total\ time}$ = 360m/18s = 20ms^{-1}

ii) From O to P and back to Q

$Average\ velocity = \frac{Total\ displacement}{Total\ time}$ = +240m/(18+6)s = 240m/24s = +10ms^{-1}

$Average\ Speed = \frac{total\ Distance\ travelled}{Total\ time}$ = (OP+PQ)m/(18+6)s

= (360+120)m/ 24s = 20ms^{-1}

Acceleration

It is defined by the equation

$$acceleration = \frac{Change\ in\ velocity}{time\ taken}$$

average acceleration:- It is defined by the equation $a_{av} = \frac{v_2 - v_1}{t_2 - t_1}$

Instantaneous acceleration is defied by the equation $\vec{a} = \lim_{\Delta t \to 0} \left(\frac{\Delta v}{\Delta t}\right)$

Kinematic Equations for Uniformly accelerated motion

1. $v = v_0 + at$
2. $x - x_0 = v_0 t + \frac{1}{2} a t^2$ or $s = v_0 t + \frac{1}{2} a t^2$
3. $v^2 = v_0^2 + 2a(x - x_0)$ or $v^2 = v_0^2 + 2as$ where $s = x - x_0$

Derive the equation $v = v_0 + at$

We know $a = \frac{v_2 - v_1}{t_2 - t_1}$ at $t_1 = 0$ let $v_1 = v_0$ and $t_2 = t$ let $v_2 = v$ then

$$a = \frac{v - v_0}{t - 0} \text{ or}$$

$$at = v - v_0 \text{ or } v = v_0 + at$$

Derive the relation $x-x_0=v_0t+\frac{1}{2}at^2$

we know $Average\,velocity\,,v_{av}=\frac{x_2-x_1}{t_2-t_1}$ at $t_1=0$ let $x_1=x_0$ and $t_2=t$ let $x_2=x$

then $v_{av}=\frac{x-x_0}{t-0}$ or $x-x_0=v_{av}t$ .....(1)

but $v_{av}=\frac{v_0+v}{2}$ therefore equation becomes

$x-x_0=(\frac{v_0+v}{2})t$ or $x-x_0=(\frac{v_0+v_0+at}{2})t$ [since $v=v_0+at$]

$x-x_0=(\frac{2v_0+at}{2})t$

$x-x_0=v_0t+\frac{1}{2}at^2$

Derive the relation $v^2=v_0^2+2a(x-x_0)$

we know $v=v_0+at$ on squaring

$v^2=(v_0+at)^2 = v_0^2+2v_0at+a^2t^2$

$= v_0^2+2a(v_0t+\frac{1}{2}at^2)$

$v^2=v_0^2+2a(x-x_0)$ [since $x-x_0=v_0t+\frac{1}{2}at^2$]

Equations of motion for a freely falling body

1) $v=v_0+gt$ 2) $s=v_0t+\frac{1}{2}gt^2$ 3) $v^2=v_0^2+2gs$ [for a freely falling body a = g]

Position -time graphs

position -time graph of an object at rest.

The position time graph of an object at rest is a straight line parallel to the time axis. It is shown in the figure 1.

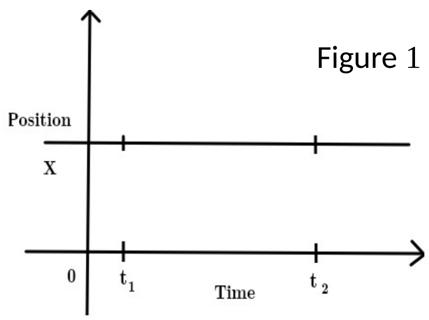


Figure 1

Position -time graph for uniform motion

The graph will be a straight line inclined to the time axis as shown in figure 2.From the graph

$slope=\frac{X_2-X_1}{t_2-t_1}$. this is the velocity of the body . $V=\frac{X_2-X_1}{t_2-t_1}$

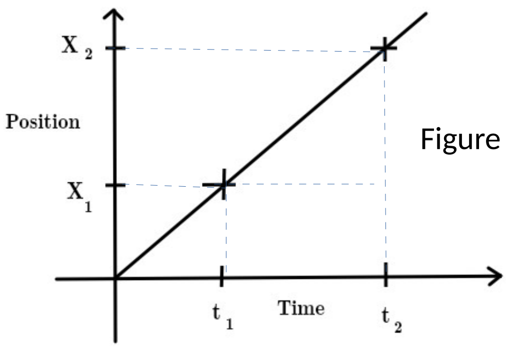


Figure 2

That is slope of position time graph gives velocity

position-time graph for accelerated motion (figure 3)

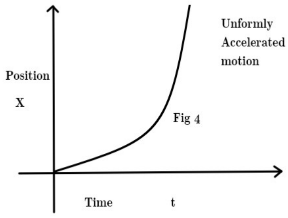


Figure 3

10.Velocity -time graphs

Velocity-time graph for uniform motion.

In uniform motion ,velocity is a constant. So the graph will be a straight line parallel to the time axis as shown in figure 4 . It is shown in the figure .

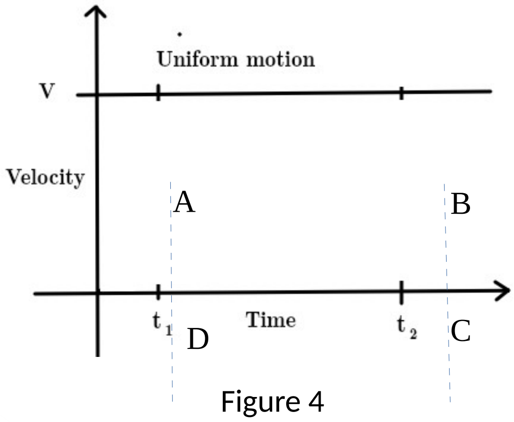


Figure 4

Area under the velocity time graph gives displacement.

In figure 4 , area under the graph between time t_1 and t_2

= area of rectangle ABCD

= AD x DC = Velocity x time =displacement.

Velocity-time graph for uniformly accelerated motion

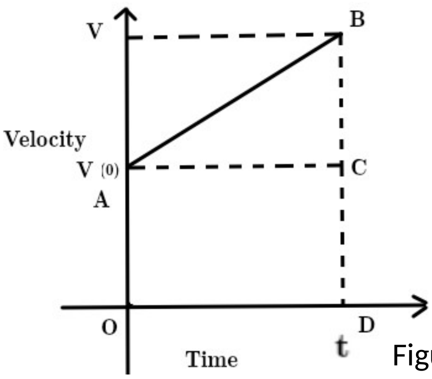


Figure 5

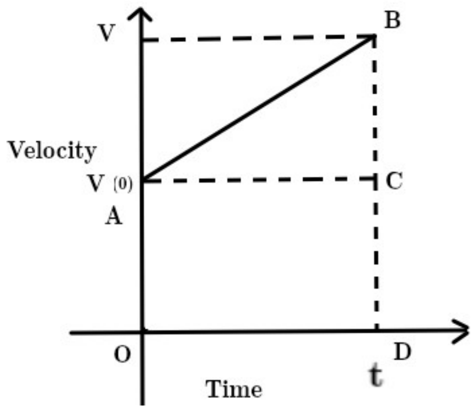
In uniformly accelerated motion velocity changes equally in equal intervals of time. So the graph will be a straight line inclined to the time axis as shown in figure 5

slope of the graph = $\frac{BC}{CA}=\frac{V-V_0}{t-0}$ = acceleration.

Slope of velocity-time graph gives acceleration

Using velocity-time graph derive the relation $s = v_0 t + \frac{1}{2} a t^2$

We know area under the velocity-time graph gives displacement from the figure Then



total displacement = Area OABCD

= Area OACD + Area ABC.

$$Area\ OACD = V_{(0)} t$$

$$Area\ ABC = \frac{1}{2}(V - V_{(0)})t$$

But $(V - V_{(0)}) = at$

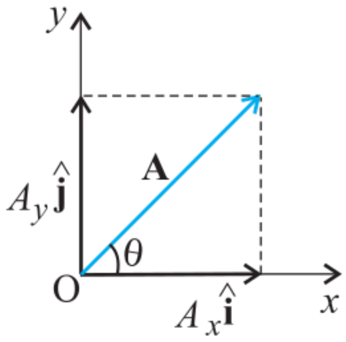
so $Area\ ABC = \frac{1}{2}(at)t$

$$Area\ ABC = \frac{1}{2} a t^2$$

So Displacement $S = V_{(0)} t + \frac{1}{2} a t^2$

CHAPTER 3
MOTION IN A PLANE

1.Resolution of a vector into its rectangular components.



$$\vec{A}=\vec{A}_x+\vec{A}_y$$

$$\vec{A}_x=A_x\hat{i} \quad \vec{A}_y=A_y\hat{j}$$

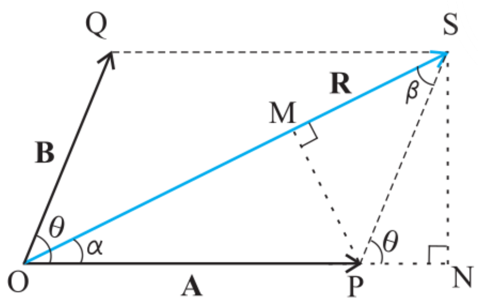
$$A_x=A\cos\theta \quad A_y=A\sin\theta$$

therefore $\vec{A}=A\cos\theta\hat{i}+A\sin\theta\hat{j}$

$A_x=A\cos\theta$ and $A_y=A\sin\theta$ are the rectangular components of the $\vec{A}$.

2.Parallelogram law of vector addition

In the figure below OP and OQ represent the two vectors $\vec{A}$ and $\vec{B}$ making an angle θ. OS represents the resultant vector $\vec{R}$



From the geometry of the figure,

$OS^2 = ON^2 + SN^2$

ON = OP + PN = A + B cos θ

SN = B sin θ

$OS^2 = (A + B\cos\theta)^2 + (B\sin\theta)^2$

$R^2 = A^2 + B^2\cos^2\theta + 2AB\cos\theta + B^2\sin^2\theta$

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

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

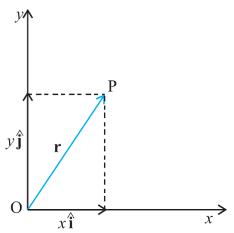
to find the direction of R we use the angle α using the equation

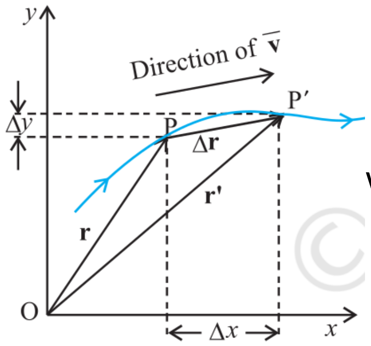
$$\tan\alpha=\frac{SN}{ON}=\left(\frac{B\sin\theta}{A+B\cos\theta}\right) \qquad \alpha=\tan^{-1}\left(\frac{B\sin\theta}{A+B\cos\theta}\right)$$

3.Motion in a plane

Position Vector and Displacement.

Fig.shows the position vector $\vec{r}$ of a particle P located in a plane is given by $\vec{r}=x\hat{i}+y\hat{j}$.





This figure shows displacement in the x-y plane.
Displacement $\Delta\vec{r}=\vec{r}'-\vec{r}$.
$\Delta\vec{r}=\Delta x\hat{i}+\Delta y\hat{j}$
where $\Delta x=(x'-x)$ and $\Delta y=(y'-y)$

Velocity

$$\overline{\mathbf{v}}=\frac{\Delta\mathbf{r}}{\Delta t}=\frac{\Delta x\,\hat{\mathbf{i}}+\Delta y\,\hat{\mathbf{j}}}{\Delta t}=\hat{\mathbf{i}}\frac{\Delta x}{\Delta t}+\hat{\mathbf{j}}\frac{\Delta y}{\Delta t}$$

$$\overline{\mathbf{v}}=\overline{v}_x\,\hat{\mathbf{i}}+\overline{v}_y\,\hat{\mathbf{j}}$$

Average acceleration

$\vec{a}=a_x\hat{i}+a_y\hat{j}$ where $a_x=\frac{\Delta v_x}{\Delta t}$ and $a_y=\frac{\Delta v_y}{\Delta t}$

4.Equations of motion in a plane

1) $\vec{v}=\vec{v}_0+\vec{a}t$ where $\vec{v}=v_x\hat{i}+v_y\hat{j}$, $\vec{v}_0=v_{0x}\hat{i}+v_{0y}\hat{j}$ and $\vec{a}=a_x\hat{i}+a_y\hat{j}$

2) $\vec{r}-\vec{r}_0=\vec{v}_0t+\frac{1}{2}\vec{a}t^2$ where $x-x_0=v_{0x}t+\frac{1}{2}a_xt^2$ and $y-y_0=v_{0y}t+\frac{1}{2}a_yt^2$

3) $v^2=v_0^2+2as$ where $v_x^2=v_{0x}^2+2a_xs_x$ and $v_y^2=v_{0y}^2+2a_ys_y$ are the horizontal and vertical components of velocity

5.Projectile and projectile motion

An object that is in flight after being thrown or projected is called a projectile.
(a football kicked or a cricket ball thrown can be considered as a projectile).

The motion of a projectile is the result of two simultaneously occurring components of motions.
a)One component is along a horizontal direction without any acceleration.
b)the other component in the vertical direction with constant acceleration due to the force of gravity.

6.Equation of path of a projectile

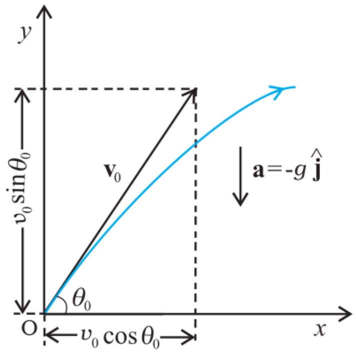
(show that the path of a projectile is parabolic in shape**)**

After being projected, at a time t , let

x and y be the horizontal and vertical component of the displacements.

$$x=(v_0\cos\theta_0)t \quad ......(1)$$

$$y=(v_0\sin\theta_0)t-\frac{1}{2}gt^2 \quad .....(2)$$



where $v_0\cos\theta_0$ is initial horizontal component of velocity of projection.

$v_0\sin\theta_0$ is the initial vertical component ;of the velocity of projection

from equation(1) $t=\dfrac{x}{v_0\cos\theta_0}$ .....(3)

substituting equation(3) in equation(2)

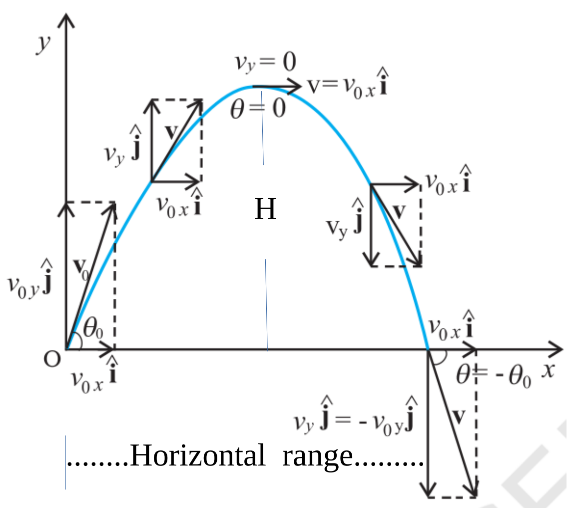
we get

$$y=(v_0\sin\theta_0)\frac{x}{v_0\cos\theta_0}-\frac{1}{2}g\left(\frac{x}{v_0\cos\theta_0}\right)^2$$

$$y=(\tan\theta_0)x-\frac{g}{2(v_0\cos\theta_0)^2}x^2$$

This is the equation of a parabola.

The path of a projectile is a parabola which is shown in the figure.



7.Maximum height of a projectile (H)

it is the maximum vertical distance reached by the projectile .
For vertical motion we use the equation

$v_y^2 = v_{0y}^2 + 2a_y s_y$ ....(1)

here a_y = -g

At the highest point vertical velocity (v_y = 0 and s_y = H

$v_{0y} = v_o \sin\theta$ (here we considered θ as the angle of projection.)

now equation (1) becomes

$0 = (v_0 \sin\theta)^2 - 2gH$ OR $H = \frac{(v_0^2 \sin^2\theta)}{2g}$

8.Time of filght. (T)

It is the time taken by the projectile from the instant it is projected till it reaches a point in the horizontal plane .
Net vertical displacement covered during the time of flight(T) =0

we know $S_y = v_{0y}t + \frac{1}{2}a_y t^2$ here a_y = -g $v_{0y} = v_o \sin\theta$

when t = T , S_y = 0 that is

$0 = (v_0 \sin\theta)T - \frac{1}{2}gT^2$

$\frac{1}{2}gT^2$ = $(v_0 \sin\theta)T$ or $T = \frac{2v_0 \sin\theta}{g}$

9.Horizontal range (R)

It is the horizontal distance travelled by the projectile during its time of flight.
Horizontal range = horizontal velocity x time of flight

R = $v_0 \cos\theta_0$ x $\frac{2v_0 \sin\theta}{g}$ = $\frac{v_o^2}{g} 2\sin\theta\cos\theta$

since $2\sin\theta\cos\theta$ = $\sin 2\theta$

R = $\frac{v_0^2 \sin 2\theta}{g}$

Uniform circular motion

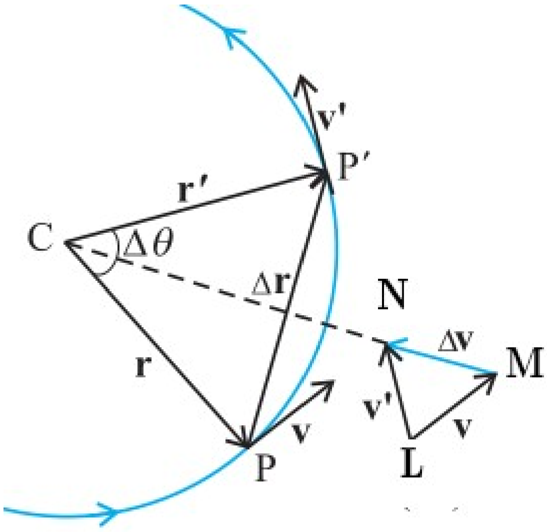
When an object follows a circular path at a constant speed, the motion of the object is called uniform circular motion.

1)Angular displacement (θ):- The angle swept over by the radius vector in a given interval of time is called angular displacement.

Unit: radian.

2) Angular velocity (ω):- Angular velocity is the rate of change of angular displacement.

11.Expression for centripetal acceleration



Let r and r′ be the position vectors and v and v′ be the velocities of the object at points P and P ′. it is shown in the figure.

Using the two identical triangles L M N and C P P' in the figure, we write

$$\frac{\Delta v}{v}=\frac{\Delta r}{r}$$

$$\Delta v=\frac{v\Delta r}{r} \quad .....(1)$$

since Δv is directed perpendicular to Δr and is always directed towards the centre of the circle , the direction of this acceleration is towards the centre.

Dividing equation(1) by Δt we get

$$\frac{\Delta v}{\Delta t}=\frac{v\Delta r}{r\Delta t}$$

Or acceleration $a=\frac{v^2}{r}$ Since $a=\frac{\Delta v}{\Delta t}$ $v=\frac{\Delta r}{\Delta t}$

This acceleration is called centripetal acceleration. So the force due to this acceleration is called centripetal force F = ma or $F=\frac{mv^2}{r}$

CHAPTER 4
LAWS OF MOTION

Important concepts.

1. Inertia :- it is the property of a body by virtue of which it cannot change ,by itself , it's state of rest or of uniform motion.

Three types of inertia. 1) **inertia of rest** (eg:- a person standing in a bus falls backward when the bus suddenly start moving) 2) **inertia of motion**(eg:- when a moving bus suddenly stops, a person in it falls forward) 3) **inertia of direction** (when a bus takes a sharp turn , person sitting in the bus experience a push radially outward)

2. linear momentum($\vec{p}$:- Linear momentum of a body is the product of it's mass(m) and velocity(v).

linear momentum = mass x velocity.

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

SI unit of momentum is kg ms^{-1}

3. Force :- a push or a pull that changes or tends to change the state of rest or of uniform motion.

4. Newton's three laws of motion.

a) **first law** (law of inertia):- Every body continues to be in its state of rest or of uniform motion in a straight line unless compelled by some external force to act otherwise.

First law defines inertia.

Illustration of first law:- 1. dust is removed from a hanging carpet by beating it with a stick.(as the carpet is beaten it suddenly moves forward while the dust particles tend to remain at rest due to inertia of rest and so fall off)

b) **second law** :- it states that the rate of change of linear momentum of a body is directly proportional to the force applied and the change takes place in the direction of the applied force.

Measurement of force from Newton's second law:-

if a body of mass m is moving with velocity $\vec{v}$, then it's linear momentum is $\vec{p} = m\vec{v}$

according to Newton's second law applied force $\vec{F} \propto \frac{d\vec{p}}{dt}$

now $\frac{d\vec{p}}{dt} = \frac{dm\vec{v}}{dt}$ = m($\frac{d\vec{v}}{dt}$) =m $\vec{a}$

that is $\vec{F} \propto m\vec{a}$ or $\vec{F}$ =k $m\vec{a}$. the proportionality constant k =1

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

SI unit of force :- newton (N) is the unit of force is SI system
$1N = 1kg \times 1ms^{-2}$
in CGS system the unit of force is dyne
$1 \text{ dyne} = 1g \times 1cms^{-2}$
c)**Newton's third law** :- To every action ,there is always an equal and opposite reaction.
force on body A by body B is equal and opposite to the force on the body B by body A .

$\vec{F}_{AB} = - \vec{F}_{BA}$

* action and reaction are forces. * action and reaction always act on different bodies.
(so action and reaction never cancel each other.)
while walking we press the ground (action) with our feet, the ground exert an equal and opposite force on us.

5. Law of conservation of linear momentum:-In the absence of an external force, the total linear momentum of a system is a constant.

Proof (based on third law) :- consider a collision between two bodies 1 and 2 , force on body 1 due to body 2 ,

$\vec{F}_{12} = \frac{d\vec{p}_1}{dt}$. or $\vec{F}_{12}\, dt = d\vec{p}_1$

now the force on body 2 due to body 1 is $\vec{F}_{21} = \frac{d\vec{p}_2}{dt}$ or $\vec{F}_{21}\, dt = d\vec{p}_2$

$\vec{F}_{12}\, dt + \vec{F}_{21}\, dt = d\vec{p}_1 + d\vec{p}_2$

according to Newton's third law $\vec{F}_{12} = - \vec{F}_{21}$
that is $0 = d\vec{p}_1 + d\vec{p}_2$
or $0 = d(\vec{p}_1 + \vec{p}_2)$ or $\vec{p}_1 + \vec{p}_2$ = a constant.
That is total linear momentum is a conserved.

6.Practical applications of the law of conservation of linear momentum.

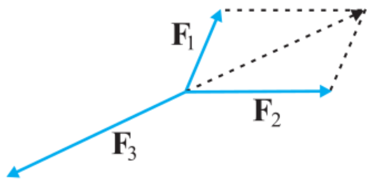
Recoil of a gun:- The backward movement of the gun while firing is called recoil of a gun. The velocity with which the gun recoils is called recoil velocity. Let M be the mass of the gun and m be the mass of the bullet. Before firing, both the gun and the bullet are at rest. After firing , the bullet moves with velocity $\vec{v}$ and the gun moves with velocity $\vec{V}$ .As no external force acts on the system ,
total linear momentum before firing = total linear momentum after firing

or $0 = m\vec{v} + M\vec{V}$

or $\vec{V} = - \frac{m\vec{v}}{M}$, the negative sign shows that $\vec{V}$ and $\vec{v}$ are in opposite directions.

7. Impulse:- a large force acting for short interval of time to produce a change in momentum.
Example:-. Force exerted by a bat while hitting a ball.
Impulse $\vec{I} = \vec{F}\ \Delta t$.
Impulse = change in momentum
proof :- we know $\vec{I} = \vec{F}\ \Delta t = \frac{\Delta \vec{p}}{\Delta t}\ \Delta t = \Delta \vec{p}$ = change in linear momentum.

8.Equilibrium of concurrent forces:-
Equilibrium under three concurrent forces F_1 , F_2 and F_3 requires that the vector sum of the three forces is zero. $F_1 + F_2 + F_3 = 0$

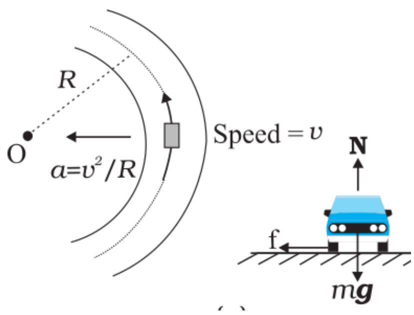


9.friction.
Force opposes (impending or actual) relative motion between two surfaces in contact.
Static friction f_s opposes impending relative motion; **kinetic friction f_k** opposes actual relative motion.

10.Laws of friction
law of static friction
$f_s = \mu_s N$
law of kinetic friction
$f_k = \mu_k N$

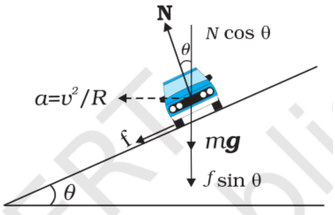
11.Circular motion of a car on a level road.
Equation for the maximum speed of circular motion of the car
Three forces act on the car (Fig. 5.14(a):(i)The weight of the car, mg (ii)Normal reaction, N (iii)Frictional force, f_s. Here N = mg. Static friction provides the centripetal force.

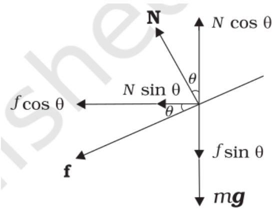
$$\frac{mv^2}{R} = f_s \ , \ \frac{mv^2}{R} = \mu_s N \ , \ \frac{mv^2}{R} = \mu_s mg \ , \ \frac{v^2}{R} = \mu_s g \ , \ v = \sqrt{\mu_s Rg}$$



12.Circular motion of a car on a banked road.

(expression for maximum speed)





N cos θ = mg + f_s sin θ or

mg =N cos θ - f_s sin θ ....(1)

N sin θ + f_s cos θ = $\frac{mv^2}{R}$ ....(2)

to obtain maximum speed we put f_s = $\mu_s N$ then eqn (1) and (2)become

mg= N cos θ - $\mu_s N$ sin θ ....(3)

N sin θ + $\mu_s N$ cos θ = $\frac{mv^2}{R}$ ....(4)

dividing (3) by (4) and rearranging we get

$$v=\sqrt{Rg\frac{(\mu_s+\tan\theta)}{(1-\mu_s\tan\theta)}}$$

Friction is a necessary evil. Explain

*It is due to friction between the ground and the feet that we are able to walk.

*The brakes of a vehicle cannot work without friction.

*It is possible to write on a paper because of friction.

Disadvantages of friction.

Wear and tear of the machinery parts is due to friction.

Large power is wasted to overcome friction.

Methods of reducing friction

1) by polishing 2)lubrication 3) by using ball-bearing.

Methods of increasing friction

1) treading of tyres.

2)on a rainy day we throw some sand on the slippery ground.

CHAPTER 5
WORK ENERGY AND POWER

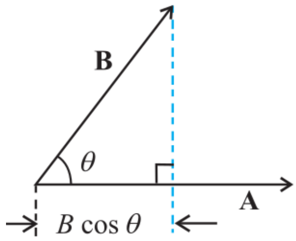
important concepts

1. Scalar product of two vectors.

The scalar product or dot product of any two vectors $\vec{A}$ and $\vec{B}$ denoted as $\vec{A}\cdot\vec{B}$ (read as A dot B) is defined as

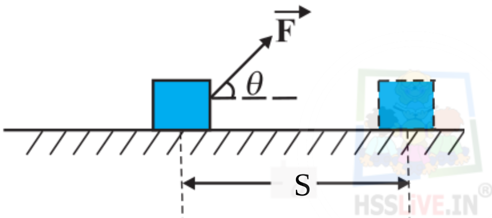
$\vec{A}\cdot\vec{B}$ = A B cos θ

θ is the angle between the two vectors



2 .work

it is defined by the equation $W=\vec{F}\cdot\vec{S}$ = $FS\cos\theta$



An object undergoes a displacement S under the influence of the force F.

Positive , negative and zero work

if θ < 90° (acute) the work done by the force is positive.

Examples:- when a ball falls freely under gravity the work done by the gravitational force is positive.

If θ>90° (obtuse) the work done by the force is negative.

Example :-when the brakes are applied to a moving vehicle, the work done by the breaking force is negative. (braking force and the displacement are in opposite direction (θ = 180°)

If the angle between force and displacement is 90° , the work done is zero .

Example :-work done by the centripetal force .

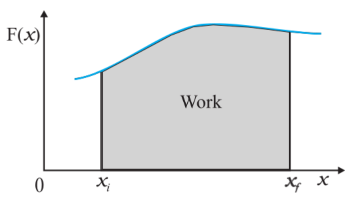
SI unit of work is joule (J)

1J = 1N x 1m.

Force displacement graph

area under the force displacement graph gives work done

.



3.work -energy theorem

The change in kinetic energy of a particle is equal to the work done on it by the net force.

$$\frac{1}{2}mv^2-\frac{1}{2}mu^2=\vec{F}\cdot\vec{S}$$

4. potential energy

Energy stored in a body by virtue of it’s position in a force field.

Gravitational potential energy.

The work done against gravity is stored as the gravitational potential energy(U) of the body.

U = mgh

5.conservative force

if the work done by the force in moving a particle around any closed path is zero, the force is conservative.

Example :- gravitational force, spring force.

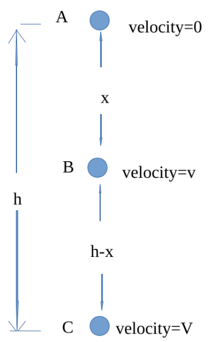
Non -conservative force:- if the work done by the force in moving a particle around any closed path is non-zero, the force is non-conservative.

Example :- friction

6.Mechanical energy

Mechanical energy of a body = potential energy + kinetic energy

7.Conservation of mechanical energy in a freely falling body.



At point A. The body is at rest.

Kinetic energy of the body at A ,

$K_A = 0$

potential energy of the body

U_A=mgh

total mechanical energy at A $E_A = K_A + U_A$ = 0 + mgh =mgh ......(1)

at the point B .

suppose the body falls freely through height x and reaches the point B with velocity v. Then

$v^2-0^2 = 2gx$ [using $v^2-u^2=2as$]

$v^2=2gx$

therefore

$K_B = \frac{1}{2}mv^2 = \frac{1}{2}m2gx = mgx$

U_B=mg(h-x)

total mechanical energy at B

$E_B = K_B + U_B = mgx$ +mg(h-x) =mgh...........(2)

At point C

suppose the body finally reaches a point C on the ground with velocity .Then considering motion from A to C,

$V^2 - 0^2 = 2gh$

or $V^2 = 2gh$

therefore kinetic energy at C

K_C = $\frac{1}{2}mV^2$ **=** $\frac{1}{2}m2gh$ **=mgh**

potential energy at C

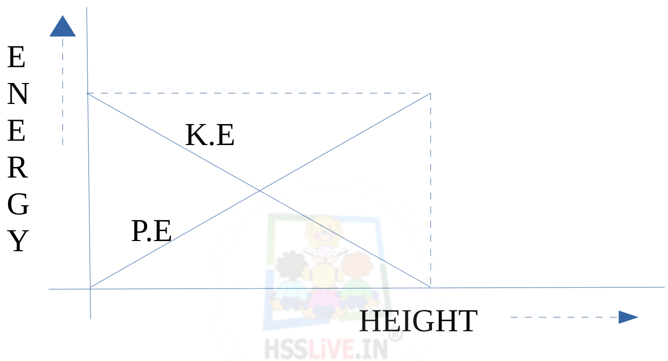
U_C =mg x 0 =0

therefore the total mechanical energy at C

$E_C = K_C + U_C$ = mgh + 0 = mgh ....(3)

from equations 1,2 and 3 , it is clear that the total mechanical energy of a freely falling body is constant throughout its fall. That is it's mechanical energy is conserved.

8.Plot of kinetic and potential energy during free fall of a body.



9.Spring force

according to Hooke's law , the spring force for an extension x is

$F_s = -k\,x$

10.work done by a spring force for an extension x_m

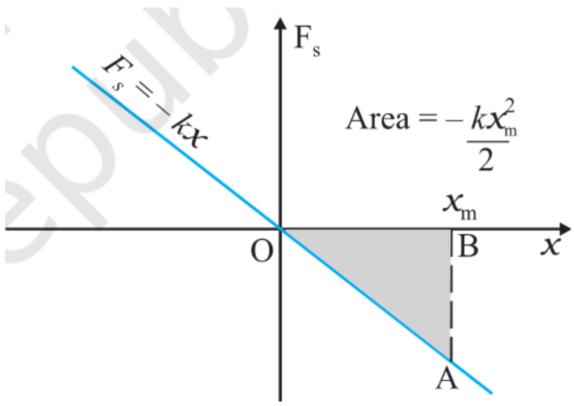
$w = \frac{-1}{2} k x_m^2$

11.work done by the external force for an extension x_m

$w = \frac{1}{2} k x_m^2$

12.The plot of F_s versus x.

The area of the shaded triangle representsthe work done by the spring force.



13.Conservation of energy in an elastic spring

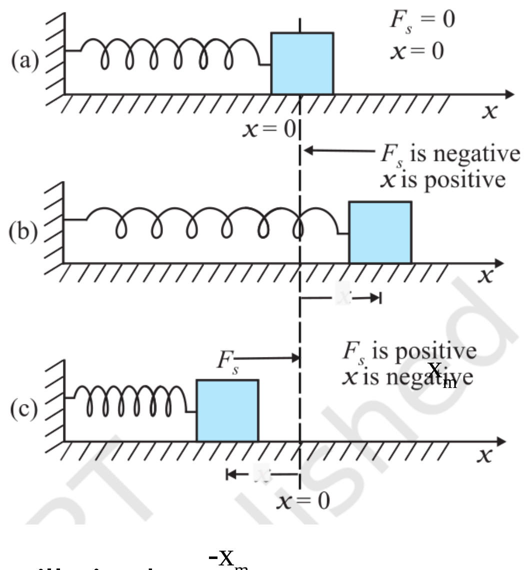


figure shows a spring oscillating between $\pm x_m$

at extreme positions $\pm x_m$, v=0. So K.E = 0 , P.E = $\frac{1}{2}kx_m^2$

so total mechanical energy at $\pm x_m$,

E =(P.E)$_{max}$= $\frac{1}{2}kx_m^2$

at any intermediate positions

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

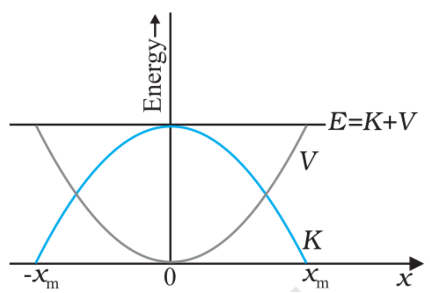
at the equilibrium position x=0

P.E =0 , so K.E is maximum K.E at x=0 is (K.E)$_{max}$= $\frac{1}{2}mv_m^2$

since spring force is conservative

$\frac{1}{2}kx_m^2 = \frac{1}{2}mv^2 + \frac{1}{2}kx^2 = \frac{1}{2}mv_m^2$

14.Plot showing the variation of kinetic and potential energy in an elastic spring



15.Power:-Power is defined as the time rate at which work is done(or the rate at which the energy is transferred)

average power(P_{av}).

$$P_{av}=\frac{W}{t}$$

(The average power of a force is defined as the ratio of the work, W to the total time t taken.)

The instantaneous power

$$P_{inst}=\frac{dW}{dt} \quad .$$

* $P_{inst}=\frac{dW}{dt} = \frac{\vec{F}\cdot\vec{ds}}{dt} = \vec{F}\cdot\vec{v}$

(That is instantaneous power can also be expressed as $P_{inst} = \vec{F}\cdot\vec{v}$)

In the SI, unit of power is called a watt (W).

16.Collision.

An event in which two or more bodies exert forces on each other in a short interval of time .

In all collisions linear momentum is conserved.

17.Types of collisions

elastic collision:- if there is no loss in kinetic energy during a collision , it is called an elastic collision.(kinetic energy is conserved in an elastic collision).

18.Characteristics of elastic collision.

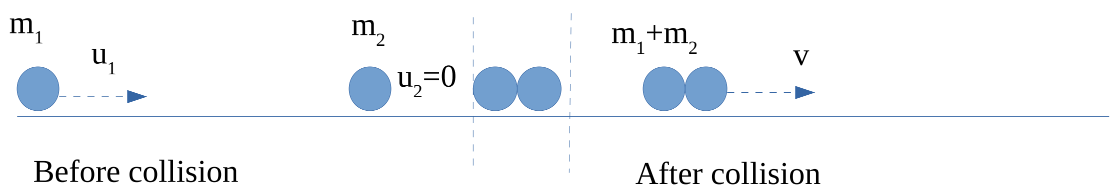
1. the momentum is conserved .
2. total energy is conserved
3. the kinetic energy is conserved.

Inelastic collision:-if there is loss in kinetic energy during a collision , it is called inelastic collision.

1. the momentum is conserved.
2. total energy is conserved.
3. kinetic energy is not conserved.

Perfectly inelastic collision:- if two bodies stick together after collision and move as a single body, the collision is called perfectly inelastic.

19.Expression for loss in kinetic energy in a perfectly inelastic collision in one dimension



before collision m_1 is moving with a velocity u towards m_2 at rest. After collision m_1 and m_2
stick together and move with a velocity v.
Law of conservation of linear momentum is

$m_1u_1+0 = (m_1+m_2)v$ ....(1)

v = $\frac{m_1 u_1}{(m_1+m_2)}$ ....(2)

kinetic energy before collision $K_i=\frac{1}{2}m_1u_1^2+0$ ....(2)

kinetic after collision , $K_f=\frac{1}{2}(m_1+m_2)v^2$ ....(3)

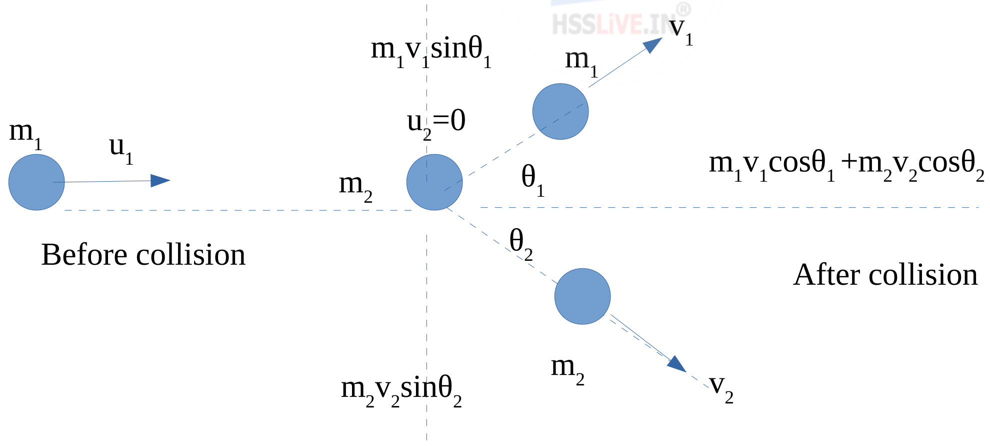
change in kinetic energy ΔK = $K_f-K_i = \frac{1}{2}(m_1+m_2)v^2 - \frac{1}{2}m_1u_1^2$

$$\Delta K= \frac{1}{2}(m_1+m_2)(\frac{m_1u_1}{m_1+m_2})^2 - \frac{1}{2}m_1u_1^2$$

$$\Delta K = \frac{1}{2}m_1u_1^2 [\frac{m_1}{(m_1+m_2)}-1] = -[\frac{1}{2}\frac{m_1m_2u_1^2}{(m_1+m_2)}]$$

therefore loss in kinetic energy = $[\frac{1}{2}\frac{m_1m_2u_1^2}{(m_1+m_2)}]$

20.Collisions in Two Dimensions



Conservation of linear momentum in two dimensional collision.

Along horizontal $m_1u_1 +0 = m_1v_1\cos\theta_1+m_2v_2\cos\theta_2$

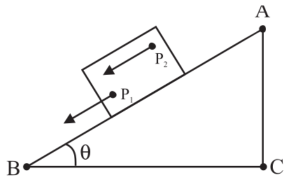
Along vertical $0 = m_1v_1\sin\theta_1 - m_2v_2\sin\theta_2$

$\mathbf{m_1v_1\sin\theta_1 = m_2v_2\sin\theta_2}$

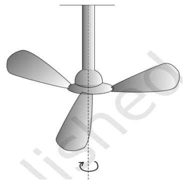
CHAPTER 6
SYSTEM OF PARTICLES AND ROTATIONAL MOTION

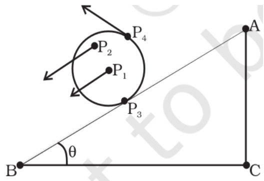
Rigid body
a rigid body is a body with a perfectly definite and unchanging shape.
In a rigid body inter particle distances remains constant.

2.Motions possible for a rigid body
1. translation 2. rotation and 3. rolling.



Translation


Rotation



Rolling=translation+rotation

Centre of mass:-the centre of mass of a body is a point where the whole mass of the body is supposed to be concentrated.

Position vector of the centre of mass of two particle system

$$\vec{R}=\frac{m_1\vec{r}_1+m_2\vec{r}_2}{m_1+m_2}$$

X component of $\vec{R}$ is $X=\frac{m_1x_1+m_2x_2}{m_1+m_2}$

Y component of $\vec{R}$ is $Y=\frac{m_1y_1+m_2y_2}{m_1+m_2}$

For an n particle system, the position vector of the centre of mass is

$$\vec{R}=\frac{\sum m_i\vec{r}_i}{M}$$

Motion of centre of mass

We have $\vec{R}=\frac{\sum m_i\vec{r}_i}{M}$ ....(1)

that is $M\vec{R}=\sum m_i\vec{r}_i$ = $M\vec{R}=m_1\vec{r}_1+m_2\vec{r}_2+.....+m_n\vec{r}_n$ ....(2)

Differentiating the two sides of the equation (2)with respect to time we get

$M\vec{V}=m_1\vec{v}_1+m_2\vec{v}_2+.....+m_n\vec{v}_n$ ....(3)

Differentiating Eq.(3) with respect to time,

$M\vec{A}=m_1\vec{a}_1+m_2\vec{a}_2+.....+m_n\vec{a}_n$ ....(4) that is

$\vec{F}=\vec{F}_1+\vec{F}_2+.....+\vec{F}_n$

Vector product of two vectors(cross product)

a vector product of two vectors $\vec{A}$ and $\vec{B}$ is defined by the equation

$\vec{A}$¿ x $\vec{B}$ = $\vec{C}$ where $\vec{C}$ = AB sin θ $\hat{n}$ where $\hat{n}$ is the unit vector showing the direction of $\vec{C}$. it is given by the right hand screw rule .

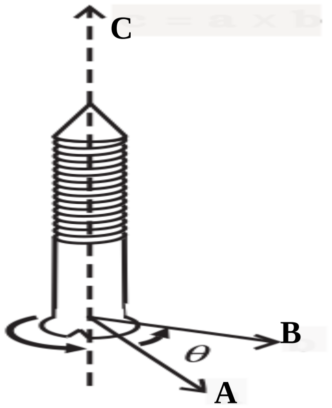


Figure explains the **right hand screw rule**.

if we turn the head of the screw in the direction from $\vec{A}$ to $\vec{B}$, then the tip of the screw advances in the direction of $\vec{C}$.

some important results:

1.) $\vec{A}$ x $\vec{A}$ = $\vec{0}$ (a vector with zero magnitude). From this follow the result

(i) $\mathbf{i} \times \mathbf{i} = \mathbf{0},\ \mathbf{j} \times \mathbf{j} = \mathbf{0},\ \mathbf{k} \times \mathbf{k} = \mathbf{0}$ and

(ii) $\hat{\mathbf{i}} \times \hat{\mathbf{j}} = \hat{\mathbf{k}}$

Note that the magnitude $\hat{\mathbf{i}} \times \hat{\mathbf{j}}$ of is sin 90° or 1. similarly

$\hat{\mathbf{j}} \times \hat{\mathbf{k}} = \hat{\mathbf{i}}$ and $\hat{\mathbf{k}} \times \hat{\mathbf{i}} = \hat{\mathbf{j}}$

2) $\vec{A}$ x $\vec{B}$ ≠ $\vec{B}$ x $\vec{A}$

$\vec{A}$ x $\vec{B}$ = -($\vec{B}$ x $\vec{A}$)

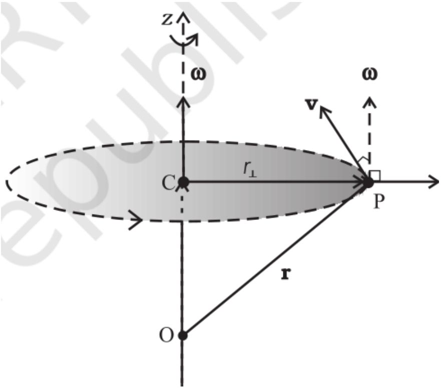
3)From the above results, it follows:

$$\hat{\mathbf{j}} \times \hat{\mathbf{i}} = -\hat{\mathbf{k}},\quad \hat{\mathbf{k}} \times \hat{\mathbf{j}} = -\hat{\mathbf{i}},\quad \hat{\mathbf{i}} \times \hat{\mathbf{k}} = -\hat{\mathbf{j}}$$

.Angular velocity $\vec{\omega}$ and its relation with linear velocity $\vec{v}$

using vector cross product we can arrive at the relation

$\vec{\omega}$ x $\vec{r}$ = $\vec{v}$



The angular velocity vector ω is directed along the fixed axis as shown. The linear velocity of the particle at P is v = ω × r. It is perpendicular to both ω and r and is directed along the tangent to the circle described by the particle.

Angular acceleration.(α)

Angular acceleration α as the time rate of change of angular velocity.

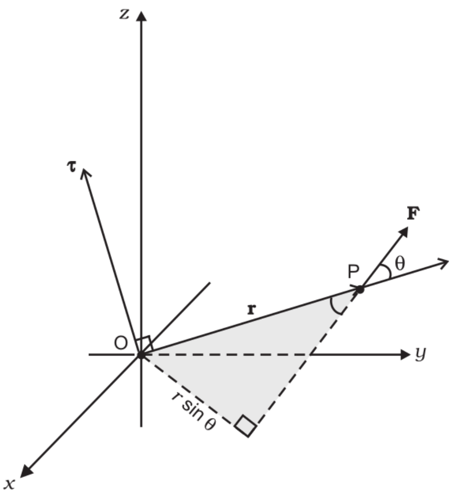
$$\vec{\alpha}=\frac{d(\vec{\omega})}{dt}$$

Torque ($\vec{\tau}$)

The rotational analogue of force in linear motion is torque (or moment of force or couple).

Torque of a particle with respect to an origin is defined as the vector product

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



The magnitude of $\vec{\tau}$ is **τ = r F sin θ**

r is the magnitude of the position vector $\vec{r}$ i.e. the length OP, F is the magnitude of force $\vec{F}$ and θ is the angle between $\vec{r}$ and $\vec{F}$

torque has dimensions $M L^2 T^{-2}$.

The SI unit of torque (moment of force) is newton metre (N m).

Angular momentum of a particle($\vec{L}$)

The angular momentum $\vec{L}$ of a particle with respect to the origin O is defined to be

$$\vec{L} = \vec{r} \times \vec{P}$$

The magnitude of the angular momentum vector is l = r p sin θ.

Show that $\frac{d\vec{L}}{dt} = \vec{\tau}$

ans: $\frac{d\vec{L}}{dt} = \frac{d(\vec{r}\times\vec{p})}{dt} = \frac{d\vec{r}}{dt}\times\vec{p}+\vec{r}\times(\frac{d\vec{p}}{dt})$

the velocity of the particle is $\vec{v} = \frac{d\vec{r}}{dt}$ and $\vec{P}$ =m $\vec{v}$, therefore

$\frac{d\vec{r}}{dt} \times \vec{P} = \vec{v} \times m\vec{v} = 0$ also $\frac{d\vec{p}}{dt} = \vec{F}$ therefore

$\frac{d\vec{L}}{dt}$ **= 0 +** $\vec{r} \times \vec{F} = \vec{\tau}$

Law of Conservation of angular momentum

if $\vec{\tau}_{ext} = 0$ $\frac{d\vec{L}}{dt}$ =0 means $\vec{L}$ = a constant. That is

If there is no external torque acting on a system of particles 'it's total angular momentum is conserved. This is the law of conservation of angular momentum.

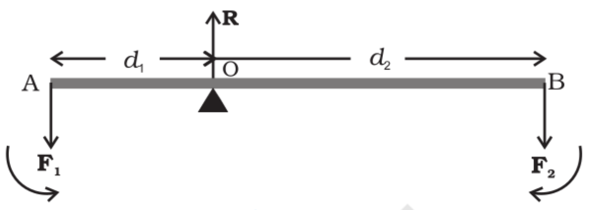
Equilibrium of a rigid body

A rigid body is said to be in equilibrium if

1) $\sum\vec{F}_{ext} = 0$ (condition for translational equilibrium)
2) $\sum\vec{\tau}_{ext} = 0$ (condition for rotational equilibrium)

Principle of moments

load arm × load = effort arm × effort



In the figure

d_1 is the load arm , F_1 is the load

d_2 is the load arm , F_2 is the effort.

So principle of moments can be written as $d_1 F_1 = d_2 F_2$

the ratio F_1 / F_2 is called the Mechanical Advantage (M.A.)

M.A = F_1 / F_2 **=** d_2/d_1

Centre of gravity

The centre of gravity of an extended body is that point where the total gravitational torque on the body is zero.

kinetic energy of a rotating body

consider a body of mass m undergoing rotation about aafixed axis . Let r be radius of the circular track.

If v is it's speed the kinetic energy K = $\frac{1}{2}mv^2$

now v = ωr , so K = $\frac{1}{2}m(\omega r)^2$ = $\frac{1}{2}mr^2\omega^2$ = $\frac{1}{2}I\omega^2$

the quantity I= mr^2 is called moment of inertia of the body about the axis.

Moment of inertia of a rigid body about an axis.

It is defined by the $I=\sum m_i r_i^2$

m_i 's are the masses of the individual particles. r_i are the magnitude of the radius vectors of the particles.

Work done by a torque

d W = τ d θ

gives the work done by the total (external) torque τ which acts on the body rotating about a fixed axis.

Relation between torque (τ)and moment of inertia(I)

we know the magnitude of

τ = r F sin θ . if θ = 90°

τ = rF but F ma . Also a = r α where α = $\frac{d\omega}{dt}$

now τ = rma= rmrα = mr^2α = Iα

that is τ = Iα

Relation between angular momentum(*L*) and moment of inertia(I)

show that L = I ω

we know L= rpsinθ if θ =90°

L = rp = r mv = r m rω = mr^2 ω = Iω

that is

Law of conservation of angular momentum.

If there is no external torque L = a constant (I ω = a constant)

Comparison of Translational and Rotational Motion.

	Linear Motion	Rotational Motion about a Fixed Axis
1	Displacement x	Angular displacement θ
2	Velocity $v = dx/dt$	Angular velocity $\omega = d\theta/dt$
3	Acceleration $a = dv/dt$	Angular acceleration $\alpha = d\omega/dt$
4	Mass M	Moment of inertia I
5	Force $F = Ma$	Torque $\tau = I\,\alpha$
6	Work $dW = F\,ds$	Work $W = \tau\, d\theta$
7	Kinetic energy $K = Mv^2/2$	Kinetic energy $K = I\omega^2/2$
8	Power $P = F\,v$	Power $P = \tau\omega$
9	Linear momentum $p = Mv$	Angular momentum $L = I\omega$

kinematic equations for rotational motion with uniform angular acceleration.

We know the kinematical equations of linear motion with uniform (i.e. constant) acceleration are

$$v = v_0 + at$$

$$x = x_0 + v_0 t + \frac{1}{2}at^2$$

$$v^2 = v_0^2 + 2ax$$

The corresponding kinematic equations for rotational motion with uniform angular acceleration are:

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

$$\theta = \theta_0 + \omega_0 t + \frac{1}{2}\alpha t^2$$

$$\text{and } \omega^2 = {\omega_0}^2 + 2\alpha(\theta - \theta_0)$$

CHAPTER 7
GRAVITATION

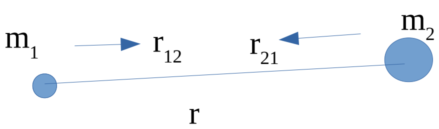
Newton's universal law of gravitation.

Newton's law of universal gravitation states that the gravitational force of attraction between any two particles of masses m_1 and m_2 separated by a distance r has the magnitude

$F = Gm_1 m_2/r^2$

where G is the universal gravitational constant, which has the value 6.672×10^{-11} N m^{2} kg^{-2}

Gravitational force in vector form



in the figure, gravitational force on m_1 due to m_2 is

$$\vec{F}_{12} = G\frac{m_1 m_2}{r^2}\hat{r}_{12}$$

gravitational force on m_2 due to m_1 is

$$\vec{F}_{21} = G\frac{m_1 m_2}{r^2}\hat{r}_{21}$$

* since $\hat{r}_{12}$ = -($\hat{r}_{21}$)

$\vec{F}_{12}$ = - $\vec{F}_{12}$

i.e action = -(reaction)

Show that $g = G\frac{M_E}{R_E^2}$

We know Gravitational force experienced by a body of mass m on the surface of earth

is $F = G\frac{M_E m}{R_E^2}$

According to Newton's second law F = mg

i.e mg = $G\frac{M_E m}{R_E^2}$ or $g = G\frac{M_E}{R_E^2}$

Kepler's laws of planetary motion

(a)**Law of orbits**:- All planets move in elliptical orbits with the Sun at one of the focal points

(b) **Law of areas**:-The radius vector drawn from the Sun to a planet sweeps out equal areas in equal time intervals.

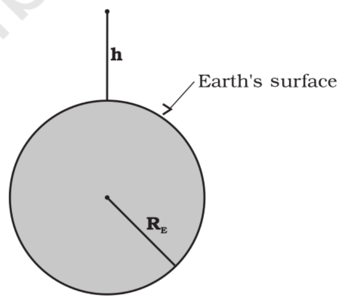
(c) **Law of periods**:-The square of the orbital period of a planet is proportional to the cube of the semi- major axis of the elliptical orbit of the planet

The period T and radius R of the circular orbit of a planet about the Sun are related by

$$T^2 = \left(\frac{4\pi^2}{GM_s}\right)R^3$$

The variation of acceleration due to gravity with altitude(height)

at a height h above the earth's surface acceleration due to gravity is



$$g(h) = \frac{GM_E}{(R_E+h)^2}$$

$$g(h) = \frac{GM_E}{R_E^2\left(1+\frac{h}{R_E}\right)^2}$$

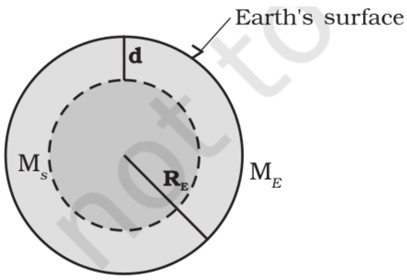
$$g(h) = \frac{g}{\left(1+\frac{h}{R_E}\right)^2} = g\left(1+\frac{h}{R_e}\right)^{-2}$$

for $h/R_E << 1$ using binomial expression,

$$g(h) = g\left(1-\frac{2h}{R_E}\right)$$

The variation of acceleration due to gravity with depth.

consider a point mass m at a depth d below the surface of the earth. Its distance from the centre of the earth is ($R_E - d$)



If M_s is the mass of the smaller sphere of radius ($R_E - d$)

$$\frac{M_S}{M_E} = \frac{(R_E-d)^3}{R_E^3} \quad \text{or} \quad M_S = \frac{M_E(R_E-d)^3}{R_E^3} \quad ......(1)$$

force on the point mass at depth d is

$$F(d) = \frac{GM_S m}{(R_e-d)^2} \quad .....(2)$$

substituting the value of M_S in the equation we get

$$F(d) = \frac{G M_E m (R_E - d)}{R_E^3}$$

$$g(d) = \frac{F(d)}{m}$$

$$= \frac{G M_E (R_E - d)}{R_E^3} = \frac{G M_E (R_E - d)}{R_E^2 R_E}$$

$$= \frac{g (R_E - d)}{R_E}$$

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

Gravitational potential energy(V)

Gravitational potential energy of a body at a point near earth is the amount of work done by the gravitational force of earth to bring the body from infinity to that point.

$$V = \frac{-G m_1 m_2}{r}$$

if m_1 is the mass of earth M_E and m is the mass of the body at a distance(R_E + h) from the centre of the earth , then

$$V = \frac{-G M_E m}{(R_E + h)}$$

Escape speed

it is the minimum speed with which a body must be projected vertically upwards so that it may just escape the gravitational field of the earth.

Expression for escape speed is $v_e = \sqrt{2 g R_E}$

proof:-

consider a body of mass m being projected from the surface of earth to infinity (where the potential energy is zero) so that it can escape from the gravitational field of earth.

On the surface its

total energy = kinetic energy + potential energy

$$= \frac{1}{2} m v^2 + \frac{-G M_E m}{R_E}$$

when it just manage to escape the attraction of earth ,its speed will be zero .

When it just escape it's Potential energy will also be zero. So

we can write , in order to escape

$$\frac{1}{2} m v_e^2 + \frac{-G M_E m}{R_E} = 0$$

or $\frac{1}{2}mv_e^2 = \frac{GM_E m}{R_E}$

or $v_e^2 = \frac{2GM_E}{R_E} = \frac{2GM_E R_E}{R_E^2} = 2gR_E$

or

$$v_e = \sqrt{2gR_E}$$

Orbital velocity

It is the velocity required to put the satellite into its orbit around the earth.

Expression for orbital velocity.

According to the law of gravitation, the force of gravity on the satellite is

$$F = \frac{GM_E m}{(R_E + h)^2} \quad .....(1)$$

The centripetal force required by the satellite to keep it in its orbit is

$$F = \frac{mv_o^2}{(R_E + h)} \quad .....(2)$$

in equilibrium,

$$\frac{mv_o^2}{(R_E+h)} = \frac{GM_E m}{(R_E+h)^2} \quad \text{or}$$

$$v_0^2 = \frac{GM_E}{(R_E+h)} \quad \text{or} \quad v_o = \sqrt{\frac{GM_E}{R_E+h}}$$

when the satellite revolve close to the surface of the earth, h=0 and the orbital velocity will become

$$v_o = \sqrt{\frac{GM_E}{R_E}} = \sqrt{\frac{GM_E R_E}{R_E^2}} = \sqrt{gR_E}$$

Relation between orbital velocity and escape velocity.

The escape velocity of a body from the earth's surface is $v = \sqrt{2gR_E}$
the orbital velocity of a satellite revolving close to the earth's surface is
$v_o = \sqrt{gR_E}$ comparing the two equations we have v = $\sqrt{2v_o}$

Energy of an orbiting satellite

It is the sum of its kinetic and potential energies.

Kinetic energy = $\frac{1}{2}mv_o^2$ but $v_0^2=\frac{GM_E}{(R_E+h)}$. therefore

kinetic energy of the satellite = $\frac{\frac{1}{2}mGM_E}{(R_E+h)}$

the potential energy of the satellite = $\frac{-GM_Em}{(R_E+h)}$

now the total energy 0f the satellite = $\frac{\frac{1}{2}mGM_E}{(R_E+h)}$ + $\frac{-GM_Em}{(R_E+h)}$

$$= \frac{-GM_Em}{2(R_E+h)}$$

CHAPTER 8
MECHANICAL PROPERTIES OF SOLIDS

Elasticity
The property of a body, by virtue of which it tends to regain its original size and shape when the applied force is removed, is known as elasticity and such substances are called elastic .

- Eg: Steel, Rubber

Plasticity
Some substances have no tendency to regain their previous shape on the removal of deforming force and they get permanently deformed. Such substances are called plastic and this property is called plasticity.

- Eg:Putty and mud

Stress
Stress is the restoring force per unit area

Stress = $\frac{F}{A}$ F = applied force

A= area of cross section of the body

S IUnit = pascal(Pa) 1 Pa = 1Nm^{-2}

Dimension = M L^{-1} T$^{-2]}$

there are three types of stresses

(a) tensile stress — longitudinal stress

(associated with stretching) or compressive stress (associated with compression),

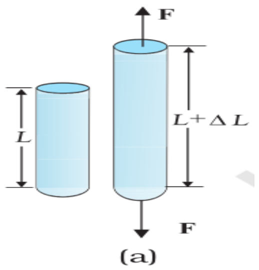
(b) shearing stress, and

(c) hydraulic stress

Strain
Strain = change in dimension/ original dimension

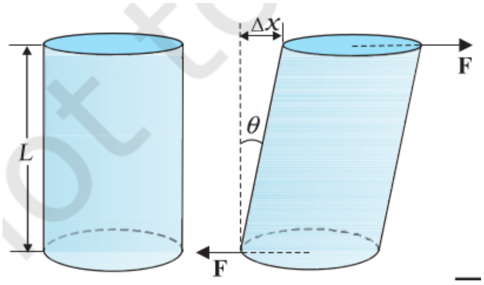
Longitudinal strain

The change in the length ΔL to the original length L of the body is known as longitudinal strain.



$$Longitudinal\ strain = \frac{\Delta L}{L}$$

Shearing strain
In the case of a cylinder given in the figure , shearing strain is defined by the equation



$$Shearing\ strain = \frac{\Delta x}{L} = \tan\theta$$

here F is the tangential force .

Volume strain

The strain produced by a hydraulic pressure is called volume strain

$$Volume\, strain = \frac{\Delta V}{V}$$

- **Strain is a unit less , dimensionless quantity.**

Hydraulic Stress

The restoring force per unit area of solid sphere, placed in the fluid is called hydraulic stress

Hooke's Law

For small deformations the stress is directly proportional to strain.

stress ∝ strain

stress = k × strain , where k is the proportionality constant and is

known as modulus of elasticity

Modulus of elasticity k = $\frac{stress}{strain}$

Unit = pascal(Pa)

Dimension = M L^{-1} T^{-2}

- Depending upon the types of stress and strain there are three modulii of elasticity.

1.Young's Modulus(Y)

2.Shear Modulus or Rigidity Modulus (G)

3.Bulk modulus(B)

Young's Modulus(Y)

The ratio of longitudinal stress to longitudinal strain is defined as Young's modulus

Y = $\frac{longitudinal\ stress}{longitudinal\ strain}$ Unit = pascal(Pa) Dimension = M L^{-1} T^{-2}

$$Y = \frac{(F/A)}{(\Delta L/L)} = \frac{(FxL)}{(\Delta LxA)}$$

Shear Modulus or Rigidity Modulus(G)

The ratio of shearing stress to the shearing strain is called the shear modulus or rigidity modulus

$$G = \frac{(F/A)}{(\Delta x/L)} = G = \frac{(FL)}{((\Delta x)A)}$$

Bulk Modulus(B)

The ratio of hydraulic stress to the c hydraulic strain is called Bulk modulus.

$$B = \frac{-P}{\left(\frac{\Delta V}{V}\right)}$$

Compressibility(k)

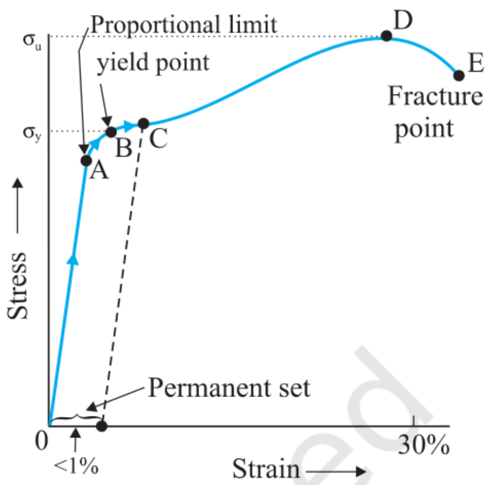
The reciprocal of the bulk modulus is called compressibility

$K = 1/B$

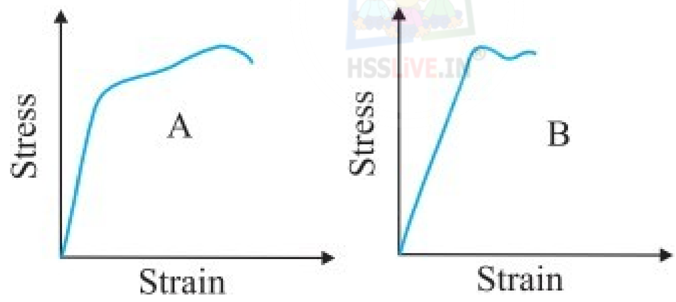
Steel is more elastic than rubber

The Young's modulus of steel is more than that of rubber. Thus steel is more elastic than rubber

Stress -Strain Graph



The stress-strain graphs for materials A and B are shown in Figure.



(a)Which of the materials has the greater Young's modulus?
(b)Which of the two is the stronger material?
(c)Which of the two materials is more ductile?
Ans:- (a)A (Slope of graph for material A is greater than that of B).

(b)A (The fracture point is greater for material A)

(c) A (The fracture point is greater for material A)

Elastomers:-Substances which can stretched to cause large stains are called elastomers(eg:-rubber)

CHAPTER 9

MECHANICAL PROPERTIES FLUIDS

Thrust

The total normal force acting on a surface

Pressure

The normal force per unit area f the surface

$P = \frac{F}{A}$ Unit = pascal(Pa) Dimension = $ML^{-1}T^{-2}$

Pressure is a scalar quantity

Expression for pressure exerted by a liquid column

$P = h\rho g$

Pascal's Law

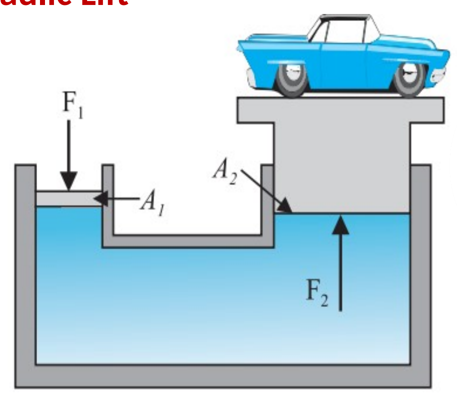
The pressure applied at any part of an enclosed fluid is transmitted undiminished to every part of the fluid.

Applications of Pascal's Law

1.Hydraulic Lift

2.Hydraulic Brakes

Hydraulic Lift



The pressure on the smaller piston = F_1/A_1

The pressure on the smaller piston = F_2/A_2

According to Pascal's law $F_1/A_1 = F_2/A_2$

$F_2 = F_1(A_2/A_1)$

Since $A_2 >> A_1$ $F_2 >> F_1$

Streamline flow: -

The regular flow of liquid is called streamline flow

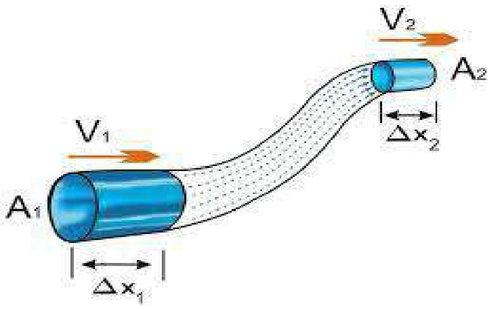
Turbulent flow:-

The irregular flow of liquid is called turbulent flow

Equation of Continuity

Statement : **A v = a constant** A = area of cross section, v = velocity of fluid

proof:



Consider steady flow of liquid through a pipe,

Mass of the liquid entering per unit time = mass of the liquid leaving per unit time

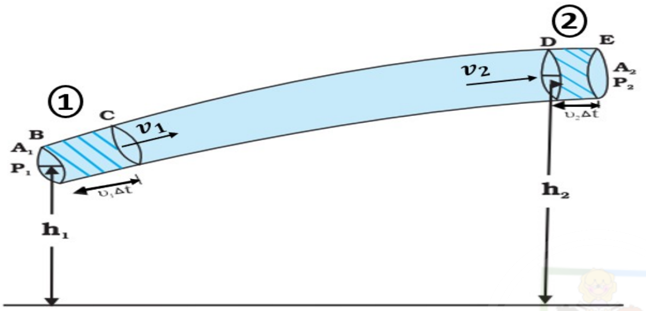
$\rho A_1 v_1 = \rho A_2 v_2$

A v = a constant

Bernoulli's Theorem

Statement : $P + \frac{1}{2}\rho v^2 + \rho gh =$ a constant

Proof:



Consider steady flow of liquid through a pipe

The total W.D = $P_1V - P_2V$

Increase in K.E = $\frac{1}{2}mv_2^2 - \frac{1}{2}mv_1^2$

Increase in P.E = $mgh_2 - mgh_1$

According to work Energy Theorem

$P_1V - P_2V = \frac{1}{2}mv_2^2 - \frac{1}{2}mv_1^2 + mgh_2 - mgh_1$

$P_1V + \frac{1}{2}mv_1^2 + mgh_1 = P_2V + \frac{1}{2}mv_2^2 + mgh_2$

$PV + \frac{1}{2}mv^2 + mgh =$ a constant

(or) $PV + \frac{1}{2}\rho v^2 + \rho gh =$ a constant

Conditions for Bernoulli's Theorem:-1.The flow must be steady

2.The fluid must be in-compressible

Applications of Bernoulli's Theorem:-Speed of efflux,2)Magnus effect

Torricelli's Law:-The speed of a fluid through a small hole at a depth (h)of an open tank is equal to the speed of a freely falling body ($v=\sqrt{2gh}$)

Magnus effect:-The dynamic lift of a body due to spinning is called Magnus effect

Viscosity:-The internal frictional force that acts when there is relative motion between layers of the liquid is called viscosity.

Coefficient of viscosity(η)

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

F= Viscous force,A= Area of the layer

dv =relative velocity of the layers

dx = distance between the layers

- Unit of coefficient of viscosity = poiseiulle (Pl).
- Dimension = $ML^{-1}T^{-1}$
- The viscosity of liquids decreases with temperature
- The viscosity of gases increases with temperature

Stokes' Law:- Stokes' law states that the viscous drag force on a sphere moving in a fluid is,**F = 6πηav** a =radius of the sphere ,v = velocity of the sphere η = coefficient of viscosity

Terminal velocity:-The constant velocity when an object falls through a viscous medium is called terminal velocity

Expression for Terminal velocity

When the object (sphere) falls through the fluid

Stokes force = weight of the body in the fluid – upthrust

$= \frac{4}{3}\pi a^3 \rho g - \frac{4}{3}\pi a^3 \sigma g$ where ρ is the density of the sphere,and σ is the density of the fluid

$6\pi\eta a v = \frac{4}{3}\pi a^3(\rho - \sigma)g$ that is $v = \frac{2a^2(\rho-\sigma)g}{9\eta}$

Reynold Number(R):-A number which shows whether the flow of liquid is streamline or turbulent. It is given by R = $\frac{\rho v d}{\eta}$

ρ =density of fluid, v=velocity of fluid,d=diameter of pip η = coefficient of viscosity

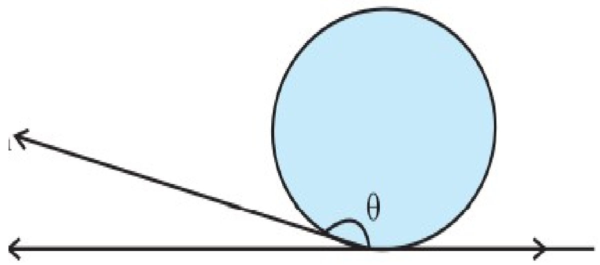
If R < 1000 ,the flow is streamline. If R > 2000 ,the flow is turbulent

Surface Tension:-The property due to which the free surface of a liquid tends to have minimum surface area and behaves like a stretched membrane is called surface tension.

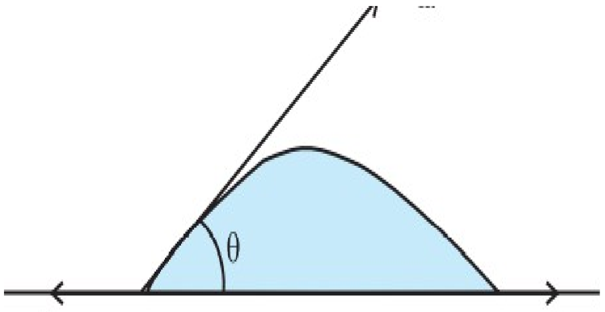
Why are small drops and bubbles spherical?

Due to surface tension ,liquid surface has the tendency to reduce surface area. For a given volume sphere has minimum surface area. So small drops and bubbles are spherical.

Angle of Contact:-The angle between tangent to the liquid surface and solid surface inside the liquid is termed as angle of contact(θ)

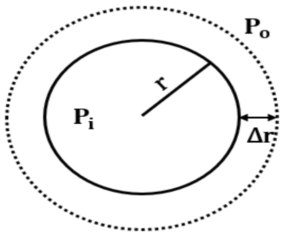


If the angle of contact (θ) > 90,the liquid does not wet the solid



If the angle of contact (θ) <90 ,the liquid wet the solid

Excess Pressure inside a spherical drop



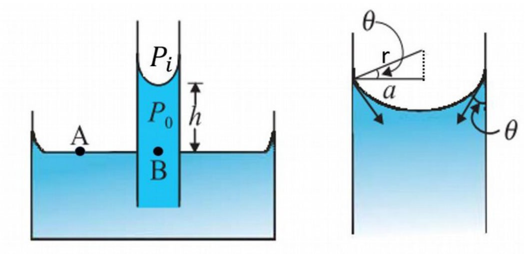
$P_i - P_O = 2S/r$

Excess Pressure inside a liquid bubble:-$P_i - P_O = 4S/r$

Capillarity:-The phenomenon of rise or fall of a liquid through a narrow tube is called capillarity

Capillary rise:-The phenomenon of rise o of a liquid through a narrow tube is called capillary rise

Relation for capillary rise



Exces Pressure $P_i - P_O = 2S/r$

$h\rho g = 2S/r$ $h = 2S/r\rho g$ $\cos\theta = a/r$ $r = a/\cos\theta$

therefore $h = 2S\cos\theta/a\rho g$ for very small angles $h = 2S/a\rho g$

Some effects of surface Tension:-Oil and water do not mix,Water wets you and me but not ducks. Mercury does not wet glass but water wets . Oil rises up a cotton wick, inspite of gravity. Sap and water rise up to the top of the leaves of the tree.Hairs of a paint brush do not cling together when it is dry, but when dipped in water and taken out , it form a fine tip

Note :-1 atmospheric pressure = 76 cm of mercury = 1.013X 10^5 Pa

CHAPTER 10
THERMAL PROPERTIES OF MATTER

Relation between Fahrenheit scale and Celsius scale:- (F-32)/180 = C /100

Eg:-Convert 37 ^{0} C to farenheit

(F -32)/180 = 37/100, F-32 = (37X180)/100 , F-32 = 6660/100

F-32 = 66.6 , F = 66.6+32 =98.6

Relation between Celsius scale and Kelvin scale:- K= C+273

Eg:-Convert 37 ^{0} C to Kelvin: K=37+273 = 310

Boyle's Law:- P ∞ 1/V OR PV = a Constant P =Pressure, V = volume
Charle's Law :- V ∞ T OR V/T = a constant
Ideal gas equation:- PV = n RT n = number of moles R = universal gas constant T = absolute temperature K_B =Boltzmann constant N =number of molecules of the gas
Absolute zero Temperature or Zero kelvin (OK):-The minimum temperature for an ideal gas is called Absolute temperature or zero Kelvin (OK). This temperature is found to be – 273.15 °C
Thermal Expansion:-The increase in the dimensions of a body due to the increase in its temperature is called thermal expansion.
The three types of thermal expansions are (1) linear expansion(2)area expansion(3)volume expansion
Linear Expansion:-The expansion in length is called linear expansion.
Expansion in length $\Delta L = \alpha L \Delta T$ α= Coefficient of linear expansion

L=length of the material ,ΔT =increase in temperature

Area Expansion:-The expansion in area is called area expansion.
Expansion in area $\Delta A = \beta A \Delta T$ β= Coefficient of area expansion

A=Area , ΔT =increase in temperature

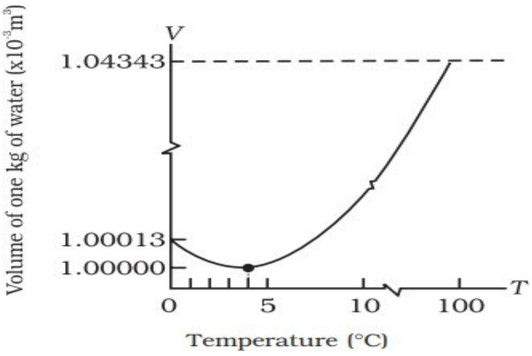
Volume Expansion:-The expansion in volume is called volume expansion.

Expansion in volume $\Delta V = \gamma V \Delta T$ γ= Coefficient of volume expansion

V=volume ,ΔT =increase in temperature

Realation between α, β, γ:- α:β:γ = 1:2:3

Thermal Expansion of Water(- Anomalous Behaviour of Water)



Water exhibits an anomalous behaviour ; it contracts on heating from 0 °C to 4 °C. When it is heated after 4 °C ,it expands like other liquids.

Water has minimum volume and maximum density at 4 °C

Without anomalous behaviour of water **Aquatic animal life and plant life in cold countries in winter season is impossible**

As a lake cools toward 4 °C, water near the surface becomes denser, and sinks. Then the warmer, less dense water near the bottom rises. When this layer cools below 4 °C, it freezes, and being less dense, remain at the surfaces. Thus water bodies freeze at the top first. Water at the bottom protects aquatic animal and plant life

Heat Capacity

Heat capacity (S) of a substance is the amount of heat required to raise the temperature of the substance by one unit.

$S=\Delta Q/\Delta T$ unit = J/K

Specific Heat capacity

Specific heat capacity (s) of a substance is the amount of heat required to raise the temperature of unit mass of the substance by one unit

Specific heat capacity = Heat capcity/mass

$s = \Delta Q/m\Delta T$

Molar Specific Heat Capacity

Molar Specific heat capacity (C) of a substance is the amount of heat required to raise the temperature of one mole of the substance by one unit.

$C= (1/\mu)(\Delta Q/\Delta T)$

Gases have two types of molar specific heat capacities

(1)Molar specific heat capacity at constant Pressure (C_P)

(2) Molar specific heat capacity at constant volume (C_v)

Calorimetry:-Calorimetry means measurement of heat

Melting point:-The temperature at which solid and liquid coexist in thermal equilibrium with each other is called melting point.

The melting point decreases with pressure.

Boiling point.:-The temperature at which liquid and vapour state of substance

coexist in thermal equilibrium with each other is called boiling point.
The boiling point increases with pressure .

Cooking is difficult on hills.:- At high altitudes, atmospheric pressure is lower, boiling point of water decreases and thus it is difficult to cook on hills

Cooking is easy using pressure cooker:- When pressure increase boiling point of water increases in pressure cooker. Hence cooking is faster

Regelation: When pressure is applied, ice melts at low temperature. If pressure is removed, water refreezes. This refreezing is called regelation

Skating is possible due to regelation. Water is formed due to increase in pressure and serves as lubricant

Latent Heat(L):-The amount of heat for the change of state of the substance is called latent heat of the substance .

Q =mL m = mass of the substance

L=Q/m Q= amount of heat

Latent Heat of Fusion (L_f) or heat of fusion:-The latent heat for a solid -liquid state change is called the latent heat of fusion (L_f)

Latent Heat of Vaporisation (L_V) or heat of vapourisation

The latent heat for a liquid-gas state change is called the latent heat of vaporisation (L_V)

Heat Transfer:-There are three distinct modes of heat transfer.
(1)conduction (2)convection (3) radiation

Conduction:-The transfer of heat through matter due temperature differences is called conduction.

Metals are good thermal conductors.Silver is the best thermal conductor

Some cooking pots have copper coating at the bottom :- Being a good conductor copper promotes the distribution of heat over all area of the bottom of the pots

Convection:-Convection is a mode of heat transfer by actual motion of matter.
It is possible only in fluids .Sea breeze and land breeze are due to convection

Radiation:-The mechanism for heat transfer which does not require a medium is called radiation

Heat is transferred to the earth from the sun through empty space as radiation

Sea breeze:-During the day, the ground heats up more quickly than water . This is due to greater specific heat capacity of water.The air in contact with the warm ground is heated . It expands, becomes less dense and rises . Then cold air above sea moves to fill this space and is called as sea breeze .

Land breeze:-At night, the ground loses its heat more quickly, and the water surface is warmer than the land. The air in contact with water is heated. It expands, becomes less dense and rises . Then cold air above the ground moves to fill this space and is called as land breeze .

Newton's Law of Cooling

Newton's Law of Cooling states that the rate of loss of heat(rate of cooling) of a body is proportional the temperature difference between the body and the surroundings .

$-dQ/dt = K(T_1 - T_2)$ T_1 = Temperature of the body
T_2 =Temperature of surroundings

- The change of state from solid to liquid is called **melting**
- The change of state from liquid to solid is called **fusion**
- phenomenon of refreezing is called **regelation**.
- The change of state from liquid to vapour (or gas) is called **vaporisation**
- The temperature at which the liquid and the vapour states of the substance coexist is called its **boiling point**.
- The change from solid state to vapour state without passing through the liquid state is called **sublimation**
- The boiling point of a substance at standard atmospheric pressure is called its **normal boiling point.**

CHAPTER 11

THERMODYNAMICS

Thermodynamics is the branch of physics that deals with the concepts of heat and temperature
and the inter-conversion of heat and other forms of energy.
***Thermodynamics is a macroscopic science**

Thermodynamic system.
An assembly of large number of particles having a certain value of pressure, volume and temperature is called a thermodynamic system.
Surroundings
everything outside the system which can have a direct effect on the system is called its surroundings.

Thermodynamic variables
the quantities like pressure(P), volume(V) and temperature(T)which help to study the behaviour of a thermodynamic system are called thermodynamic variables.
Equation of state
the mathematical relation between the pressure , volume and temperature of a thermodynamic system is called its equation of state.
$PV=\mu RT$ **is the equation of state for the μ moles of an ideal gas**

Thermal equilibrium.
Two systems are said to be in thermal equilibrium with each other if they have the same temperature.

Adiabatic wall
an insulating wall that does not allow the flow of heat between a thermodynamic system and its surroundings is called an adiabatic wall.
Diathermic wall
a conducting wall that allow heat to flow through it is called a diathermic wall.
Zeroth law of thermodynamics.

Zeroth law of thermodynamics.
It states that if two systems A and B are separately in thermal equilibrium with a third system C , then A , B and C are also in thermal equilibrium with each other.
Concept of temperature.
Zeroth law of thermodynamics implies that temperature is a physical quantity which has the same value for all systems which are in thermal equilibrium with each other.

Heat and work are the two ways of changing the internal energy of a system.
Heat is a mode of energy transfer due to temperature difference between the system and the surroundings.
Work is the mode of energy transfer done by not involving the temperature difference between the system and the surroundings(such as moving the piston of a cylinder containing the gas, by applying force on it)

Internal energy
the internal energy of system is the sum of molecular kinetic and potential energies in the frame of reference relative to which the centre of mass of the system is at rest.

Non-cyclic process.
A non cyclic process is one in which the system does not return to its initial state.
Cyclic process.
Any process in which the system returns to its initial state after a series of changes is known as a cyclic process. In a cyclic process $\Delta U = 0$

FIRST LAW OF THERMODYNAMICS
$\Delta Q = \Delta U + \Delta W$
The above Equation is known as the First Law of Thermodynamics.
(ΔQ = Heat supplied to the system by the surroundings
ΔW = Work done by the system on the surroundings
ΔU = Change in internal energy of the system)

Note:-if a system is taken through a process in which $\Delta U = 0$ (for example, isothermal expansion of an ideal gas,),$\Delta Q = \Delta W$

note:-If the system is a gas in a cylinder with a movable piston, the gas in moving the piston does
work. Since force is pressure times area, and area times displacement is volume, work done
by the system against a constant pressure P is $\Delta W = P\,\Delta V$
for this case, the first law of thermodynamics gives
$\Delta Q = \Delta U + P\,\Delta V$.

Mayer's relation (Cp – Cv = R)

To prove the relation, we begin with

ΔQ = ΔU + P ΔV. for 1 mole of the gas

If ΔQ is absorbed at constant volume, ΔV = 0

$$C_V=(\frac{\Delta Q}{\Delta T})_V = (\frac{\Delta U}{\Delta T})_V = \frac{\Delta U}{\Delta T}$$

If, ΔQ is absorbed at constant pressure,

$$C_p=(\frac{\Delta Q}{\Delta T})_P=(\frac{\Delta U}{\Delta T})_P+P(\frac{\Delta V}{\Delta T})_P$$

$$C_p=(\frac{\Delta U}{\Delta T})+P(\frac{\Delta V}{\Delta T})_P$$

$C_p=C_V+P(\frac{\Delta V}{\Delta T})_P$ for a mole of an ideal gas PV = RT which gives

$P(\frac{\Delta V}{\Delta T})_P$ = R . that is $C_P=C_V+R$

$$C_P-C_V=R$$

Different types of thermodynamic processes

1. **isothermal processes**

it is a thermodynamic process which occur at a constant temperature.

2. **isobaric processes**.

it is a thermodynamic process which occur at a constant pressure.

3. **isochoric process**

it is a thermodynamic process which occur at a constant volume.

4. **adiabatic process**.

it is a thermodynamic process in which there is no heat transfer occur between system and surroundings.

What is a quasi-static process?

An infinitely slow process such that the system remains in thermal and chemical equilibrium with the surroundings is called a quasi static process.

Conditions for an isothermal process to take place.

1. the walls of the container must be perfectly conducting. It allows the free exchange of heat between the system and the surroundings.

2. the process of expansion or compression should be very slow.

Equation for isothermal process.

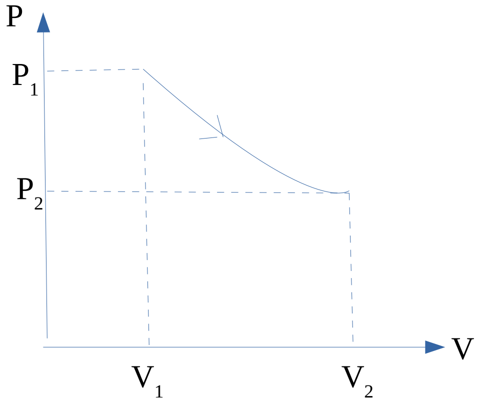
$$PV=a\,constant.$$

this is the equation of state of an isothermal process.

(The ideal gas equation for n moles of a gas is $PV=nRT$ for an isothermal process T is a constant. Therefore $PV=a\,constant.$)

P-V diagram for an isothermal process.

Figure below shows a P-V diagram showing the isothermal expansion of a gas from $[P_1,V_1,T]$ TO $[P_2,V_2,T]$.



For an isothermal process ΔU =0.
now applying first law of thermodynamics to an isothermal process,
ΔQ = ΔU + P ΔV = 0 + P ΔV . or
ΔQ = P ΔV. This is the first law of thermodynamics applied to isothermal process.

Work done in an isothermal process.

Suppose the gas expands isothermally from $[P_1,V_1,T]$ to $[P_2,V_2,T]$.
the total amount of work done by the gas will be

$$W=2.303nRT\log\left(\frac{V_2}{V_1}\right) = 2.303nRT\log\left(\frac{P_1}{P_2}\right)$$

Conditions for an adiabatic process to take place.

1. the walls of the container must be perfectly insulated so that it will not conduct heat between the system and the surroundings.
2. the process of compression or expansion should be sudden, so that the heat does not get time to get exchanged with the surroundings.

Equation for adiabatic process.

$PV^{\gamma}=a\,constant$, where $\gamma=\frac{C_p}{C_V}$

the work done in an adiabatic change of an ideal gas from the
state (P_1, V_1, T_1) to the state (P_2, V_2, T_2).

$$W=\int_{V_1}^{V_2} PdV$$

we know for an adiabatic process $PV^{\gamma}=a\,constant$

$P=\frac{a\,constant}{V^{\gamma}}$ therefore

$W=a\,constant\int_{V_1}^{V_2}\left(\frac{dV}{V^{\gamma}}\right)$ gives $W=\frac{1}{(1-\gamma)}(P_2V_2-P_1V_1)$ or $W=\frac{1}{(\gamma-1)}(P_1V_1-P_2V_2)$

or $W = \frac{\mu R}{(\gamma - 1)} (T_1 - T_2)$

Isobaric process

In an isobaric process

Work done by the gas is W = P (V_2 – V_1) = μ R (T_2 – T_1)

Second law of thermodynamics

No process is possible whose sole result is the absorption of heat from a reservoir and the complete conversion of the heat into work.(Kelvin-Planck statement)

No process is possible whose sole result is the transfer of heat from a colder object to a hotter object.(Clausius statement)

Reversible process

A process is reversible if it can be reversed such that both the system and the surroundings return to their original states

Carnot engine

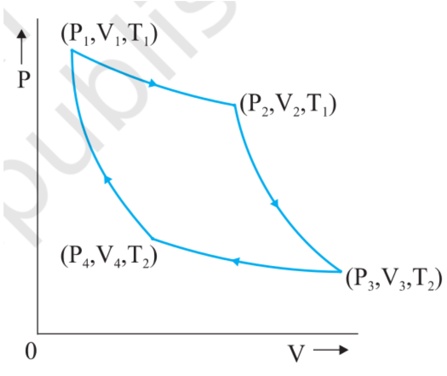
Carnot engine is a reversible engine operating between two temperatures T_1 (source) and T_2 (sink).

Carnot cycle

a Carnot engine have the following sequence of steps constituting one cycle, called the Carnot cycle.

1) Isothermal expansion of the gas from (P_1 , V_1 , T_1) to (P_2 , V_2 , T_1).
2) Adiabatic expansion of the gas from (P_2 , V_2 , T_1) to (P_3 , V_3 , T_2)
3)Isothermal compression of the gas from (P_3 , V_3 , T_2) to (P_4 , V_4 , T_2)
4) Adiabatic compression of the gas from (P_4 , V_4 , T_2) to (P_1 ,V_1 , T_1)

Figure shows a Carnot cycle for a heat engine with an ideal gas as the working substance.



CHAPTER 12
KINETIC THEORY

Postulates of Kinetic Theory of an Ideal Gas

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 onserved .

Pressure of an Ideal Gas :- $P=\frac{1}{3}nm(\overline{v})^2$

Kinetic Interpretation of Temperature

$$P=\frac{1}{3}nm\overline{v^2}$$

$$PV=\frac{1}{3}nVm\overline{v^2}$$

$$n=\frac{N}{V}, \quad N=nV$$

$$PV=\frac{1}{3}Nm\overline{v^2}$$

where N is the number of molecules in the sample.

$$PV=\frac{2}{3}\left(N\,\frac{1}{2}m\overline{v^2}\right)$$

The quantity in bracket is the average translational kinetic energy of the molecules in the gas.

$$N\,\frac{1}{2}m\overline{v^2}=E$$

$$PV=\frac{2}{3}E\text{---------------------}(1)$$

Ideal gas equation, PV =NkBT -------------------(2)

From eq(1)and (2) $\frac{2}{3}E=Nk_BT$ or $E=\frac{3}{2}Nk_BT$ or $\frac{E}{N}=\frac{3}{2}k_BT$

The average kinetic energy of a molecule is proportional to the absolute temperature of the gas; it is independent of pressure, volume or the nature of the ideal gas.

Root Mean Square (rms) Speed:- $\frac{E}{N} = \frac{3}{2} k_B T$

$\frac{1}{2} M (\overline{v})^2 = \frac{3}{2} k_B T$ OR $\overline{v}^2 = \frac{3 k_B T}{m}$

The square root of $\overline{v^2}$ is known as root mean square (rms) speed and is denoted by

$$v_{rms} = \sqrt{\frac{3k_B T}{m}}$$

Degrees of Freedom

The total number of independent ways in which a system can possess energy is called degrees of freedom.

A molecule has one degree of freedom for motion in a line.,Two degrees of freedom for motion in a plane Three degrees of freedom for motion in space.

Law of Equi partition of Energy

Law of Equipartition of Energy states that, in equilibrium, the total energy is equally distributed in all possible energy modes, with each mode having an average energy equal to $\frac{1}{2} k_B T$

CHAPTER 13

OSCILLATIONS

Periodic Motion:-A motion that repeats itself at regular intervals of time is called periodic motion.
Eg:-motion of a simple pendulum, uniform circular motion

Oscillatory Motion:-Periodic to and fro motion is called oscillatory motion.
Eg:- motion of a cradle , motion of a swing, motion of the pendulum of a wall clock. Every oscillatory motion is periodic, but every periodic motion need not be oscillatory.

Period (T):-The period (T) is the time required for one complete oscillation or one cycle. It's SI unit is second.

Frequency:-The frequency ν of periodic or oscillatory motion is the number of oscillations per unit time.

It is the reciprocal of period ν = 1/T . It's SI unit is **hertz(Hz)**

Amplitude:-The maximum displacement from the mean position is called amplitude (A) of oscillation

Simple Harmonic Motion(SHM):-Simple harmonic motion is the simplest form of oscillatory motion.

Simple harmonic motion is the to and fro motion under a restoring force, which is proportional to the displacement of the particle and is directed towards the mean position.

Mathematical expression for an SHM:- $y = A \sin(\omega t + \phi)$

y= displacement ,A= Amplitude ,ω =Angular frequency ,Φ= initial phase

Eg : If a body oscillates with SHM according to the equation

$y = 5 \sin(2\pi t + \pi/4)$,in SI system .Then Amplitude (A) = 5 m,

Angular frequency (ω)= 2π S^{-1}.Time period(T) = 2π/ω = 2π/2π = 1 S, Phase constant (Φ) = π/4

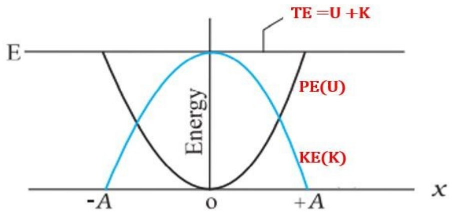
Kinetic Energy of Simple Harmonic Motion :-K.E = ½ $m\omega^2x$

Potential Energy of Simple Harmonic Motion

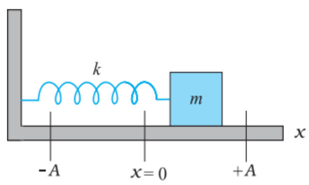
P.E = ½ mω^2 (A^2 – x^2) A is amplitude and x is displacement

Total Energy of Simple Harmonic Motion Total Energy =K.E + P.E = ½ mω^2A^2

Variation of Potential energy , kinetic energy and the total energy for a linear harmonic oscillator



Time period of a loaded a spring

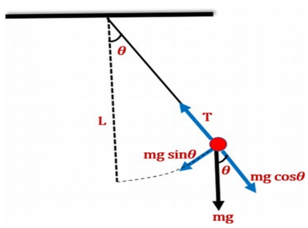


Restoring force $F=-kx$ or $ma=-kx$ but for SHM $a=-\omega^2 x$

therefore $-m\omega^2 x=-kx$ or $m\omega^2=k$ or $\omega^2=\frac{k}{m}$ or $\omega=\sqrt{\frac{k}{m}}$

we know $\omega=\frac{2\pi}{T}$ or $\frac{2\pi}{T}=\sqrt{\frac{k}{m}}$ or $T=2\pi\sqrt{\frac{m}{k}}$

Expression for the time period of a simple pendulum



$mgsin\theta$ acts as the restoring force $F = -mgsin\theta$ for small angles $sin\theta=\theta$ So

$F = -mg\theta$, $ma = -mg\theta$, or $a = -g\theta$

$a=-\omega^2 x$ so $-\omega^2 x = -g\theta$ but $\theta=\frac{x}{l}$ [since angle= arclength/radius]

now $-\omega^2 x = -g\frac{x}{l}$ or $\omega^2=\frac{g}{l}$ or $\omega=\sqrt{\frac{g}{l}}$ or $\frac{2\pi}{T}=\sqrt{\frac{g}{l}}$ or $T=2\pi\sqrt{\frac{L}{g}}$

The time period of a simple pendulum is independent of the mass of the bob, but depends on length of the pendulum and acceleration due to gravity

CHAPTER 14

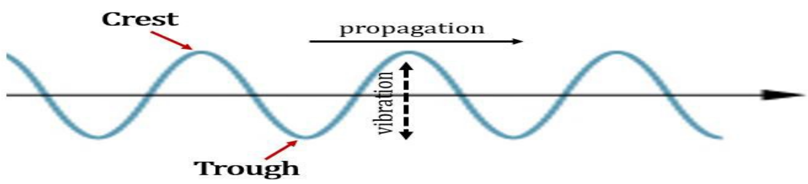
WAVES

Wave Motion:- **The propagation of disturbance which carries energy from one point to another point without the transfer of the medium is known as a wave motion.**

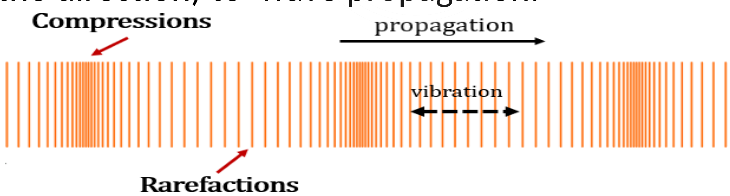
Mechanical waves:-Waves which require a medium for propagation are known as mechanical waves. Eg **:** Sound waves ,waves in a stretched string , seismic waves, Ripples formed on the surface of water, etc.

Types of Mechanical Waves:-(1)Transverse waves (2)Longitudinal waves

Transverse waves:-In transverse waves, the particles of the medium oscillate perpendicular to the direction of wave propagation.Eg:-waves in a stretched string



Longitudinal waves:-In longitudinal waves the particles of the medium oscillate parallel (along the direction) to wave propagation.



Eg: -sound waves, vibrations in a spring.

Progressive Waves(Travelling Waves):-A wave which travels from one point of the medium to another is called a progressive wave or travelling wave.

Relation for displacement of Travelling waves (Progressive Waves)

$y = A \sin (kx - \omega t + \phi)$ A = Amplitude, $(kx - \omega t + \phi)$ = Phase,K= Wave Number = $2\pi/\lambda$
ω = Angular frequency,Φ= Initial phase angle

Example:-A wave travelling along a string is described by $y = 0.005 \sin (80.0\,x - 3.0\,t)$, in which the numerical constants are in SI units . Calculate

(a)the amplitude, (b)the wavelength, (c)the period and (d)frequency

We have $y = A \sin (kx - \omega t + \phi)$

Comparing these equations (a)Amplitude A =0.005m (b)Wave number k = 80

$2\pi/\lambda = 80$ so Wave length $\lambda = 2\pi/80$ m Angular frequency (ω)=3

$2\pi/T = 3$ (c) Time period $T = 2\pi/3$ S (d) Frequency $\nu = 1/T = 3/2\pi$ HZ

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

μ = linear mass density or mass per unit length , T=Tension

Speed of Longitudinal Wave in Solids:- $v = \sqrt{Y/\rho}$ Y= Young's Modulus

ρ= density of medium

Speed of Longitudinal Wave in Fluids:- $v = \sqrt{B/\rho}$ B= Bulk modulus, ρ= density of medium

Newtons Formula

According to Newton ,velocity of sound waves

$v = \sqrt{P/\rho}$ P=Pressure ρ= density of medium

Laplace correction :-Laplace corrected velocity of sound waves as

$v = \sqrt{\gamma P/\rho}$ P =pressure ρ=density of medium and $\gamma = C_P/C_V$

Check the dimensional correctness of speed of a transverse wave on Stretched String

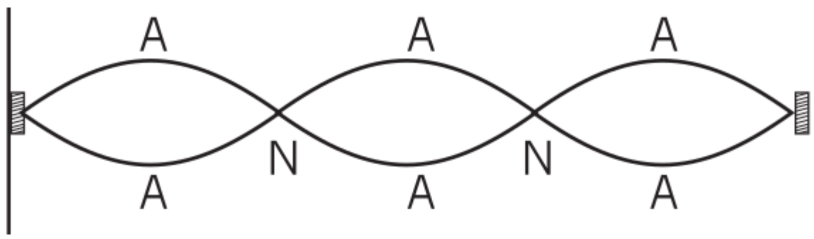
$v = \sqrt{T/\mu}$, where T=Tension in the string and μ = linear mass density or mass per unit length.

Dimension of LHS = LT^{-1} Dimension of RHS $= \sqrt{(MLT^{-2})/(M/L)} = \sqrt{L^2T^{-2}} = LT^{-1}$

Since dimension of LHS = dimension of RHS, the equation is correct

Standing waves

When two waves of same amplitude and frequency travelling in opposite direction super impose , the resulting wave pattern does not move to either sides. This pattern is called standing waves



Nodes(N) The position of zero amplitude in a standing wave is called nodes

Anti Nodes(A)

The position of zero amplitude in a standing wave is called nodes

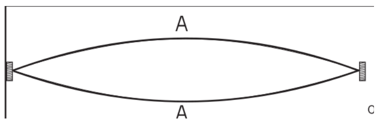
Notes:-

- (1) The distance between two nodes $=\lambda/2$
- (2) The distance between two anti nodes $=\lambda/2$
- (3)The distance between a node and antinode $= \lambda/4$

Standing waves in a Stretched String fixed at both the ends

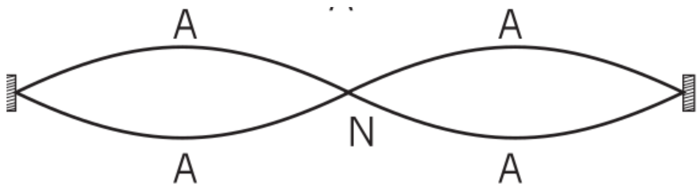
For a stretched string of length L, fixed at both ends

First mode of vibration or fundamental mode



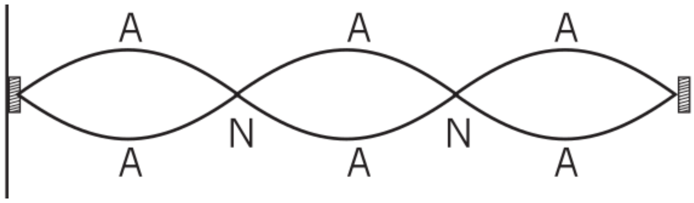
Frequency $\nu_1 = V/2L$ (Fundamental frequency or first harmonic)

<u>Second mode of vibration</u>



Frequency $\nu_2 = V/L = 2\nu_1$ (Second harmonic or first overtone)

<u>Third mode of vibration</u>



Frequency $\nu_3 = 3V/L = 3\nu_1$ (Third harmonic or second overtone)

thus $\nu_1 : \nu_2 : \nu_3 = 1:2:3$

The modes of vibration in a closed pipe (closed at one end and the other end open)

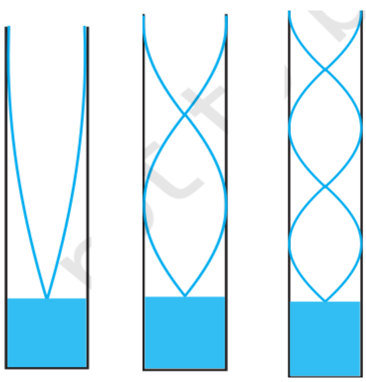


FIG.1 represent the first mode . In this case **Frequency $\nu_1 = V/4L$ (fundamental frequency or first harmonic)**

FIG.2 represent scond mode of vibration. Frequency **$\nu_2 = 3V/4L = 3\nu_1$.** FIG.3 represent the third mode of vibration. Frequency **$\nu_3 = 5V/4L = 5\nu_1$**

thus $\nu_1 : \nu_2 : \nu_3 = 1:3:5$

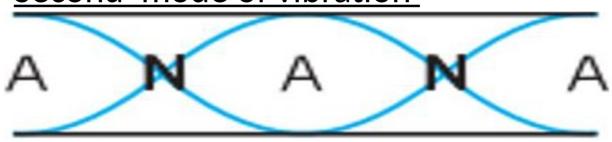
FIG.1 FIG.2 FIG.3

The modes of vibration in a an open pipe (open at both ends)

First mode or Fundamental mode

Frequency v_1= V/2L (Fundamental frequency or first harmonic)

Second mode of vibration



Frequency v_2 = V/L = 2v_1 (Second harmonic or first overtone)

Third mode of vibration

Frequency v_3= 3V/L = 3v_1 (Third harmonic or second overtone)

thus $v_1 : v_2 : v_3$ =1:2:3

....