01. Physics

Physics : Physics is associated with those aspects of nature which can be understood in the most fundamental way in terms of the elementary principles and laws. In other words Physics is that branch of physical science in which matter and energy mutually interact with each other.

Physics is usually studied in the following groups—

I. General Physics (Mechanics)

1. Quantity and Measurement

Quantity : Anything, which is expressed in number or whose representation is totally numerical is called quantity.

Example : Population, Ages of men or women, weights of objects etc.

Physical quantity : Quantities expressed in terms of laws of physics are called physical quantities.

Example : Mass of an object, length, force, speed, distance, displacement, momentum , electric current etc. These physical quantities are of two types (i) scalars (ii) vectors.

(i) Scalars : Those physical quantities which have magnitude only and whose direction is not taken into the consideration are called *scalars*.

Example : Mass, temperature, density, volume, electric current, work etc.

(ii) Vectors : Those physical quantities which have both magnitude and direction and which are represented by the directed line segment (→) obeying the triangle law of vectors or parallelogram law of vectors are called *vectors*.

Example : Displacement, linear momentum, angular velocity, torque, magnetic field intensity, electric displacement, current density etc.

A physical quantity which has both magnitude and direction but which doesn't obey vector laws of addition or subtraction is not a vector quantity, like electric current, pressure, work etc. Also there are certain physical quantities which are used both as scalar and vector. Simply *area* is treated as a scalar, while normal area is treated as a vector.

Units of Measurement : To measure any quantity, a definite and a substantial amount of that quantity, is assumed to be standard which is called *unit* of the quantity and when any given quantity is measured in the terms of this unit, the process is called *measurement*. There are usually two types of units—

(i) Fundamental Units (ii) Derived Units

(i) Fundamental Units : If a physical quantity is expressed in terms of units which are used as standards and these standards are independent of each other, then these units are called *Fundamental*

During the early stage of research and development the units of Length, Mass and Time were assumed to be Fundamental. But later the units of Electric Current, Temperature, Luminous Intensity and the amount of substance were added and thus at present there are seven Fundamental Units.

Derived Units : If a physical quantity is expressed in terms of two or more fundamental units then these units are called *Derived Units*. These units have no independent existence like fundamental units. The unit of Force, Momentum, Work, Potential Energy, Density etc. are Derived Units.

System of Units

Usually physical quantities are measured in four systems of units.

(i) CGS System (Centimeter/Gram/Second System) : In this system of units Length, Mass and Time are measured in Centimeter, Gram and Second respectively. CGS system is also called *Metric or French System of Units.*

(ii) FPS System (Foot/Pound/Second System) : In this system of units Length, Mass and Time are measured in Foot, Pound and Second. FPS system is also called British System of Units.

(iii) MKS System (Meter/Kilogram/Second System) : In this system of units Length, Mass and Time are measured in Meter, Kilogram and Second.

(iv) SI System (International System of Units) : In the International Conference of Weights and Measures held at Geneva in 1960 the SI System of Units was adopted and accepted on the basis of a comprehensive consensus. In fact SI system is extended and modified form of the MKS System.

There are *Seven Fundamental Units* and *two Supplementary Units* in SI system.

Seven Fundamental Units of SI System :

(i) Length : In SI System Length is measured in *meter* and is defined as—

Total distance travelled by light in vacuum in 1/299792458 sec is called 1 *meter.*

(ii) Mass : In SI system Mass is measured in *Kilogram* and is defined as—

The amount of the mass of a cylindrical alloy of Platinum-Iridium kept at International Bureau of Weight and Measure at Severis in France is called 1 *kilogram.*

(iii) Time : In SI system Time is measured in *second* and it is defined as—

In the transition of two hyper fine levels of energy in the ground state of an atom of Cesium–133 by means of radiation between an interval of 9192631770 time-periods is called 1 second.

Einstein in his special Theory of Relativity used Time as fourth coordinate in Space-Time coordinate system.

(iv) Electric current : In SI system Electric current is measured in *Ampere* and is defined as—

If two long parallel wires (coils) are kept 1 meter apart through which an electric current is passed in such a way that it produces a magnetic force of 2×10^{-7} N, then the magnitude of the electric current is called 1 Ampere.

(v) Temperature : In SI system Temperature is measured in *Kelvin* and is defined as—

Three phases of water-solid (ice), liquid and vapour-coexist at 273.16 K which is called triple point of water and this temperature is called critical temperature and its 1/273.16th part is called 1 *kelvin.*

(vi) Luminous Intensity : In SI system luminous intensity is measured in *Candela* which is defined as—

If any monochromatic source of light produces a frequency of 540×10^{12} Hz in a definite direction and if its intensity is 1/683 watt/steradian, then is Luminous Intensity is of 1 *Candela.* If 1 Joule energy is emitted in 1 sec within any solid angle, then it is called 1 watt/steradian.

(vii) Amount of Substance : In SI system Amount of Substance is measured in Mole which is defined as—

If the number of molecules, atoms or ions present in any substance or element is 6.023×10^{23}, then the required amount of the substance or element is called 1 mole.

If this number of molecules, atoms or ions in any substance or element is 6.023×10^{23}, then it is also called *Avogadro's Number.* Thus *Avogadro's Number* = 6.023×10^{23}.

or, 1 mole = Avogadro's number

Supplementary Units of SI system

There are two Supplementary Units in SI system.

(i) Radian : The plane angle made by any arc of a circle of equal radius is called 1 radian. All plane angles are measured in *radian.*

(ii) Steradian : The solid angle made on the centre of a sphere by the area formed as a square on the surface of the sphere where the side of the square is equal to the radius of the sphere is called 1 steradian. All the solid angles are measured in *steradian.*

Fundamental Units

Physical Quantity	S.I. Units	Symbol
Length	Meter	m
Mass	Kilogram	kg
Time	Second	s
Electric current	Ampere	A
Temperature	Kelvin	θ or K
Luminous Intensity	Candela	cd
Amount of Substance	Mole	mol

Supplementary Units

Physical Quantity	S.I. Units	Symbol
Plane Angles	Radian	rad
Solid Angles	Steradian	Sr

Some Important Derived Units

Physical Quantity	Definition of Quantity	S.I. Units
Area	Length Square	m^2
Volume	Length Cube	m^3
Density	Mass per unit Volume	kgm^{-3}
Velocity	Displacement per unit Time	ms^{-1}
Force	Mass × Acceleration	$kg\ ms^{-2}$ *or* Newton
Linear Momentum	Mass × Velocity	$kg.\ ms^{-1}$
Pressure	Force per unit Area	Nm^{-2} or Pascal
Work or Energy	Force × displacement	N-m or Joule
Magnetic Field Intensity	$\frac{\text{Force}}{\text{electric current} \times \text{displacement}}$	$N\text{-}amp^{-1}\ m^{-1}$ or Tesla or weber / m^2

Various Exponents of 10

Exponent of 10	Prefix	Symbol	Exponent of 10	Prefix	Symbol
10^{18}	Exa	E	10^{-1}	Deci	d
10^{15}	Peta	P	10^{-2}	Centi	c
10^{12}	Tera	T	10^{-3}	Milli	m
10^{9}	Giga	G	10^{-6}	Micro	μ
10^{6}	Mega	M	10^{-9}	Nano	n
10^{3}	Kilo	k	10^{-12}	Pico	p
10^{2}	Hecto	h	10^{-15}	Femto / Fermi	f
10^{1}	Deca	da	10^{-18}	Atto	a

Units for Astronomical distance :

(i) Astronomical Unit (A.U.) : It is a *unit of distance*. It is mean distance between Sun and Earth.

1 A. U. = 1.495×10^{11} meter.

(ii) Light Year : It is also a *unit of distance* and it is distance travelled by light in vacuum in one year.

1 Light Year = 9.46×10^{15} meters.

(iii) Par sec (Parallax Second) : It is the *largest unit of distance* among all the astronomical units of distance and 1 Par sec = 3.08×10^{16} meters.

Units of Length or distance

1 km	= 1000 m
1 mile	= 1.60934 km
1 NM	= 1.852 km
1 AU	= 1.495×10^{11} m
1 LY	= 9.46×10^{15} m
	= 48612 A.U.
1 Par sec	= 3.08×10^{16} m
	= 3.26 ly

Units of Mass

1 Ounce-OZ	= 28.35 gm
1 pound-lb	= 16 OZ
	= 453.52 gm
1 kg	= 2.205 lb
	= 1000 gm
1 Quintal	= 100 kg
1 Metric ton	= 1000 kg

Units of Time

1 minute	= 60 sec
1 hour	= 60 min
	= 3600 sec
1 day	= 24 hours
1 week	= 7 days
1 lunar month	= 28 days
	= 4 weeks
1 solar month	= 30 or 31 days
	= 28 or 29 days (Feb)
1 year	= 13 lunar month 1 day
	= 12 solar month
	= 365 days
1 leap year	= 366 days

Units of Area

1 acre	= 4840 sq. yard
	= 43560 sq. feet
	= 4046.94 sq. meter
1 hectare	= 2.5 acre
1 sq. km	= 100 hectare
1 sq. mile	= 2.6 sq. km
	= 256 hectare
	= 640 acre

Units of volume

1 litre	= 1000 cubic cm (cc)
	= 0.2642 gallon
1 gallon	= 3.785 lit.

Dimensions of Physical Quantities

In Physics Length, Mass, Time, Temperature, Electric Current etc. which are symbolically represented by L, M, T, O, A have vital and significant roles. All physical quantities are expressed in terms of power (exponents) of these symbols called *dimension*.

Example : Area = $L \times L = L^2$, Density $= \frac{\text{Mass}}{\text{Volume}} = \frac{M}{L^3} = ML^{-3}$

Force = mass × acceleration $= M \times LT^{-2} = MLT^{-2}$

$$\text{Magnetic Field Intensity} = \frac{\text{Force}}{\text{current} \times \text{displacement}} = \frac{MLT^{-2}}{A \times L} = MA^{-1}T^{-2}$$

2. Motion and Force

Rest and Motion : If the position of a body changes with time, then the body is said to be in *motion* but if the position of the body does not change with time then it is said to be in *rest*.

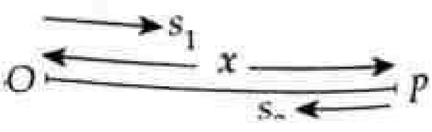
Distance : The total length of the path travelled by a body in any given time interval is called *distance*. In other words, distance is total length between the initial and final positions of the body in a particular interval of time without taking into account the direction of the motion. This is a scalar quantity and is never –ve, and its S.I. unit is meter.

Displacement : The least distance executed by a body between the initial and final points (position) of a straight line motion in a definite direction is called *displacement* and it is a vector quantity. The displacement may be +ve, –ve or zero, and its S.I. unit is meter.

Velocity : If a body going in a definite (fixed) direction during its straight line motion changes its position in unit time, then this is called the velocity of the body. Thus *velocity* of a body is the rate of change of its position in a fixed direction. Velocity is a vector quantity and its S.I. unit is ms^{-1} and its value may be +ve, –ve or zero.

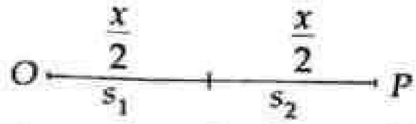
Average Speed : Average speed is defined as total distance travelled by a body upon total time elapsed. Thus

$$\text{Average Speed} = \frac{\text{Total distance travelled}}{\text{Total time elapsed}}$$



If a body travels x distance with speed s_1 and comes back with speed s_2 and the body takes t_1 and t_2 times respectively then

$$\text{Average Speed} = \frac{x+x}{t_1+t_2} = \frac{2x}{\frac{x}{s_1}+\frac{x}{s_2}} = \frac{2\,s_1 s_2}{s_1+s_2}$$



If a body covers half of the distance with speed s_1 and another half with speed s_2 then the average speed for the distance OP of the body $= \dfrac{\frac{x}{2}+\frac{x}{2}}{t_1+t_2}$

$$\Rightarrow \quad \text{Average Speed} = \frac{s_1 t_1 + s_2 t_2}{t_1+t_2}$$

$$= \frac{(s_1+s_2)t}{2t} = \frac{s_1+s_2}{2} \qquad [t_1 = t_2 = t\ (\text{say})]$$

Speed : Total distance covered by a body between the initial and final points of a straight line motion without any consideration of direction in unit time is called speed of the body. Thus speed of a body is *the rate of change of its position*. It is a scalar quantity and its S.I. unit is ms^{-1}.

Average Velocity : The average velocity of a body is defined as total displacement of the body upon total elapsed time.

$$\text{Thus Average Velocity} = \frac{\text{Total displacement}}{\text{Total time}}$$

Instantaneous Velocity : If a body moves in such a way that its average velocity measured for a number of different time intervals does not turn out to be constant and the body is said to be moving with variable velocity, then the velocity of the body at any given instant of time is called instantaneous velocity and it is expressed as

$$= \vec{v} = \lim_{\Delta t \to 0} \frac{\Delta \vec{r}}{\Delta t}$$

Acceleration : The *rate of change of velocity* of the body is called *acceleration* of the body. If the velocity changes uniformly at equal interval of time, then acceleration is said to be *uniform acceleration*. If the velocity of a body increases with time then the body is said to be *accelerated* and conversely if velocity decreases with time then the body is said to be *retarded* or *deaccelerated*. Acceleration is a vector quantity and its S.I. unit is ms^{-2}

Mathematically, acceleration $= \dfrac{d\vec{v}}{dt}$ and if $\vec{v} = \dfrac{d\vec{x}}{dt}$

then acceleration $= \dfrac{d\vec{v}}{dt} = \dfrac{d}{dt}\left(\dfrac{d\vec{x}}{dt}\right) = \dfrac{d^2\vec{x}}{dt^2}$

If any body moves with a constant velocity then

acceleration $= \dfrac{d\vec{v}}{dt} = 0$ (as $\vec{v}$ is constant)

Thus in uniform motion acceleration does not exist. If the body is in *rest* then obviously *velocity does not exist* and thus *no acceleration* exists.

Relative Velocity : The relative velocity of one body with respect to that of another is the rate of change of displacement of one body relative to that of another and vice-versa.

If $\vec{v}_A$ and $\vec{v}_B$ are the constant velocities of two bodies A and B, then $\vec{v}_{BA}$ is the symbolical representation of the relative velocity of B with respect to A and the relative velocity of A with respect to B is expressed as $\vec{v}_{AB}$.

Mathematically; these are expressed as; $\vec{v}_{BA} = \vec{v}_B - \vec{v}_A$ and $\vec{v}_{AB} = \vec{v}_A - \vec{v}_B$

Equations of Motion : If a body describes a straight line motion with an initial velocity u in time t, covers a distance s with a uniform acceleration a and finally acquires velocity v then, by applying the fundamental principles of *Classical Newtonian Mechanics*, Galileo derived the following equations which are called Kinematical Equations of Motion.

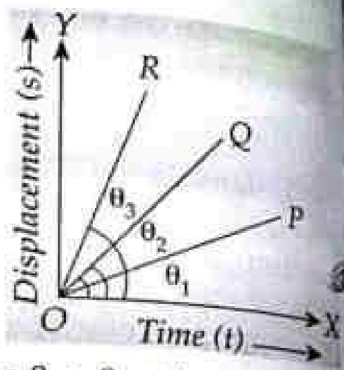
Equations of motion are : (i) $v = u + at$ (ii) $s = ut + \frac{1}{2}at^2$

(iii) $v^2 = u^2 + 2as$ (iv) $S_n = u + \frac{1}{2}a(2n-1)$,

where S_n = distance covered by the body in n^{th} second.

Graphical representation of motion

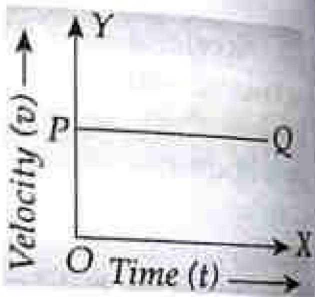
(i) Displacement-Time Graph :



If a body moves with a uniform velocity then displacement-time graph is a straight line as shown in the figure. The slope or gradient of the straight line provides speed. Also the greater the slopes of the straight lines, the larger the speed.

Obviously in the figure straight lines OP, OQ, and OR have increasing order of the speeds as $\theta_3 > \theta_2 > \theta_1$.

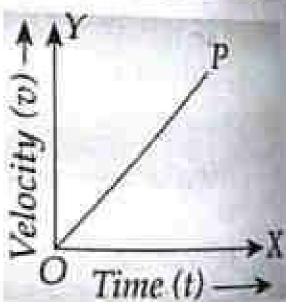
(ii) Velocity-Time Graph :



(a) Constant Velocity or Uniform Motion : If a body moves with a constant velocity in a uniform motion, then Velocity-Time graph is a straight line, parallel to Time-Axis as shown in the figure.

The straight line PQ represents uniform motion.

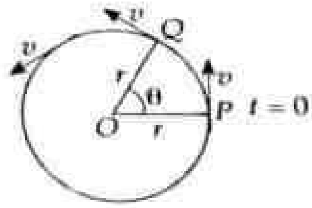
(b) Uniformly Accelerated Motion : If a body describes a uniformly accelerated motion in a straight line, then the Velocity-Time graph is a straight line as shown in the figure.



Obviously, straight line OP represents Velocity-Time graph of the uniformly accelerated motion.

Two Dimensional Motions : If the motion of a body is *described in two dimensional Co-ordinate axes or in a rectangular Co-ordinate axis*, then it is called *two dimensional motion*. The circular motion, projectile motion, motion of a canonical pendulum, etc. are all examples of two dimensional motion.

(i) Circular Motion : If a body describes its motion on a circular track or path, then the motion is called *circular motion*. In circular motion, since velocity of the body is tangential at every point of the track, its direction changes everywhere. This shows that as the magnitude of the velocity remains constant (speed constant) and velocity doesn't remain constant (as its direction changes) so the motion is accelerated. Thus motion of a body on a circular path with a *constant speed* is called *Uniform circular motion.*



Let P and Q are any two instantaneous positions of a body describing a uniform circular motion with linear velocity v. Here O is the centre of the circular track and r is its radius.

If a body describes an angular displacement in t sec and its position on the circular track changes from P to Q then the *angular velocity* of the body is defined as *angular displacement per unit time.* Thus angular velocity $\omega = \frac{\theta}{t}$ (expressed in rad / sec.)

If a body moves on a circular track and completes one revolution, then the time required for it is called Time period. The inverse of this time period is called angular frequency.

Thus $\omega = \frac{2\pi}{T} = 2\pi n$ Here, n is called angular frequency and T is time period. Thus $n = \frac{1}{T}$.

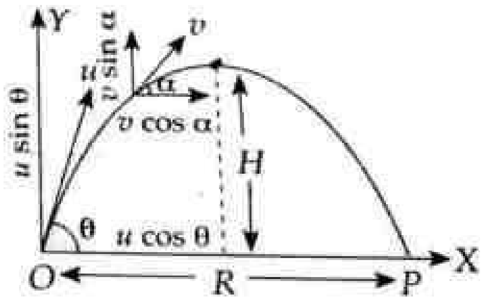
Also the linear velocity $(v) = \frac{\text{Circumference of the circular track}}{\text{Time elapsed}}$

or, $v = \frac{2\pi r}{T} = \left(\frac{2\pi}{T}\right) r = \omega \times r$ $\left(\because \frac{2\pi}{T} = \omega = \text{angular velocity}\right)$

Thus, linear velocity (v) = angular velocity (ω) × radius (r)

(ii) Projectile Motion : If a body is projected upward with a certain initial velocity u making an angle θ with horizontal direction, then the body describes a two dimensional motion whose path (trajectory) is *parabolic* and such a body is called *projectile.*

Here a unique physical phenomenon occurs. As the body starts its motion there is no acceleration in its horizontal direction, but in the vertical direction there is a constant acceleration (acceleration due to gravity). Thus, in the projectile motion the body describes its horizontal motion with constant velocity and its vertical motion with constant acceleration.



Terms and Expressions associated with projectile motion.

Time of Ascent (t_a) : It is the time taken by a body (projectile) to reach the maximum height (H). It is given by

$$t_a = \frac{u \sin\theta}{g}$$

Time of Descent (t_d) : It is the time taken by a body (projectile) to reach the ground at P from the maximum height (H). It is given by $t_d = \frac{u \sin\theta}{g}$

Thus $t_d = t_a = \frac{u \sin\theta}{g}$

(Here air resistance is assumed to be negligible)

Time of flight (t_f): It is the sum total of the time of ascent and the time of descent i.e. the total time taken to travel the distance *OP* (Horizontal distance by the body called *Horizontal Range* or *Range*.)

$$\text{Thus } t_f = t_a + t_d = \frac{u \sin\theta}{g} + \frac{u \sin\theta}{g} = \frac{2u \sin\theta}{g}$$

Maximum Height (H) : It is the maximum vertical distance travelled by a body (projectile) at which its velocity becomes Zero at glance. It is given by $H = \frac{u^2 \sin^2\theta}{2g}$

Horizontal Range (R) : It is the total horizontal distance (*OP*) travelled by a body (projectile) in the total time of flight (t_f). It is given by $R = \frac{u^2 \sin 2\theta}{g}$

Obviously range *R* would be maximum if sin 2θ be maximum. But max. value of sin 2θ = 1

$\Rightarrow \sin 2\theta = 1 = \sin 90^\circ \Rightarrow \theta = 45^\circ$

Thus *any projectile would have max. range* if θ (*angle of projection*) $= 45^\circ$ and it would be $R_{max} = \frac{u^2 \sin 90^\circ}{g} = \frac{u^2}{g}.1 = \frac{u^2}{g}$

Also if the angle of projections are θ and (90° − θ) then *horizontal range R* would be the *same* in *both cases,* whatever be the initial velocity of projection, max. height attained, time of flight, etc.

Equation of the trajectory of the projectile

The overall equation of the trajectory of any projectile, whatever be the individual parameter, is given by

$$y = (\tan\theta)\,x - \frac{gx^2}{2u^2}\sec^2\theta. = (\tan\theta)\,x - \frac{g}{2(u\cos\theta)^2}\cdot x^2$$

Obviously, it is the *equation* of a *parabola*. That's why *every projectile* traces out a *parabolic trajectory (path).*

Newton's Laws of Motion : Firstly in 1687 Sir Isaac Newton, who was a great mathematician of his time, propounded the laws of motion in his book *Principia*. There are three laws of motion.

First Law (*Law of Inertia*) : A body continues in its state of rest or uniform motion in a straight line in the same direction unless some external force is applied to it. This is *Newton's first law of motion.*

The tendency of bodies or objects to remain in the original initial state of rest or uniform motion is called *inertia*. Inertia is of two types (i) Inertia of rest and (ii) Inertia of motion. Also the external force which is accountable to change the state of the bodies provides us the definition of force.

Examples of inertia : (i) If a train suddenly starts to move from the position of rest then a passenger sitting in it leans in the opposite direction. This happens due to the inertia of the body of the passenger. Due to sudden start of the train the lower part of the body of the passenger which is in contact with the train comes in motion whereas the upper part, due to inertia of rest, stays at rest. Thus, there is a relative displacement of the two parts of the body of the passenger and consequently the passenger leans in the opposite direction.

(ii) To remove dirt from a coat we hit it with a stick. On being hit the coat comes into motion but the dirt, due to its inertia remains at rest and so gets detached from the coat and falls off.

(iii) Before taking a long jump an athlete runs for a while and then takes a leap. By running for a while he gains inertia of motion which helps him take a longer *jump*.

(iv) While alighting from a slowly moving train one must run for a short while in the direction of the moving train and then let off the train. When you set your foot on the ground, the lower part of your body comes to rest instantaneously but the upper part of the body continues to move in the direction of the train. Due to relative displacement you are liable to fall forward and hurt yourself. If you run for a short while all the parts of the body will be in the same state and hence there will be no relative displacement of the different parts of the body.

Second Law (*Law of Measurement of Force*) : The rate of change of linear momentum ($p = mv$) of a body is proportional to the force applied and it takes place in the direction of the force. i.e. $\boxed{F \propto \frac{dp}{dt}}$

or, $F = k\frac{dp}{dt} = k\frac{d(mv)}{(dt)} = km\frac{dv}{dt}$ (here mass m is constant)

Where, k = proportionality constant

$= kma$ (as $a = \frac{dv}{dt}$ = acceleration)

If the proportionality constant $k = 1$ then $F = ma$.

$\Rightarrow$ Force = mass × acceleration.

If $F = ma = m\frac{dv}{dt} = 0$, then no acceleration would be produced.

If the *acceleration* of the body is *zero* ($a = \frac{dv}{dt} = 0$) then the body will move either with a *constant velocity* or be in *a position of rest*. This implies that in the absence of an external force the body either *moves* with *constant velocity* or *comes* to *rest*. This also concludes that in the *absence* of an *external force* the inertia of a body is *conserved*.

Third Law *(Law of Action and Reaction)*: To every action, there is an equal and opposite reaction. Action and reaction act on different bodies. Since their lines of action are different, the resultant force is not zero. This is Newton's Third law of motion.

Examples : (i) A rocket whose mass decreases continuously due to ejected mass in the form of gases during its forward motion.

(ii) During firing of a bullet the gun recoils back with a great force.

(iii) To drive water boat forward the bamboo stick is pressed into the land of water.

(iv) During pulling water from the well sometimes the rope breaks and the man falls behind the well.

Units of Force : The S.I. Unit of force is *Newton. Forces* are *defined* by *Newton's first law* of *motion* and *measured by Newton's second law of motion*.

By Newton's second law $F = ma$. Here if $m = 1$ kg and $a = 1$ meter / second^2, then F = 1 N. Thus 1 Newton is the force required to produce an acceleration of 1 ms^{-2} in a body of mass 1 kg.

The CGS unit of force is *Dyne* and $1N = 10^5$ dyne.

Another unit of force is kg-wt which is also used for *Gravitation*. 1 kg-wt is the force required resulting from the acceleration of gravity on the body of 1 kg mass. Thus by Newton's second law, Force due to gravity = mass × acceleration due to gravity. The force of gravity acting on a body is the weight of the body.

Thus weight $(W) = mg$.

Here the value of g (acceleration due to gravity) = 9.8 ms^{-2}

Thus, 1 kg.weight = 1 kg × 9.8 ms^{-2} = 9.8 kg.ms^{-2} = 9.8 N.

Linear Momentum and Impulse : The product of the mass of a moving object or body with its velocity (constant) is called Linear Momentum and it is a vector quantity.

Thus momentum (p) = mass × velocity

$$\Rightarrow \quad p = mv.$$

The S.I. unit of the linear momentum is kg.ms^{-1}

If any external force is operative on an object or a body for a very short span of time, then the product of this external force and the time is called *Impulse* and the force is called *Impulsive Force*.

Thus Impulse (J) = Force × time interval

$$\Rightarrow \quad J = F.\Delta t = \frac{\Delta p}{\Delta t}\cdot \Delta t = \Delta p$$

$$\Rightarrow \quad J = \Delta p = \text{change in linear momentum.}$$

Thus *impulse* is also defined as *change* in the *linear momentum* of the body for a *short span of time*.

The S.I. Unit of the impulse is that of linear momentum and given by kg.ms^{-1}

Examples of the linear momentum and the impulse

(i) Cricket players while taking a catch move their hands in the direction of the motion of the ball to avoid maximum injuries and for minimum hurt.

(ii) In heavy and light vehicles springs and shock observers are installed to avoid exertion and for comfortability.

(iii) To hit nail in depth, a heavy hammer is used.

Law of conservation of linear momentum

The *linear momentum conservation* is the *outcome* of *Newton's second* and third *law of motion*. Under the mutual action and reaction of two or more bodies, free from external forces, the algebraic sum of the linear momenta of the bodies in any assigned direction remains conserved. Thus, in general, *if no external force is operative on a system of particles or bodies under the mutual action and reaction of the particles, the momentum of the system in any direction remains conserved*. This is the *law of conservation of linear momentum*.

Example

(i) When a shot is fired, the cannon recoils. This is an example of the law of conservation of momentum. Here the system (*Shot + Cannon*) is at rest with respect to reference frame fixed to the earth. When a shot is fired with a velocity say v, it gains a certain velocity, say V and by the conservation law the cannon must also acquire the same velocity in the opposite direction so that the algebraic sum of the momenta becomes zero. If m and M be the masses of shot and cannon, then by conservation law of linear momentum;

$$mv + MV = 0 \quad \text{or,} \quad V = -\frac{mv}{M}$$

$-ve$ sign indicates that V must be necessarily opposite to v. This velocity of the cannon is called the *velocity of recoil.*

(ii) In the process of collisions, elastic or inelastic the total linear momentum before collision is equal to the total linear momentum after collision. Thus, total linear momentum of the system of colliding particles is conserved.

If m_1 and m_2 the two masses of colliding particles, u_1 and u_2 are the velocities of the respective particles before collision and v_1 and v_2 are the velocities of the particles after collision.

Then by the law of conservation of linear momentum

Total linear momenta before collision $= m_1 u_1 + m_2 u_2$

Total linear momenta after collision $= m_1 v_1 + m_2 v_2$

Thus $m_1 u_1 + m_2 u_2 = m_1 v_1 + m_2 v_2$

Elastic and Inelastic collision : When two particles or bodies directly strike (collide) in such a way that the total kinetic energy and the total linear momentum of the colliding particles during the collisions remain constant (conserved) then it is called elastic collision. If the relative velocity of separation and approach is equal for the two colliding particles, then the collision is said to be perfectly elastic and the particles of equal masses mutually exchange their velocities to each other after the collision.

But when two particles or bodies collide in such a way that the total linear momenta of the colliding particles or bodies remain constant or conserved but the total kinetic energy of the colliding particles system is not constant (conserved) then it is called inelastic collision.

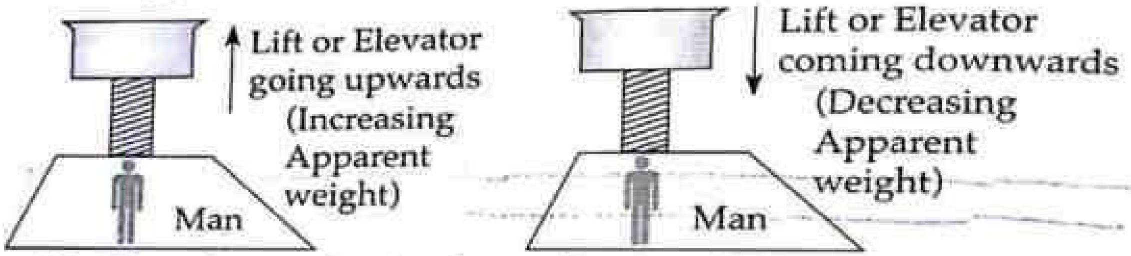
Rocket Motion *(A system of variable mass)* : The basic principle on which Rocket motion occurs or a Rocket is propelled is the *Newton's third law of motion* and the *law of conservation of linear momentum.*

A typical example of variable mass system is that of a rocket motion from which hot gases keep on escaping, thereby continuously decreasing its mass. A rocket may use either a liquid or a solid fuel. In the former case the fuel (*like liquid H_2 or liquid paraffin*) and a suitable oxidizer (like O_2, H_2O_2 or HNO_3), stored up in separate chamber are injected into a combustion chamber where the fuel is burnt. In the latter case, the fuel itself carries its own oxidizer and hence a separate chamber is not needed. In both cases large quantity of the heat of combustion is produced, which largely raises the internal pressure and temperature of the chamber and burnt up gases (like CO, steam etc) are pumped out from an orifice at the back or the tail end of the rocket in the form of a high velocity stream called the *jet.* Consequently the rocket is propelled forward (opposite to the direction of the jet). Here the momentum lost by the jet of the fuel gases must be equal to the momentum gained by the rocket.

A multistage rocket is just a combination of a number of rockets either joined consecutively in series or one inside the other or with the rear part of one inside the nozzle of the other. In all the three types, the first stage is the largest in dimension and in weight and the last stage is the smallest and the lightest. The first stage rocket is used first and when its fuel is all burnt up and it has done its job, it gets detached and discarded, with the second stage taking over the task of producing further acceleration. This too, in turn is detached when its fuel is burnt up and the third stage rocket takes over. The velocity thus goes on increasing at each stage by the same amount as it does in a single stage rocket. The fuel consumption and thrust for the first stage are about 100 times more than for the third stage and the fuel stock carried by it about 60 times that carried by the third stage.

Any rocket (Single Stage) can attain the *maximum velocity* of 3.5 kg/sec due to limitations of conventional chemical fuels, cooling problems etc. Thus a *single stage rocket is incapable* to *put space satellites* in the *orbits* or *escape through the earth's gravitation field.* Thus a *multistage rocket* is designed and fabricated to *enhance* and *achieve* a *greater velocity.*

The Apparent weight of a body in a lift or elevator.



The lift or elevator is a simple machine installed in various multiplexes through which people are transported in multi storied buildings for the business and other officials purposes.

If M be the mass of a man elevated on the lift and F be the apparent weight of the man, then for the lift going upwards :

$$F - Mg = Ma$$

$$\Rightarrow F = Mg + Ma \quad = M(a + g) \qquad \text{[larger wt.]}$$

Here a = acceleration of the lift by which it goes up or down and g = acceleration due to gravity

Now for the lift coming downwards $F + Mg = Ma$

$$\Rightarrow F = M(a - g) \text{ (Lesser wt.)}$$

Thus, the man elevated on the lift experiences larger weight of its own in *going up* and experiences *lesser weight* in *coming down.*

Types of Forces or Interactions : Everywhere in our nature there are four types of forces—

(i) Gravitational Force (ii) Weak Force
(iii) Electromagnetic Force (iv) Nuclear Force

(i) Gravitational Force : Every body in our universe *interacts (attracts)* with each other which is called *Gravitation* and the occurrence of such interactions are due to the individual masses of the bodies where gravitational fields are confined and *respondent* to each other.

The *Gravitational force* is the *weakest* among all existing forces and it is negligible for all lighter and smaller bodies but becomes significant and considerable in all celestial bodies. Since the value of *Gravitational constant* (G) measured in *Torsion balance* by Cavendish was very small only 6.67×10^{-11} $Nm^2.kg^{-2}$, gravitational force for smaller bodies is negligible and can not be realized.

(ii) Weak Force : The concept of *weak force* came into existence firstly in *Yukawa's meson theory* when explanation of β – decay was propounded. In the atomic nucleus, electron emission (β – particle decay) takes place spontaneously during the conversion of neutron into a proton by ejecting a π meson. This π meson decays almost instantly into an electron (e^-) and an anti neutrino ($\bar{v}$).

Thus; n (neutron) → p (proton) + π^{-1} (π–meson) → p (proton) + e^- (electron) β–decay + $\bar{v}$ (anti neutrino)

Here neutron is converted into proton by the exchange of π–meson and consequently interaction between *electron* (*β–decay*) and *antineutrino* is due to *weak interaction.*

(iii) **Electromagnetic Force :** Electromagnetic force operates on all charged particles and provides atomic and molecular binding forces. Thus electromagnetic interactions are charge-dependent (attractive as well as repulsive).

The electric and magnetic forces compose the electromagnetic force which acts by means of photon or quanta. If both electric and magnetic forces exist, then it is called *Lorentz's force* given by $F = qE + qvB \sin\theta$

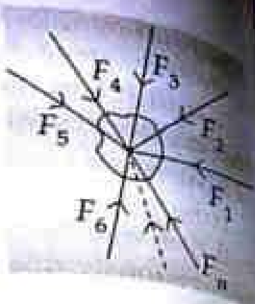
Where, q = Charge of the particle
E = Electric field strength
v = Velocity of the charged particle
B = Magnetic field intensity
θ = Angle between velocity and magnetic field

(iv) Nuclear Force *(Strong Force)*: Among *all the forces* found in nature, *nuclear force* is the *strongest force* which basically exists within atomic nucleus between proton–proton, proton–neutron, and neutron–neutron within the range up to 10^{-15} meter. *Experimental evidences* of the nuclear Physics observe that *nuclear forces* are primarily *attractive, non-electrical, non-gravitational (not central forces), extremely strong* but *spin dependent* and the *magnitude* of the force is *same* for proton-proton, proton-neutron and neutron-neutron. Explanation of the nuclear forces was given in detail by *Yukawa's Menson's theory.* Some scientists also assume that the nuclear forces originate through the mutual interaction of two *quarks.*

Comparison among four types of Interactions :

Interaction	Relative magnitude	Carrier particle	Characteristic Time
Nuclear (strong) interaction	1	π –meson	10^{-23}sec
Electromagnetic interaction	10^{-3}	photon	10^{-20}sec
Weak interaction	10^{14}	Intermediate Bosons	10^{-10}sec
Gravitational	10^{-39}	Graviton	10^{-16}sec

Balanced Force : If on a body various forces act at a time and if the resultant of all these forces is zero then the body is said to be in an equilibrium state and at this moment all forces are called a balanced force.



Thus mathematically at equilibrium

$$F = F_1 + F_2 + F_3 + F_4 \text{ .... } F_n$$

$$= \sum_{i=1}^{n} F_i = 0$$

Unbalanced Force : If on a body two or more forces operate in such a way that the body (object) starts to move towards any force, then the force acting on the body is called unbalanced force.

Frictional Force : It is our common experience that when a block (body) is set in motion on the floor it eventually comes to rest. This means that an *opposing force retards its motion* and this force is called *frictional force.*

This force is neither gravitational nor elastic in nature. This force also occurs in pair. Actually, whenever a body slides over another body, each body exerts a frictional force to each other along the surfaces of contact. The *frictional force* on *each body* acts in a direction *opposite* to its *motion.*

As the motion of a body increases, the force of friction acting on it also increases.

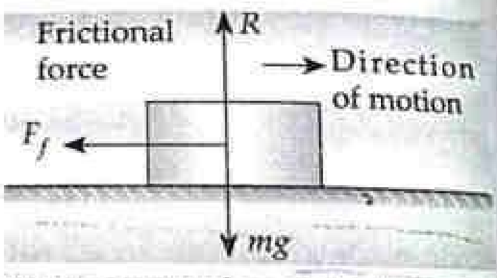
Thus, force of friction (F_f) is directly proportional to its normal reaction (R).

$\Rightarrow$ $F_f \propto R$ or, $F_f = \mu R = \mu mg$.

where, μ is a constant and called coefficient of friction.

m = mass of the sliding body

g = acceleration due to gravity



Types of frictional forces

(i) Static frictional force

(ii) Kinetic or sliding frictional force

(iii) Rolling frictional force

(i) Static frictional force : If a body kept on any surface tries to move by any force applied on it but doesn't move, then the force operative within the surfaces of both is called static force of friction which is equal to the applied force but in opposite direction.

(ii) Kinetic or sliding frictional force : If a body on any surface is sliding or moving uniformly, then the force acting within the surfaces of both is called kinetic or sliding frictional force.

(iii) Rolling Frictional force : If a body rolls on another body (or surface), then force acting within the surfaces of both is called rolling frictional force.

Static force of friction > Kinetic or sliding force of friction > Rolling force of friction i.e. $\mu_s > \mu_k > \mu_r$. Here; μ_s, μ_k and μ_r are called coeff. of static, kinetic and rolling friction.

Characteristics of frictional forces

(i) The *frictional forces* acting within the two surfaces of the bodies *do not depend on their contact area, rather they depend upon the nature of the surfaces.*

(ii) The *static force of friction* is the *largest* and the *rolling force of friction is the least or the smallest.*

(iii) To reduce friction between two rubbing surfaces, a suitable oil or grease called *lubricant* is used which is generally introduced between the two *surfaces.* This ensures smooth functioning of the different parts of a machine and prevents them from getting unduly heated. The lubricant with *ball-bearings* intervenes between the surfaces. Thus it prevents them from coming into direct contact and the kinetic friction, converted into sliding friction and that is why force of *friction,* diminishes too.

(iv) It is also observed that *force of friction* between the surfaces of the *solid-solid* is the largest while in *liquid-liquid* it is *less* than the former whereas it is *least in solid-gas surfaces.*

Advantages

(i) If the force of friction doesn't exist on the road where vehicles run, wheels will start to slip and would ultimately derail.

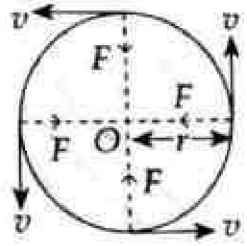
(ii) Due to the forces of friction man stands and moves.

Disadvantages

(i) Due to the forces of friction, energy is lost too much in machines and tools and ultimately the machines are damaged.

(ii) Due to the forces of friction the inner components (parts) of machines generate tremendous amount of heat (thermal energy) which distorts the machines.

Centripetal Force *(Real Force)* : When a body moves on a circular path of radius r with uniform speed v, then an acceleration of magnitude v^2/r acts towards the radius and it is called ***Centripetal*** *acceleration (Centre Seeking) or radial acceleration.* But by Newton's second law of motion, this acceleration is produced by a corresponding force (every accelerated body has a force) called *Centripetal Force* directed *inwardly* towards the radius i.e. in the direction of acceleration. Thus a body of mass m moving with a constant speed v (uniform circular motion) on a circular path of radius r has a magnitude of the centripetal force.



But F = mass × acceleration

$$\therefore F = \frac{mv^2}{r} = \frac{m\ \omega^2 r^2}{r} = m\omega^2 r \quad (\because v = \omega r)$$

where, ω = angular velocity of the body.

Thus centripetal force is a *real force* acting on the body to *maintain* a *circular motion* or to remain on a circular track. *Without* it circular motion is *not possible.*

The centripetal acceleration always acts radially inwards, while velocity (linear) acts tangentially outwards.

Thus the *centripetal acceleration* and *linear velocity* of the *body* describing a circular motion are *perpendicular* to each other throughout the motion. Also at each and every instant the direction of centripetal acceleration (radially inward) and its velocity (tangentially outward) change regularly.

This implies that in the circular motion the body moves on a circular track with *variable centripetal acceleration* and *variable velocity* (*constant speed*). But as tangential velocity changes at each and every instant, another acceleration (due to change in the direction of velocity) is also produced simultaneously. Thus a body describing a uniform circular motion with a constant speed experiences two types of acceleration–one *centripetal acceleration* acting *radially inward* and another *tangential acceleration acting tangentially* outward.

If a_c and a_t be the centripetal and tangential accelerations, then the resultant acceleration acting on the body in uniform circular motion would be expressed as below :

Resultant acceleration (a)

$$= \sqrt{[\text{centripetal acel.}(a_c)]^2 + [\text{tan gential acel.}(a_t)]^2}$$

$$\Rightarrow \; a = \sqrt{(a_c)^2 + (a_t)^2}$$

The nature of the centripetal force is not different from other ordinary forces like Gravitational forces, Frictional forces, Electrostatical Columbian forces etc, but it is simply a way of describing the behaviour of a force responsible for the maintenance of the circular motion.

Examples : (i) In the planetary motions of sun and planets and also in the orbital motions of planets and satellites (both natural and artificial) the Centripetal forces are counterbalanced by Gravitational forces.

Thus; $\frac{mv^2}{R} = \frac{GM_m}{R^2} = m\omega^2 R \qquad (\because v = \omega R)$

(ii) The centripetal force is necessarily equal to the force of friction of the wheels of the vehicle acting on the contact surfaces at the overturning of the road.

Thus; $\frac{mv^2}{r} = \mu F = \mu mg$

where μ = coeff. of friction.

(iii) An orbiting electron experiences a centripetal force about a massive nucleus which is equal to the electrostatical forces of attraction.

Thus; $\frac{mv^2}{r} = \frac{1}{4\pi \in_0} \frac{(Ze)e}{r^2} = \frac{1}{4\pi \in_0} \frac{Ze^2}{r^2}$

where, e = electronic charge, Ze = charges on the atomic nucleus

Centrifugal Force or Pseudo Force or Fictitious Force

In a uniform circular motion a centripetal force (real force) of magnitude $\frac{mv^2}{r}$ acts on the body in *inertial frame* (*Non-accelerating*). But if an observer is confined on the circumference of any circular path (track) anywhere, then he experiences a *fictitious force acting outwardly* called *centrifugal force* and due to its *fictitious existence*, it is also called a *pseudo force*. Thus centrifugal force is a fictitious force appearing in a *non-inertial frame* whose magnitude is *equal* to that of the *centripetal force* but *oppositely directed* to it. This force is *not* the *reactionary force* of the centripetal nature but a *virtual imaginary force that appears* by the *virtue of inertia*. That's why it is also called an *inertial force*.

Example : (i) If a man is travelling in a car in a straight line path and the car suddenly turns right, then the man realises a severe shock (push) towards the left. This happens because as the car turns, a centripetal force around the radius of curvature of the path is generated which is counter-balanced by the force of friction of the wheels of the car. But this centripetal force is not balanced by the man, so a shock is felt by the man which comes through the *virtue* of *inertia*. This is the required centrifugal force which acts outwardly.

(ii) The person sitting in a *merry-go-round* realises an outer push tangentially due to the appearance of a centrifugal force.

In the study of any physical phenomenon, the position of a system or body is made to be fixed and the distances of other bodies are measured called *reference frames*. It is of two types (i) Inertial (Non-accelerating) and (ii) Non-inertial (accelerating).

Inertial frames are those in which *inertia of any body remains conserved*. Thus this frame is either *in rest* or in a *uniform motion* in a straight line i.e. no force, no acceleration concept exists.

But if the force or the acceleration exists in a particular frame it is called non-inertial. Newton's laws of motion are applicable only in inertial frame of reference.

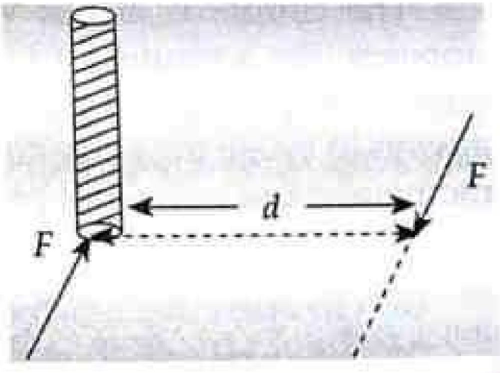
Application

Centrifuge : A device by means of which light particles and heavy particles are separated to each other.

(i) Cream Separator : In a cream separator, a vessel containing milk is rotated fast. Being lighter the cream collects in a cylindrical layer around the axis, whence it is drawn off and the skimmed milk is drained through an outlet fitted on the wall of the vessel. The particles, whose density is less than that of the liquid, are driven towards the axis of rotation and those whose density is greater than that of the liquid are driven away from the axis. Cream is lighter than milk, so it is separated from milk and collected at the axis.

(ii) The Centrifugal Drier : In laundries wet clothes are dried by packing them in a cylindrical vessel with perforated walls which rotated with a very high speed. Water particles stick to the cloths with a certain force which is called adhesive force. The water particles are not sufficient to keep them moving uniformly in a circle.

Torque or Moment of a force : The turning effect of a force about a point or a line is called the moment of force about that point or line which is called the axis of rotation. The turning effect of a force is dependent on the magnitude of the force and the perpendicular distance of its line of action from the axis of rotation.

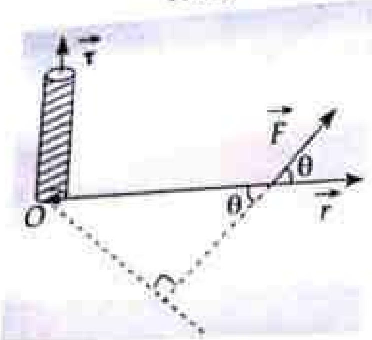


Thus the moment of the force F (τ) ... perpendicular distance (d)

The force turns or tends to turn the body either in clockwise or anti-clockwise direction. The direction of the moment of force is fixed by the direction in which the force turns or tends to turn the body. Generally the anti-clockwise direction is considered as a positive (+ve) direction of the moment of a force. For larger magnitude of the force, there must be a larger turning effect and its moment of force. Thus turning effect is too much appreciable for a larger moment of force and its perpendicular distance from the axis of rotation.

The moment of the force is defined as the product of the force and the perpendicular distance from the axis of rotation.

Thus, moment of force = Force × its perpendicular distance from the axis of rotation.



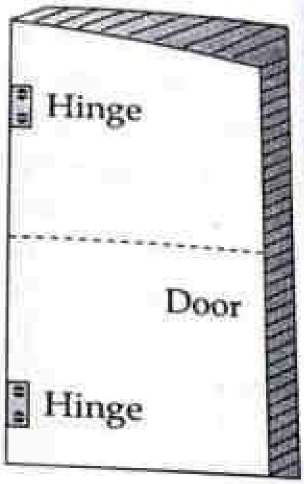
⇒ The moment of the force or torque

$$(\vec{\tau}) = \vec{r} \times \vec{F} = r F \sin\theta$$
$$= Fr \sin\theta$$

where;

θ = angle between the force and the position vector.

The moment of a force or Torque is a vector quantity and its S.I. unit is N.m



Examples : (i) For the equal forces as far as larger distance from the hinges of any door it will be needed to apply some more moment of force and correspondingly the tendency of more turning will be appeared. That's why *handles* are installed and fixed at a *larger distance* from the *hinges* of the *door.*

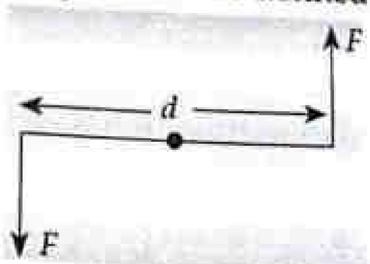
(ii) The handle of a quern is kept distant from its pivot because through a smaller force (effort) the handle can be easily turned out (rotated).

(iii) Hand pumps of water have larger handles.

Couple : Two equal and opposite forces form a couple and it is defined as the product of the force and the couple arm.

Thus; couple = force × couple arm

$= F \times d$



The couple is also a vector quantity which appears like a torque and its SI unit is N.m. The effect of applying a torque or couple on a body is always to rotate the body because a couple will always have an unbalanced moment about any point or an axis of rotation.

Examples : (i) To rotate the steering wheel of the vehicle.

(ii) To open the lock by the key. (iii) To open the water-pump etc.

Simple Machines : The Simple Machines operate on the principle of couple or torque in which on a convenient point a force is applied and from another point weight is carried out. The Lever, Pulley, Inclined Planes and Screw Jack are the examples of Simple Machines.

Machines are equipments through which more heavy objects are carried by applying a lesser force.

The efficiency of machine is given by—

$$\text{Efficiency of a machine} = \frac{\text{Work done by the machine}}{\text{Input energy provided by the machine}} \times 100$$

The efficiency of any machine can never be 100 %.

Lever : Lever is a simple machine in which a straight or an inclined rod is made to turn or rotate at a point freely or independently. In every lever there are three points namely — Fulcrum, Effort and Load.

Examples : Tongs, Nut Cracker, Scissors etc.

Fulcrum : The fixed point about which the rod of the lever moves independently is called *Fulcrum*.

Effort : To use (operate) lever the force applied externally is called *Effort*.

Load : The weight carried by the lever is called *Load*.

Theory of Lever : The basic physical principle on which a lever operates is that the product of effort and effort-arm is equal to the product of the load and load-arm.

Thus; *Effort × Effort-arm = Load × Load-arm*

Mechanical Advantage of Lever : The ratio of the load carried by the lever to the effort applied is called the mechanical advantage of the lever.

$$\text{Thus mechanical advantage} = \frac{\text{Load or weight } (W)}{\text{Effort } (E)}$$

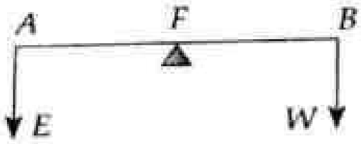
Types of Levers : On the basis of the relative positions of fulcrum, effort and load there are three types of Lever.

(i) First Type of Lever : In this type of lever the Fulcrum (F) is at midway between Effort (E) and Load or Weight (W).

$$\text{Mechanical advantage} = \frac{\text{Load or weight } (W)}{\text{Effort } (E)}$$

$$= \frac{AF}{BF} = \frac{\text{Effort arm}}{\text{Load arm}}$$

Example : Scissors, Brakes of a bicycle, balance etc.

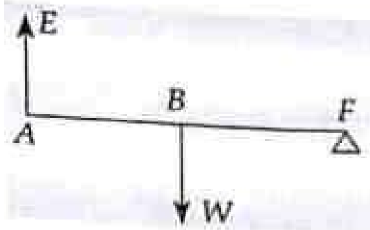


(ii) Second Type of Lever : In this type of lever the load (W) is at midway between the fulcrum (F) and the Effort (E).

$$\text{Mechanical advantage} = \frac{\text{Load } (W)}{\text{Effort } (E)} = \frac{AF}{BF} = \frac{\text{Effort arm}}{\text{Load arm}}$$

Such levers provide more than one mechanical advantages since $AF > BF$

Example : Nut cracker, Lemon squeezer, movable door on hinges, tobaco cutting machines etc.

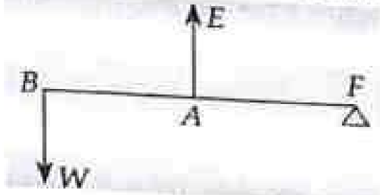


(iii) Third Type of Lever : In this type of lever the Effort (E) is located at midway between the Fulcrum (F) and the Load or Weight (W).

$$\text{Mechanical advantage} = \frac{\text{Load (W)}}{\text{Effort }(E)} = \frac{AF}{BF} = \frac{\text{Effort arm}}{\text{Load arm}}$$

Such type of levers provide mechanical advantages of less than 1, since $AF < BF$. Such levers are used and utilized to enhance the slow motion.

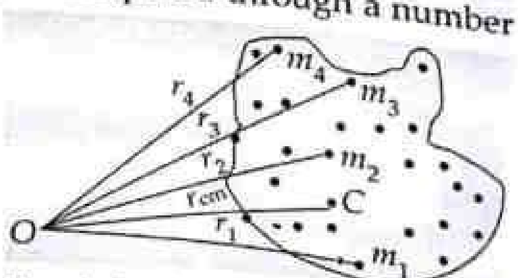
Example : Tongs, plough of the farmers, hands of a man etc.



Centre of mass : Every physical system of particles (body) is associated with a certain point whose motion is characterised by the system as a whole, and when a system moves under an external force then this point moves in a similar way as a single particle moves under the same external force. This is called *centre of mass* of the system.

Thus centre of mass of a body (system of particles) is a point where the whole (entire) mass of the body may be supposed to be concentrated so far the action of a system of parallel forces acting on the elementary masses is concerned. If a body (system of particles) is composed through a number of particles, say n of masses m_1, m_2, m_3 ..... m_n located at the distance (position vector) r_1, r_2, r_3 .....r_n then the position of the position vector r_{cm} is defined as

$$\mathbf{r}_{c.m} = \frac{m_1 r_1 + m_2 r_2 + m_3 r_3 ..... + m_n r_n}{m_1 + m_2 + m_3 ..... + m_n}$$



Centre of Gravity : The centre of gravity of a body (system of particles) rigidly connected together at a point where the whole mass of the body or the system may be supposed to be concentrated so far as gravity (force of attraction due to the earth) on the constituent particles of the body or the system is concerned. Also according to the principle of the law of gravitation every particle of a body near or upon the surface of the earth is attracted towards the centre of the earth. The vectorial sum of all ...

attractive forces on the particles is the total force with which the body is attracted towards the centre of the earth. This force is called the *weight* of the body and the point of application of this force is called the *centre* of *the gravity* of the body or the system.

For a larger body *centre of gravity* and *centre of mass* are two different points but for a *smaller body* these two are a *coincident point.*

Centre of gravity of some rigid bodies

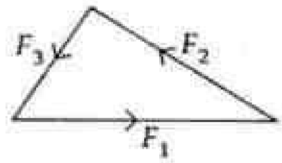
Bodies	**Position of the centre of gravity (C.G.)**
Uniform bar (rod)	Mid-point of the axis passing through the bar or rod.
Triangular solid body	The intersection point of the medians.
Rectangular or Square Solid	The intersections points of the diagonals.
Circular Lamina	Centre of the circle.
Conical Solid	At $\frac{1}{4}^{th}$ height on the axis of the cone from its base.
Hollow Cone	At $\frac{1}{3}^{rd}$ height on the axis of the cone from its base.
Solid Spherical body	Centre of the sphere

Equilibrium of Bodies : When a body under the action of several forces neither moves in a straight line nor rotates around a point then it is said to be in *equilibrium*.

Conditions for equilibrium : (i) The vector sum of all forces acting on a body along any assigned direction for translational equilibrium must be *zero*. Thus no linear motion occurs.

(ii) The algebraic sum of moments (torques) of all the forces acting on a body about any assigned point or line for rotational equilibrium must *vanish* (being zero). Thus no angular acceleration must exist.

If three forces acting on a particle as shown in the figure are capable of being represented in magnitude and direction by the three sides of a triangle taken in order, they (force) *produce an equilibrium.*

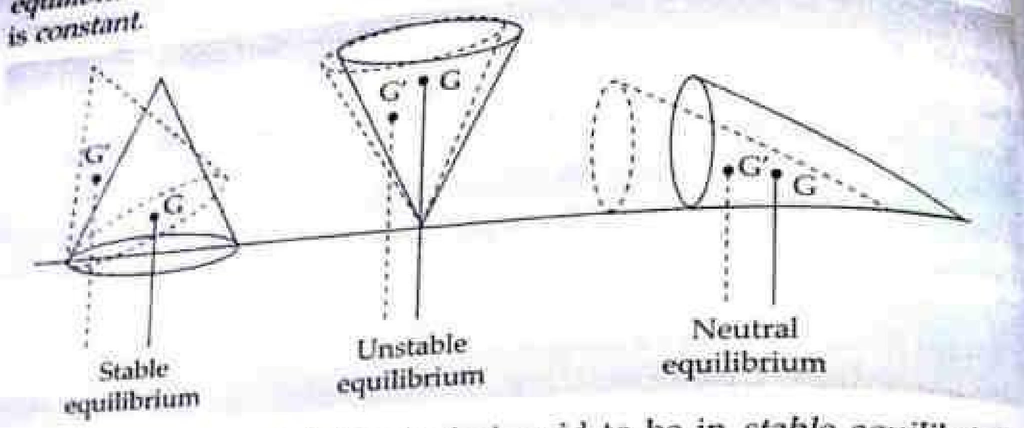


Types of Equilibrium : There are three types of equilibrium (i) Stable equilibrium (ii) Unstable equilibrium (iii) Neutral equilibrium.

(i) Stable equilibrium : When a body is in equilibrium in such a way that a slight displacement from this position produces a restoring force tending to return the body to the previous equilibrium, then body is said to be in *stable equilibrium*. In *stable equilibrium* the body possesses *minimum potential energy.*

(ii) Unstable equilibrium : When a body is in an equilibrium in such a way that any displacement from this position produces a force tending to push the body farther from the equilibrium position, then it is said to be in *unstable equilibrium*. In *this equilibrium position* the body possesses *maximum energy.*

(iii) Neutral equilibrium : When a body is in such a state of equilibrium that on displacing slightly from that position it (body) experiences neither a restoring force nor a deflecting force, then body is said to be in neutral equilibrium. *In this equilibrium position* the *potential energy* of the body *is constant.*



In the gravitational field a body is said to be in *stable equilibrium* when its *centre of gravity* (C.G.) *lies as below as possible.*

Universal conditions for the *stability* of *equilibrium*—

(a) The body must have *minimum potential energy.*

(b) The *vertical line* through the *centre of gravity* (c.g.) of the body must pass through the *base* of the body.

Examples : (i) The *tall Tower* of *Pisa* is extremely inclined for an observer and it *appears* that it may *fall down* at any moment, but it *never falls.* In fact it has been surviving (existing) since centuries. The *reason* for its *stability* is that the *vertical line* passing through the *centre of gravity* (c.g.) lies within the *base* of the *tower.*

(ii) *A double-decker bus* is found to be in *danger* of overturning if *more passengers* are *seated* on the *upper deck.* If there are more passengers on the upper deck, the *c.g.* of the *system* (bus+passenger) will be *shifted upward* and the *stability* of *equilibrium* will be *reduced.*

(iii) A man carrying a *bucket completely filled* of *water leans forward.* The man leans outward to attain an equilibrium position. When he *leans forward* the *vertical line* through the c.g. of the system (man + bucket) *passes* through the *base* of the *system* (space between his feet).

3. Work, Power and Energy

Work : When a constant force *F* acts on a particle and the motion of the particle takes place in a *straight* line in the *direction* of the *force,* the work done by the force is defined as the product of the magnitude of the force *F* and the distance *x* through which the particle moves.

Thus the work $(W) = F \cdot x$

However a force acting on a particle may not act in the direction in which the particle moves. Here the work done by the force is defined as the product of the component of the force along the line of motion of the particle.

If θ be the angle made by F with the line of motion of the particle, then by the definition of work; $W = (F\cos\theta)\cdot x = F\cdot(x\cos\theta)$

or, work done by a force = force × displacement along the force.

Work is a scalar quantity and the SI unit of Work is N–m which is called Joule (J).

The value of the work will be maximum at $\theta = 0°$

and minimum at $\theta = 90°$

$\Rightarrow \quad W_{max} = Fx$

$W_{min} = 0$

Power : The power of an agent is defined as the rate at which work is done. The average power delivered by an agent is the total work done by the agent divided by the total time interval.

Thus power $(P) = \dfrac{\text{work done }(W)}{\text{time interval }(t)}$

The instantaneous power of an agent is $P = \dfrac{dW}{dt}$

The SI unit of power is watt; 1 watt = $\dfrac{1\text{ Joule}}{\text{sec}} = 1\ \dfrac{\text{N}-\text{m}}{\text{sec}}$

The power of Machines are expressed in Horse Power (H.P.) and

1 H.P. = 746 watt.

Watt-second (Ws) - It is a unit of work.

Watt-hour (Wh) – It is also another unit of work.

$\Rightarrow$ 1Wh = 3600 Joule.

Kilo Watt-hour (kWh) – It is also the unit of work (energy)

$$\begin{aligned} 1\text{ kWh} &= 1000 \text{ watt hour} \\ &= 1000 \text{ watt} \times 1 \text{ hr.} \\ &= 1000 \text{ watt} \times 3600 \text{ sec} \\ &= 3.6 \times 10^6 \text{ watt sec} \\ &= 3.6 \times 10^6 \text{ Joule} \end{aligned}$$

Thus, W, kW, MW, and H.P. etc. are the units of power; while Ws, Wh, kWh, etc. are the units of work (energy).

If the force applied on a body is not constant, rather varies with distance, then the total work done by the force = work (W) = $\int F\cos\theta\, dx$

The work done in stretching a spring through a distance $x = \frac{1}{2}kx^2$, where k = a spring constant.

Energy : Energy of a body is its capacity of doing work. In Mechanics (General Physics) a body is capable of doing work under two circumstances–

(i) When it is in motion and (ii) When it is situated (located) in a field or when it is strained.

Thus two types of energy usually coexist— one due to the motion and the another due to the field or position.

Kinetic Energy : A body describing motion acquires a linear velocity and develop a capacity of doing work which is called kinetic energy of the body.

If m be the mass of the body having a velocity v, then kinetic energy of the body is given by

$$K.E. = \frac{1}{2}mv^2 = \frac{1}{2}(mv)^2 = \frac{p^2}{2m} \qquad (\because p = \text{linear momentum} = mv)$$

Thus, if the mass of the body is made double then its kinetic energy will become double, while if either velocity or linear momentum of the body is double, its $K.E.$ will become four times as that of the original.

Potential Energy : If a body develops a capacity of doing work due to its position or field, it is called the potential energy of the body.

If m be the mass of the body and h be the height or position of the body where acceleration due to gravity is operative, then potential energy of the body is given by $P.E. = mgh$. where; g = acceleration due to gravity.

When a bullet strikes (hits) a target it penetrates through the target and works against the resisting force offered by the target. This is the K.E. of the body and is measured by the work it can do in being brought to rest. When the body is kept in a field, it works due to its position in the field. This is obviously $P.E.$ Thus the unit of energy is obviously the same as that of work.

Conservative and Non-Conservative forces : A force is said to be conservative, if the work done by it on any particle that moves between two points depends only upon these two points and not on the path followed. A force is non-conservative if the work done by the force on a particle that moves between two points depends on the path taken between those points. Thus a force is said to be conservative if the work done by the force on a particle in a round trip is zero. A force is said to be non-conservative if work done by the force on a particle in a round trip is not zero.

Examples : The Gravitational force, Electrostatical force, Adhesive and Cohesive forces etc. are conservative forces. Viscous force, frictional force, damping force etc. are non-conservative forces.

Law of Conservation of Energy : Energy may be transformed from one form to another but it can't be created or destroyed and the total energy of any body or system is constant. Also whenever any energy in any form disappears, then the same amount of energy appears in another form. This is called the law of conservation of energy.

Transformation of Energy

Equipments / Instruments	Transformation of Energy
Solar Cell	Solar energy into Electrical energy
Dynamo	Mechanical energy into Electrical energy
Electric Motor	Electrical energy into Mechanical energy
Microphone	Sound energy into Electrical energy

Equipments / Instruments	Transformation of Energy
Loudspeaker	Electrical energy into Sound energy
Musical Instruments	Mechanical energy into Sound energy
Bulb/Tube	Electrical energy into Light energy
Heater	Electrical energy into Thermal energy
Candle	Chemical energy into Light energy and Thermal energy
Coal	Chemical energy into Thermal energy
Electric Cell	Chemical energy into Electrical energy
Heat Engine	Thermal energy (Heat energy) into Mechanical energy

4. Gravitation

Gravitation is the weakest interaction or force among all the four types of interactions existing in our Universe. Each and every body interacts (attracts) each other by virtue of its mass. This is called *Gravitation*.

Newton's Law of Gravitation

In our universe the force of interaction acting among any two bodies is directly proportional to the masses of the bodies and inversely proportional to the square of the distance between the bodies.

If m_1, m_2 be the masses of two bodies at r distance then according to the Newton's law of gravitation

$$F \propto m_1, m_2, \qquad F \propto \frac{1}{r^2}$$

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

where G is called Universal Gravitational Constant

$$= 6.67 \times 10^{-11}\ \text{Nm}^2\text{kg}^{-2}$$

Gravity : As in Newton's law of gravitation the forces of interaction exist among any two bodies, but if in these two bodies one body is the Earth, then this gravitation is called gravity and by this force of gravity the Earth attracts everybody towards its centre. If a body is projected upwards freely, then due to the force of gravity it falls back.

Acceleration due to gravity (g) : If a body is dropped freely and it executes a free falling motion, then as the body comes near the Earth's surface then its velocity increases and the acceleration produced is called acceleration due to gravity. If m be the mass of any body describing a free falling motion then due to the presence of force of gravity the weight of the body = mg.

where $g = 9.8\ \text{ms}^{-2}$ or $32\ \text{ft s}^{-2}$ = acceleration due to gravity (Near the earth's surface)

In SI unit 'g' is expressed in ms^{-2} or N. kg^{-1}.

Relation between Universal Gravitational Constant (G) and the acceleration due to gravity (*g*).

If the earth is supposed to be a homogeneous solid sphere of mass M_e and another body of inertial mass m be (located) on the surface of the earth.

Then the force of interaction on the body of mass $m = \frac{G M_e m}{R_e^2}$;

where R_e = radius of the earth

Now, by Newton's second law of motion.

Force = *inertial mass × acceleration* = mg

$$\text{Thus} \quad \frac{G M_e m}{R_e^2} = mg$$

$$\text{or,} \quad g = \frac{G M_e}{R_e^2}$$

(Here, we assume that the inertial mass is equal to the gravitational mass.)

Obviously, the value of the acceleration due to gravity (g = 9.8 m/s²) doesn't depend upon the mass of the body. Thus two bodies of different masses (if air resistance is to be negligible) fall freely and they (both) have the same value of g near the earth's surface. This shows that if two bodies of different masses, shapes and sizes are dropped in a vacuum from the same height, then both will reach the ground (surface) simultaneously. In the presence of air, the viscous drag, buoyancy etc. the motion (free falling) of the bodies are affected and thus the heavy body comes down earlier than lighter body.

Variation in acceleration due to gravity (*g*) : At the latitude of 45° and at the sea-level the standard value of g is 9.8 m/s² or 32 ft/sec²

But the value of g is not constant and varies from place to place.

(a) Due to the spheroidal (Oblate Spheroid) shape of the earth

As derived above $g = \frac{G M_e}{R_e^2}$ and since the equatorial diameter is larger than the polar diameter, the value of g in the equatorial region is less than that in the polar region.

Thus; g = max. (At poles)

g = min. (At equator)

(b) Due to the axial rotation of the earth : If a body of mass m is kept on the earth's surface at any place whose latitude is λ then due to earth's rotation the weight of body is observed to have changed. This changed weight is the apparent's weight of the body. Obviously an apparent weight appeared due to variation in g.

In fact the body describes (traces) a circle of radius $r = R_e \cos \lambda$ due to earth's rotation.

The expression of the apparent weight is derived as—

Apparent wt $(mg') = mg - m\omega^2 r \cos^2 \lambda$

Thus, apparent acceleration due to gravity

$= g' = g - \omega^2 r \cos^2 \lambda$

But at the pole $\lambda = 90°$

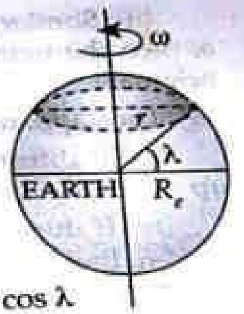
$\Rightarrow$ $g' = g$ (max. at the poles)

At the equator $\lambda = 0°$

$\Rightarrow$ $g' = g - \omega^2 r$ (At the equator)

Obviously, if the earth stops to rotate then

$\omega = 0$ and here $g' = g$



$r = Re \cos \lambda$

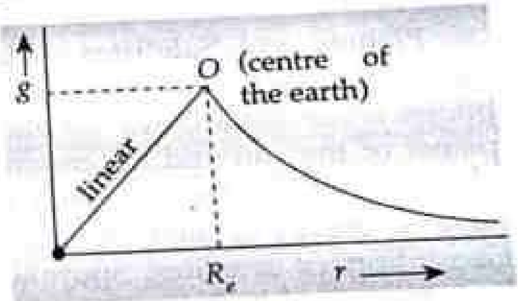
ω = angular velocity

λ = latitude of the place

If the earth's rotation increased 17 times of the present value, then the weight (apparent wt.) at the equator will be zero.

Obviously, the value of g increases on decreasing the value of angular velocity of the earth and vice-versa.

(c) With distance from the Centre of the Earth : Here the graphical representation of the variation of g with distance has been displayed—



The value of $g = 0$ at the centre of the earth. It increases linearly with distance up to the surface of the earth and then decreases rapidly and again becomes zero at infinity. The acceleration due to gravity g is maximum on the surface of the earth.

(d) Variation in going up from the earth's surface and coming down from the earth's surface.

(i) The value of g decreases in going up. If any body goes h height from the earth's surface, then the value of g decreases and say g' which is given by $g' = g\left(1 - \frac{2h}{R_e}\right)$

(ii) The value of g also decreases in coming down. If any body comes down to h height from the earth's surface, the value of g decreases and we say it g' which is given by $g' = g\left(1 - \frac{h}{R_e}\right)$

Remark : The value of g from going up or coming down inside the earth decreases but decreases more in going up than in coming down.

Applications of the variation of g

(i) If a lift or an elevator goes up with any acceleration a, then the man sitting in it experiences a larger weight than that of his original.

Thus, apparent weight $= (mg + ma)$ (increased wt.)

where; m = mass of the man.

(ii) Similarly, if a lift or an elevator comes down with any acceleration a, then the man sitting in it experiences a lesser weight than that of his original.

Thus apparent weight $= (mg - ma)$ (decreased wt.)

(iii) If a lift or an elevator moves with a constant velocity (no acceleration) up or down then there is no change in the weight of the man.

(iv) If during coming downward the rope of the lift or elevator gets broken, then a free falling motion occurs and the sitting man experiences weight lessness.

Since during free falling $a = g$.

Thus apparent $wt.$ $= ma = mg$

$$= mg - mg = 0$$

(v) If the value of the acceleration a of the lift or elevator during coming downward became more than g, then the sitting man on the floor of the lift would escape on the roof of the lift.

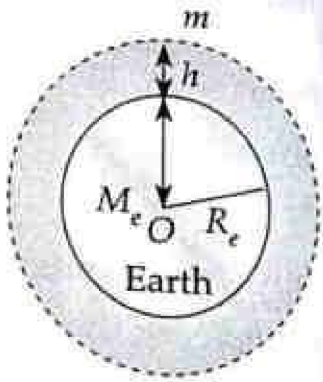
As if $a > g$ then apparent $wt. = mg - ma < 0 = -ve$

Thus apparent wt.(-ve) physically activates the man upwardly and man comes on the roof of the lift (elevator).

Planets and Satellites : Planets are the celestial bodies revolving around the elliptical orbits of the sun in our solar system. But the heavenly bodies revolving around the planets are called satellites. The Earth is the planet of the sun and the moon is a satellite (natural) of the Earth. The planets and satellites draw their light and energy from the sun because they have no energy of their own. There are so many artificial satellites like— Geostationary satellites, Sputnik-I, Aryabhatta, Rohini and Apple which have been launched in various orbits of the earth. Various communication satellites are orbiting around the Earth.

Sputnik-I was the first artificial satellite launched in 1957 by Russian scientists.

Orbital Velocity : If a body (say, a satellite) revolves around another body (say, the Earth) then the velocity of the revolution of the first body is called orbital velocity.



Let m be the mass of a satellite orbiting around the earth of the mass M_e with velocity v_0 (orbital velocity) and let R_e be the radius of the earth.

Here, gravitational pull on the satellite = Centripetal force necessary to keep the body on the circular track (orbit.)

Thus $$\frac{GM_e m}{(R_e + h)^2} = \frac{mv_0^2}{(R_e + h)}$$

where, h = height of the satellite from the Earth's surface.
and g = acceleration due to gravity on the Earth's surface.

$\Rightarrow$ v_0 = orbital velocity $= \sqrt{\dfrac{GM_e}{R_e + h}}$

$$\text{Thus; } v_0 = \sqrt{\frac{gR_e^2}{R_e + h}} = R_e\sqrt{\frac{g}{R_e + h}} \qquad \left(\because g = \frac{GM_e}{R_e^2}\right)$$

Now, if $h = 0$, Then v_0 will become the orbital velocity of the earth.

$$\text{Thus } (v_0)_{\text{earth}} = R_e\sqrt{\frac{g}{R_e + 0}} = \sqrt{gR_e}$$

Obviously from the expression of the orbital velocity of the satellite, the value of v_0 doesn't depend upon the mass (m) of the satellite rather it depends on the height (h) of the satellite, and the larger the value of h the lesser would be the value of v_0. But satellites having various masses with the same orbital radius have the same orbital velocity.

The value of orbital velocity of the earth and a geostationary satellite is 7.99 km/sec. (approx. 8 km/sec.)

Period of revolution of a satellite : The time required in which the satellite completes one rotation is called the period of revolution (T).

$$\text{Thus the period of revolution } (T) = \frac{\text{Perimeter of the orbit}}{\text{Orbital velocity}}$$

$$= \frac{2\pi(R_e + h)}{v_0} = \frac{2\pi(R_e + h)\sqrt{R_e + h}}{R_e\sqrt{g}} = \frac{2\pi(R_e + h)^{\frac{3}{2}}}{R_e\sqrt{g}}$$

$$\Rightarrow \quad T = \frac{2\pi(R_e + h)^{\frac{3}{2}}}{R_e\sqrt{g}} \qquad \left(\because v_0 = R_e\sqrt{\frac{g}{R_e + h}}\right)$$

Obviously, the period of revolution (T) of the satellite is independent of the mass of the satellite. Rather it depends on the height of the satellite from the surface, and the more the height (h) the larger the period of revolution (T).

The period of the revolution of the earth or a geostationary satellite is 84 minutes.

Geostationary Satellite : A geostationary satellite is a communication satellite which revolves from west to east and whose period of revolution is 24 hrs equal to that of axial rotation of the earth (earth's spin). Such satellites are stationary and are located at 36,000 km height from the earth's surface. Geostationary satellites (Communication Satellites) transmit signals across larger distances by receiving these signals from one point on earth's surface and reflecting them down to the another point. In order to provide a stationary target for the transmitted signals, these satellites must remain stationary at a point above the earth.

Utilities : (i) The electromagnetic radio-waves are reflected and transmitted and various programmes on the television are displayed.

(ii) It is utilised in radio transmission and telecommunication.

(iii) The Meteorological Department uses it in weather broadcasting and in earlier predictions of the floods and droughts.

Escape Velocity : The escape velocity is the minimum required velocity of a body through which it is projected. It goes beyond the gravitational pull and never comes back.

If m be the mass of a body projected from the earth's surface of radius R_e and mass M_e, the kinetic energy of the body must be equal to the gravitational potential energy.

Thus; $\frac{1}{2} m v_e^2 = \frac{G M_e m}{R_e}$

or, $v_e = \sqrt{\frac{2G M_e}{R_e}}$ where v_e = escape velocity

But $g = \frac{G m_e}{R_e^2}$

$\Rightarrow v_e$ = escape velocity $= \sqrt{2g R_e} = 11.2$ km/sec.

This implies that if a body is thrown from the earth's surface with the velocity of 11.2 km/sec, then the body will never come back to the earth.

Here we observe that escape velocity of a body on the earth's surface is

$v_e = \sqrt{2g R_e}$

and the orbital velocity of the body around the earth $v_0 = \sqrt{g R_e}$

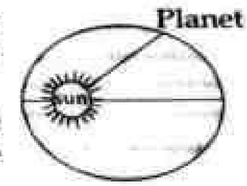
$\Rightarrow v_e = \sqrt{2} v_0$

Thus, if the velocity of an orbiting satellite close to the earth is increased $\sqrt{2}$ times or 41%, then the satellite will leave the orbit and will escape. In other words, if the kinetic energy of an orbiting satellite is doubled immediately, then the satellite will escape. The value of escape velocity is maximum on the sun and it is 614 km/sec. That's why even lighter gases like H_2, He etc. do not escape. The moon has the least value of escape velocity i.e. 2.4 km/sec. So, no gases exist on the moon. That's why the moon has no atmosphere and from the surface of the moon the sky appears black. The value of escape velocity of the gaseous molecules must be more than the root mean square (*rms*) velocity for the existence of the atmosphere.

Weightlessness inside the Satellites : In the artificial (man-made) satellite the whole of the gravitational pull provides the necessary centripetal force and no part of the gravitational pull remains unbalanced. Thus a cosmonaut feels weightlessness inside the artificial satellite. That's why a simple pendulum experiment cannot be performed and everything inside the artificial satellite is weightless. Also for the same reason food stuffs of astronaut are supplied in the form of paste. If any cosmonaut tries to drink water from a glass, then he cannot do it because as the glass is inclined water is spread out in the form of droplets.

But on the moon a cosmonaut never feels weightlessness because due to tremendous mass of the moon a gravitational pull is applied ($\frac{1}{6}$th of the earth) and so he or she doesn't feel weightlessness.

The value of acceleration due to the gravity on the moon's surface is $\frac{1}{6}$*th* of the value of acceleration due to gravity of the earth's surface.



Kepler's Laws of Planetary Motion : Kepler gave three laws regarding motion of the planets around the sun.

(i) First law *(law of elliptical orbits)* **:** Each planet moves in an elliptical orbit around the sun, the sun being at one of the foci of the ellipse.

(ii) Second law *(laws of areas)***:** The radius vector of any planet relative to the sun sweeps out equal areas in equal times, that is the real velocity of the radius vector of the planet is constant.

(iii) Third law *(harmonic laws)***:** The square of the period of revolution of any planet around the sun is proportional to the cube of the semi-major axis of the elliptical orbit. i.e. $T^2 \propto a^3$.
where; a = semi-major axis

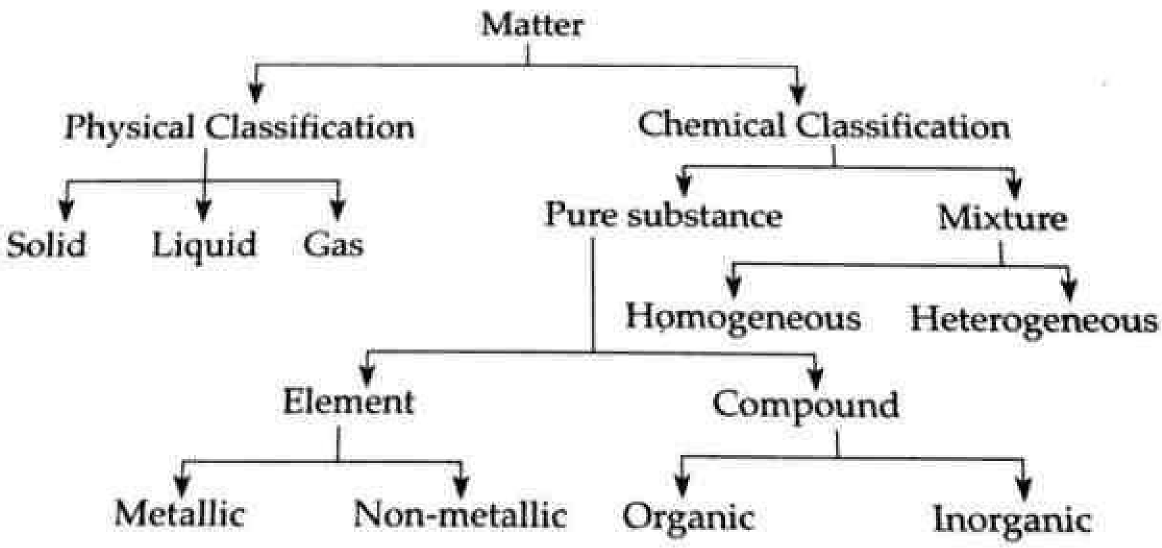
Obviously, those planets which are far away from the sun have a large period of revolution. The planet Mercury which is nearest to the sun has the period of revolution of 88 days while Neptune, which is far away from the sun, has the period of revolution of 165 years.

5. Properties of Matter

Matter : Matter is the substance that occupies space and has mass and it is perceptible to the senses. Matter is one of the two basic components of the physical science in which the another component is being energy. The distinguishing properties of matter are gravitation and inertia. Any entity exhibiting these properties at rest is matter. All material bodies have mass, which is a measure of inertia and every material body near the earth's gravitational field interacts by the virtue of its mass.

Thus two types of masses—inertial mass and gravitational mass remain in existence by their proportion of equality.

The broad classification of the matter is given as below—



The physical classification separates matter into three categories—Solid, liquid and gas-known as three states (phases) of matter. But today plasma, which appears in gaseous or ionized state is actually comes into existence during a thermonuclear process and which is composed of charged particles, is assumed to be the fourth state of matter.

Important characteristics of the Matter

Solids	- Elasticity
Liquids	- Pressure, Floatation, Surface Tension, Capillarity, Viscosity
Gases	- Atmospheric Pressure

(A) ELASTICITY

If a rigid body is in equilibrium under the inter-molecular forces of attraction, whose magnitude depends upon the spacing between the molecules, and an external force is applied, then a new internal force is developed which causes a change in the relative spacing between the molecules. Hence the body changes its shape or size or both and it is said to be *deformed*. When the external force is removed the new internal force brings the body to its normal or original state. The property of the body, by virtue of which it recovers its original shape and size when the external force (deforming force) is removed, is called the *elasticity* of the body.

A perfectly *elastic body* is one that recovers its original size and shape completely when the external force is removed. Thus a *perfectly* plastic body is one that fully maintains its altered size and shape when the external force is removed. Actual bodies behave between these two limits. No body recovers completely its original size and shape after undergoing very large deformations.

A body is said to be rigid if the relative position of its constituent particles doesn't change in equilibrium but on applying an external force a slight relative displacement takes place. In practice no body is perfectly rigid.

Elastic Limit : The maximum limit of the external force (deforming force) by applying on a rigid body, elastic characteristics are maintained, is called *elastic limit*. Different elastic limits are to be found for different bodies.

Strain : When a body suffers a change in its size or shape under the action of external forces, it is said to be *deformed* and the corresponding fractional change is called *strain*. The strain is a ratio and it has no unit, no dimension.

There are three types of strain— longitudinal (linear) strain, volume strain and shearing (shape) strain.

Stress : When external deforming forces act on a body internal forces opposing the former are developed at each section of the body. The magnitude of the internal forces per unit area of the section is called *stress*. In the equilibrium state of a deformed body, the internal forces are equal and opposite to the external forces. Thus, stress is measured by the external forces per unit area of their application. The dimension of the stress is $ML^{-1}T^{-2}$ and its units are N/m^2 (S I) and $dyne/cm^2$ (CGS).

Shear : When external forces are operative tangentially on a body, then a change in shape in the body occurs and it is said to be *sheared*. A shear is numerically equal to the ratio of the displacement of any layer to its distance from the fixed surface.

Hooke experimentally observed that within elastic limit stress is proportional to strain, provided the strain is small.

Thus, Stress $\propto$ strain, $\Rightarrow \frac{\text{stress}}{\text{strain}}$ = a constant. (Young's modulus)

This is called Hooke's law. The constant of proportionality is called *modulus of elasticity* of the body and depends upon the material of the body and it is different for different types of strain in the same material. Usually there are three types of elasticity— Young's modulus, Bulk modulus and Rigidity modulus.

(i) Young's Modulus : When equal and opposite forces act on a body along only one direction then the change in length per unit length along that direction is called longitudinal or linear strain and the force acting per unit area of cross-section is called longitudinal stress.

Here the ratio of longitudinal stress and longitudinal strain is called Young's modulus of the material of the body.

If L be the length and A be the cross-sectional area and if its length be increased by ΔL when equal and opposite forces F are applied along its length, then

Longitudinal Stress = $\frac{F}{A}$

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

Thus Young's modulus for the material of the body $Y = \dfrac{\frac{F}{A}}{\frac{\Delta L}{L}}$

The unit of Young's modulus is same as that of stress N/m^2(SI) or dyne/cm^2 (CGS).

(ii) Bulk modulus : When a uniform pressure is applied all over the surface of a body then the volume of the body changes. The change in volume per unit volume of the body is called *volume strain* and the applied pressure is called *normal stress.* Thus the ratio of normal stress to volume strain is called *bulk modulus* of the material of the body.

Let V be the volume of a body and let it be diminished by an amount ΔV when the pressure on its surface increases by Δp, then

Normal Stress = Δp and Volume strain = $\frac{\Delta V}{V}$

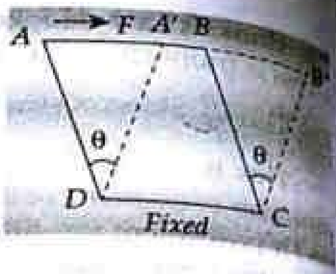
Thus Bulk-modulus for the material of the body.

$$K = \frac{-\Delta p}{\frac{\Delta V}{V}} = -\frac{V\Delta p}{\Delta V}$$

The converse of the bulk modulus is called *compressibility.* The negative sign is assigned because volume decreases when the pressure increases.

(iii) Rigidity modulus : When a body is sheared, the ratio of tangential stress to shearing strain is called *rigidity modulus* of the material of the body.

Let $ABCD$ be a section of a cube of face area A. Let its lower face be fixed and the upper face be acted upon by a tangential force F. Let θ be the angle through which its vertical sides have been turned,

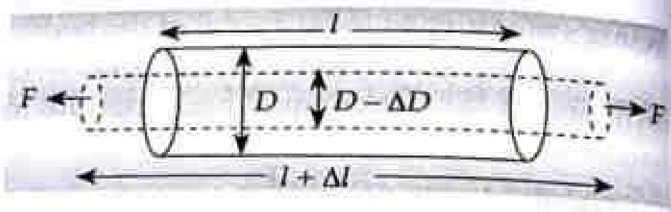


then tangential stress $= \frac{F}{A}$

and shearing strain $= \theta$

Thus rigidity modulus of the material of the cube is $(\rho) = \frac{\frac{F}{A}}{\theta}$

Poisson's ratio : When two equal and opposite forces are applied to a body along a certain specific direction, the body extends along that direction. At the same time, it also contracts along the perpendicular direction. The fractional change in the direction along which the forces have been applied is called *longitudinal strain*, while the fractional change in a transverse (perpendicular) direction is called *lateral strain*.



The ratio of lateral strain to that of longitudinal strain is called *poisson's ratio*. It is a constant for the material of a body.

If a wire of original length l and diameter D is subjected to equal and opposite force F along its length, then the length of it increases to $l + \Delta l$ and the diameter decreases to $D - \Delta D$,

Now, longitudinal strain $= \frac{\Delta l}{l}$ and lateral strain $= \frac{\Delta D}{D}$

The poisson's ratio (σ) of the material of the wire is $= \frac{\frac{\Delta D}{D}}{\frac{\Delta l}{l}}$

The theoretical value of poisson's ratio (σ) lies between -1 to $\frac{1}{2}$. However its practical value is never negative and it lies between 0 and $\frac{1}{2}$.

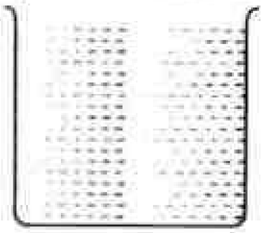
(B) PRESSURE

Pressure is defined as the force applied per unit surface area.

Thus, Pressure $= \frac{\text{Force applied}}{\text{Area of the surface}}$

Obviously, the pressure will be more for a larger force and smaller area of the surface and vice-versa. The SI unit of pressure is N/m^2 which is called pascal (pa). It is a scalar quantity.

Pressure applied on liquids : The pressure on the liquid surface is experienced due to its weight exerted everywhere. Usually molecules of a liquid are in a random motion with different speeds in different directions. If a liquid is confined in a container, then the molecules of the liquid collide with each other and also with the walls of the container (vessel). Due to it on the walls of the container and on its bottom (per unit base surface) exerted pressure is applied.



In order to evaluate the pressure exerted on any point of the liquid at height h of the liquid density ρ, the required pressure will be

$$p = \frac{\text{Force due to the wt. of the liquid}}{\text{Area of the surface upto which liquid is confined}}$$

$$= \frac{mg}{A} = \frac{V\rho g}{A} = \frac{Ah\rho g}{A} = \rho gh \qquad (\because \; V = Ah)$$

Where, V = Volume = Area × Height (Length)

g = acceleration due to gravity.

Thus, $p = \rho gh$

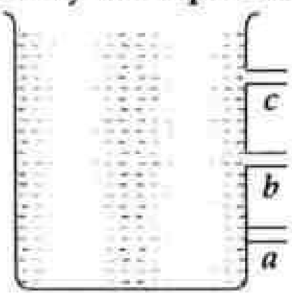
Obviously, the liquid pressure is directly proportional to the density of liquid. Also the pressure exerted on the liquid doesn't depend upon the shape or size of the container.

If on the free surface of the liquid atmospheric pressure be operative then the total pressure exerted will be

= Atmospheric Pressure (P) + ρgh

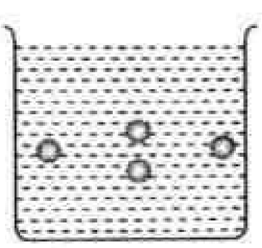
Some observations and conclusions regarding liquid pressure

(i) At any point inside the liquid the pressure exerted by the liquid is directly proportional to its depth from the free surface. Thus, as shown in the diagram the pressure will be in a decreasing order for the points a, b and c.



Thus, $p_a > p_b > p_c$; Where, p_a, p_b and p_c are the respective pressures at the points a, b and c.

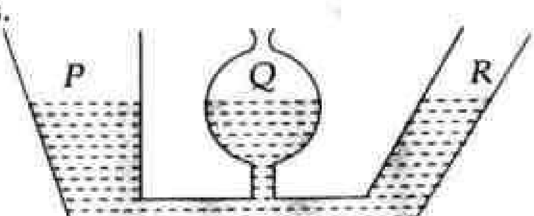
(ii) At every point and in every direction the pressure exerted inside the liquid at rest is same. If a number of holes are made after filling the container with liquid, then the liquid will be released from every hole with equal pressure.



(iii) For the same horizontal surface any liquid at rest exerts the same pressure at all points.

Thus; as shown in the diagram

$p_P = p_Q = p_R$



Where p_P, p_Q and p_R are the respective pressures at P, Q and R.

Pascal's law : This is a natural consequence of the fundamental laws of fluid mechanics and it is called Pascal's law which states that the pressure exerted anywhere in a mass of a confined liquid is transmitted undiminished in all directions throughout the mass so as to act undiminished at right angles to the surface of the vessel exposed to the liquid. According to this law a small force applied somewhere on a confined mass of liquid will appear as a very large force on the wall of the container. This law is directly followed in the working of Hydraulic Press, Hydraulic Brake, Hydraulic Lift etc.

Effect of the pressure on the melting point of the solid and the boiling point of the liquid.

On heating the solid substance if the volume of the substance increases, then by the application of pressure its melting point increases and vice-versa. Examples – wax, sulphur etc. But while on heating the solid substance if the volume of the substance decreases, then by the application of pressure its melting point decreases and vice-versa. Examples — ice, bismuth etc.

The boiling point of a liquid increases on increasing the pressure on the free surface of the liquid.

Example : At simple atmospheric pressure the boiling point of the water is 100°C but if the pressure is doubled then its boiling point becomes 125°C.

(C) FLOATATION

Upthrust or Buoyant force of a liquid : When a body is wholly or partially immersed in a liquid at rest, the liquid exerts pressure on every part of the body's surface which are in contact with the fluid. The pressure is larger on the parts immersed more deeply. So the thrusts exist on all sides in upward direction called buoyancy or buoyant force. The upthrust or the buoyant force acts on the centre of gravity (c.g.) of the displaced liquid by the body which is called *centre of buoyancy.*

Archimedes's Principle : Archimedes's principle states that when a body is partially or fully immersed into a fluid at rest, the fluid exerts an upward force of buoyancy which is equal to the weight of the displaced fluid. Here the apparent weight of the body is equal to the displaced fluid.

Fluids are those substances which can flow, the liquids and the gases both are fluids. Archimedes's principle is valid for both liquids and gases.

Applications :

(a) The relative density of any solid

$$= \frac{\text{wt. of the solid in air}}{\text{Apparent wt. of the solid in water}}$$

(b) The relative density of any liquid

$$= \frac{\text{App. wt. of the solid in the liquid}}{\text{App. wt. of the solid in the water}}$$

The relative density is a pure number and it has no unit.

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}}$$

$$\text{Relative density} = \frac{\text{density of the object}}{\text{density of the water at } 4^\circ\text{C}}$$

Note : The density of water is max. at 4°C.

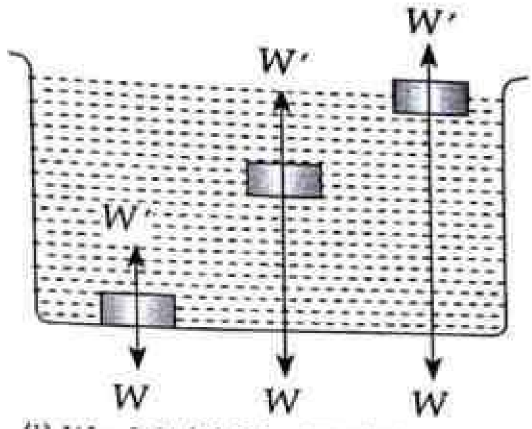
Floatation : If a body tends to sink in a liquid then two forces immediately become operative — the weight (W) of the body downwardly and the upthrust or force of buoyancy (W') upwardly.

Here three cases arise.

(i) If $W > W'$ i.e. the wt. of the body is greater than upthrust, then the body will sink.

(ii) If $W = W'$ i.e. the wt. of the body is equal to the upthrust, then the body floats inside the liquid.

(iii) If $W < W'$ i.e. the wt. of the body is less than upthrust, then the body floats partially in the liquid and the upper part of the body remains outside from the liquid.



(i) $W > W'$ (ii) $W = W'$ (iii) $W < W'$

Also for a body floating partially the ratio of the following must hold

$$\frac{\text{The density of the body}}{\text{The density of the liquid}} = \frac{\text{Total volume of the body inside liquid}}{\text{Total volume of the body}}$$

Application: If a piece of ice floats on a water surface then its $1/10^{th}$ part of the total volume remains above the surface and $9/10^{th}$ part remains submerged. Thus the density of the ice is 0.9 gm/cm^3. The density of the pure water 1 g/cm^3 or 1000 kg/m^3. On the principle of these applications the quantity of water in impure milk is measured by the *Lactometer.*

Hydrometer : The hydrometer is a device through which the relative density of fluids (liquid or gas) is measured.

The law of floatation : When an object floats inside a liquid, then the apparent wt. of the object is equal to the liquid displaced by the object. The centre of gravity (c.g.) of the object and the centre of gravity (c.g.) of the displaced water lie in the same vertical line.

Thus, the wt. of the displaced liquid = Upthrust or force of buoyancy = Apparent wt. of the object

Examples of Archimedes's principle and law of floatation

(i) The ships of iron and the boats of wood float in water but the nails of iron sink. The special design and shape of the ship and the boat through which wt. of displaced water are more than the wt. of the ship and boat, due to which more force of buoyancy becomes operative and the ships or boats float. But the wt. of the water displaced by the nails is less than the wt. of the nails that is why nails sink.

(ii) Life saving belts and submarines operate on these principles.

Meta Centre : The centre of gravity (c.g.) of the displaced liquid by a floating body is called centre of buoyancy. The vertical line drawn from the centre of buoyancy of the displaced liquid intersects the vertical line passing through the centre of gravity (c.g.) of the body. This point of intersection is called *metacentre*. A floating body is said to be in a stable equilibrium which has its metacentre higher (above) than its centre of gravity (c.g.)

If in a container (vessel) of water a piece of ice is floating, then after the complete melting of ice, the level of the water in the container is the same as earlier (original.)

Conditions of equilibrium of a floating body

(i) The wt. of the floating body is equal to the wt. of the liquid displaced.

(ii) The c.g. of the body and the c.g. of the displaced liquid (centre of buoyancy) must lie on the same vertical line.

The first condition is required for the translational equilibrium and second for the rotational equilibrium of the body.

Stability of equilibrium : The position of the metacentre relative to the centre of gravity (c.g.) of the body plays a significant role in the stability of the equilibrium of the body. When the metacentre lies above the c.g. of the body, then the body is in stable equilibrium and when the metacentre lies below the centre of gravity (c.g) of the body, then the body is in unstable equilibrium.

(D) SURFACE TENSION

Cohesive force and Adhesive force : The most basic constituents of the matter (substance) are molecules among which intermolecular forces exist. The forces (attractive) operative among these molecules are called *Cohesive force* and it is larger for the solids. That is why it has a definite size. But in liquids the value of cohesive forces is very small and it is negligible for the gases that is why gases diffuse. The forces (attractive) operative among the molecules of two different substances are called *Adhesive force.* Due to adhesive forces water wets the substances and on writing at the Blackboards by the chalk letters become visible. For a solid-liquid pair if the value of adhesive force is greater than the cohesive force among the liquid molecules, then this liquid doesn't wet the solid but if adhesive force is less than the cohesive force of the liquid, then liquid wets solid.

Example : Mercury doesn't wet glass but water wets glass.

Surface Tension : The evidences of the experiments tell us the surface (free surface) of a liquid behaves to some extent like a stretched elastic membrane having a natural tendency to contract and occupy a minimum possible surface area as permitted by the circumstances of the liquid mass. This property of the liquid is called surface tension and it is measured by the force per unit length of line drawn in the liquid surface acting perpendicularly to it and tangentially to the surface of the liquid and tending to pull the surface apart along the line.

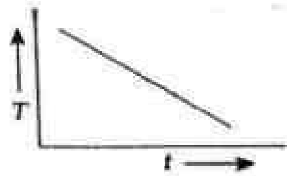
$$\text{Thus, Surface Tension } (T) = \frac{\text{Force } (F)}{\text{length of the line drawn liquid } (l)}$$

The surface tension of the all liquids decreases linearly with temperature over the small temperature range.

Thus, $T = T_0(1 - \alpha t)$

where, T_0 = value of the surface tension at t °C

α = Temperature coeff.



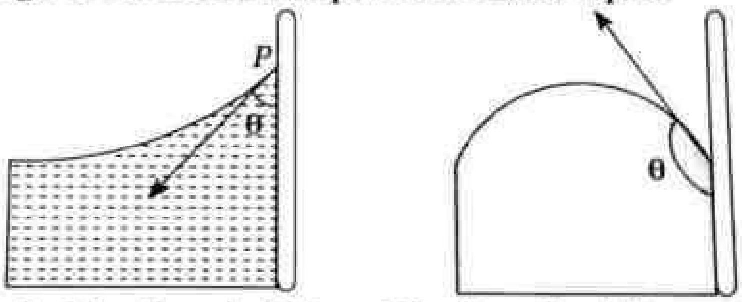
Surface tension is a vector quantity and its SI unit is N/m i.e. Nm^{-1}.

Note : The value of the surface tension becomes zero at the critical temperature.

Surface Energy : Every strained body possesses potential energy. Thus surface of a liquid behaves also like a strained system and hence the surface of the liquid also has a potential energy which is equal to the work done in creating the surface. This energy per unit area of the surface is called surface energy. The surface energy of a liquid is numerically equal to the surface tension. Thus, surface energy and surface tension both can be expressed in Joule/meter^2

The free surface of the liquid tries to acquire the minimum area due to surface tension and that's why rain drops, liquid drops, drops of mercury etc. are spherical.

Angle of contact : When a solid body in the form of a tube or a plate is immersed in a liquid, the surface of the liquid near the solid in general is curved (concave or convex). The angle between the tangents of the liquid surface and the solid surface at the point of contact, inside the liquid is called the angle of contact for that pair of solid and liquid.



Pressure Inside a Soap bubble and inside a liquid drop : The pressure inside a soap bubble or a liquid drop must be in excess of the pressure outside the bubble or drop because without such pressure difference, a bubble or a drop cannot remain in a stable equilibrium. Due to surface tension the bubble or drop has a tendency to contract and disappear altogether. To balance the tendency to contract, there must be an excess of pressure inside the bubble or drop.

The excess pressure inside a soap bubble = $\frac{4T}{R}$

Where; T = Surface Tension

R = Radius of the soap bubble

and the excess pressure inside a liquid drop = $\frac{2T}{R}$

Where, T = Surface Tension

R = Radius of the liquid drop

For a soap bubble two surfaces are taken under consideration upon which surface tension is effective, while for a liquid drop and for an air bubble one surface is assumed to be effective for the surface tension.

Some incidents and facts related to surface tension

(i) A thin little needle can float in water due to surface tension.

(ii) Soaps and Detergents reduce the surface tension of the water and clothes are thereby cleaned up.

(iii) Through the soap solution a great bubble can be produced as water reduces its surface tension.

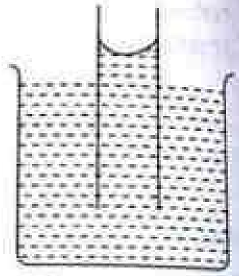
(iv) On a spray of kerosene oil (K-oil) the surface tension of water reduces and mosquitoes sink into the water and die.

(v) Hot soup is tasty (delicious) because its surface tension is reduced and it spreads uniformly on the mouth-tongue.

(vi) The hairs of shaving brush stick to each other due to surface tension on drawing it out from the water.

(E) CAPILLARY ACTION OR CAPILLARITY

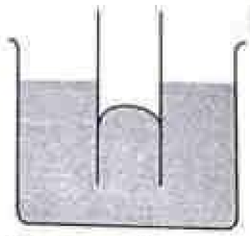
When a long glass tube of very fine bore called capillary tube is dipped into a liquid, then the liquid rises or depresses in the tube. If the angle of contact is acute (less then 90°) then liquid rises and if the angle of contact is obtuse (more than 90°) then the liquid depresses. It is called capillary action or capillarity.



Water rised

Generally the liquid which wets glass rises upwards and the liquid which doesn't wet glass depresses downwards.

When a capillary tube is dipped into water it rises, while in the case of mercury it depresses.



Mercury depressed

Let us suppose r be the radius of a capillary tube, T be the surface tension of the liquid and ρ be its (liquid) density. Let if it rises or depresses h height or depth then the radius of the tube is given as :

$$r = \frac{2T\cos\theta}{h\rho g} \quad \text{or,} \quad h = \frac{2T\cos\theta}{r\rho g}$$ where, θ = angle of contact

Obviously; a liquid will rise the most for the least radius and vice-versa.

For pure water and glass $\theta = 0°$

For pure mercury and glass; $\theta = 135°$

If a capillary tube be of height less than h, then the liquid doesn't overflow. The angle made by the liquid surface with the capillary tube changes in such a way that the force $2\pi rT\cos\theta$ becomes adjustable and equalises to the weight of the liquid raised in the capillary tube.

Examples of Capillarity :

(i) Blotting paper sucks to ink due to the small holes (pores) of the paper which act like the capillary tubes.

(ii) Through the wicks of K-oil lamp, K-oil rises into the wick due to capillary action.

(iii) In the branches of plants and leafs the water and nutritional salts are transported through the capillary action.

(iv) In the artificial satellites (in their state of weightlessness) if a capillary tube is dipped into water, then the water will rise upto its full height.

(v) Just after heavy rainfall farmers plough their agriculture lands to break the capillaries form by the soil so that water doesn't come upto upper surface and the soil remains wet (wetted).

(F) VISCOSITY

If the layers of a fluid (liquid or gas) slip or tend to slip on another layers in contact, then any two such layers exert a tangential force on each other. The directions of these forces are such that the relative motion between the layers are opposed. This property of the fluid to oppose relative motion between its layers is called viscosity. The forces between the layers opposing the relative motion between them are called the forces of viscosity. Thus, viscosity may be thought to be an internal friction of the fluid in motion.

Let us suppose a liquid is flowing as shown in the figure (i) and AB is the ground level at which the lowermost layer is at rest.

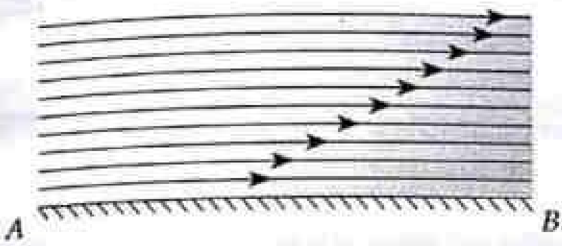


Fig. (i)

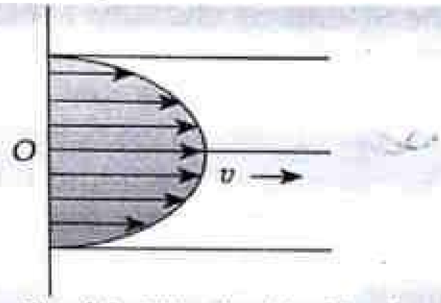


Fig. (ii) : Velocity distribution curve

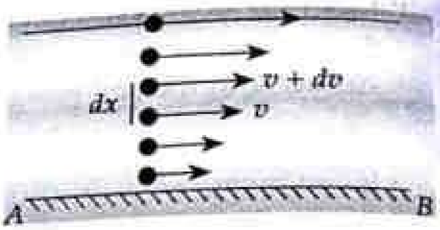
As we move from the lowermost layer to upward the flow velocities of the liquid layers go on increasing and the uppermost layer has maximum velocity. Thus every lower layer has lesser velocity than consecutive upper layers and others. In fact every upper layer tries to drag forward every consecutive (adjacent) lower layer, but a lower layer tries to pull consecutive (adjacent) upper layer backwards.

If a liquid flows in a cylindrical pipe or tube as shown in figure (ii) a velocity distribution curve is obtained which is *parabolic* and the velocity of the mid. Layer is the maximum and decreases for other adjacent layers.

Thus, viscosity is the internal characteristics of liquids and gases which are produced by the cohesive forces of the molecules. When the liquid flows a relative motion among its various layers start due to which the distance among the molecules increases and it is opposed by the cohesive forces and thus viscosity is produced. But in gases viscosity is generated due to molecules transfer from one place to another. That is why, in the gases viscosity is less than that of the liquids. In liquids viscosity is also measured by their concentration. The liquids which are more dense (concentrated) have more viscosity. Examples - Glycerine and Honey have more viscosity than water.

Due to viscosity in air the cloud particles come slowly and clouds seem to be floating.

Coefficient of viscosity: The coefficient of viscosity is the only parameter through which the viscosity of the fluid is measured. Let a liquid be flowing from the ground level and let v be the velocity of layer at a distance x from the bed and $v + dv$ be the velocity at a distance $x + dx$.



Thus, the velocity differs by dv in going through a distance dx perpendicular to it.

Here, $\frac{dv}{dx}$ is called velocity gradient.

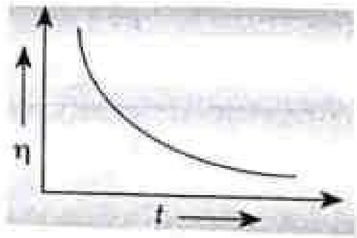
Newton observed that the viscous force acting between any two adjacent layers of the liquid is proportional to the velocity gradient $\left(\frac{dv}{dx}\right)$ in the direction perpendicular to the layers and the area (A) of the layer.

Thus, $F \propto A\frac{dv}{dx} \qquad \Rightarrow F = -\eta\, A\,\frac{dv}{dx}$

where; η = a proportionality constant called coeff. of viscosity. Negative sign indicates that the viscous force opposes the relative motion.

The SI unit of viscosity is $N.Sm^{-2}$ and its C.G.S. unit is dyne. Scm^{-2}. However poise is another SI unit of viscosity which has been given in the honour of the French scientist Poiseulle.

Also, 1 poise = $0.1\ N.Sm^{-2}$



The viscosity of the liquid falls very rapidly with rise in temperature. But no actual theory of temp. variation with viscosity has been until developed.

The viscosity of a gas increases with rise in temperature.

Streamline flow or Steady flow : The flow of a fluid is said to be streamlined or steady if the velocity at every point in the fluid remains constant both in magnitude and direction and the energy needed to drive the fluid being used up in overcoming the *viscous drag* between its layers. Thus, in steady flow, each small volume element of the fluid (say a particle of the fluid) follows exactly the same path and has exactly the same velocity as its predecessor.

The line along which the particles of the fluid move one after another, with their constant velocities at various points and their motion are along the tangents to those points, is called a streamline. This also concludes that a streamline is a curve and the tangent to it at any point gives the direction of the fluid-flow at that point.

Turbulent flow : In the flow of another type, the fluid doesn't maintain constancy of the velocity of its fluid particle both in magnitude and direction and this is called turbulent flow. Most of the external energy in maintaining this type of flow is used in setting up eddy–current in the fluid.

Critical Velocity and Reynold's Number : The flow of a liquid remains steady or orderly only till its velocity doesn't exceed a certain limiting value of it which is called its critical velocity. Beyond the critical velocity, the flow loses all its steadiness with the paths and velocities of the liquid ...

change continuously and haphazardly. Such a flow is called turbulent flow and most of the energy needed to drive the liquid is now dissipated in setting up eddies and whirlpools.

O. Reynolds determined the value of the critical velocity v_c for a liquid as; $v_c = \frac{k\eta}{\rho r}$. Where, η = Coeff. of viscosity

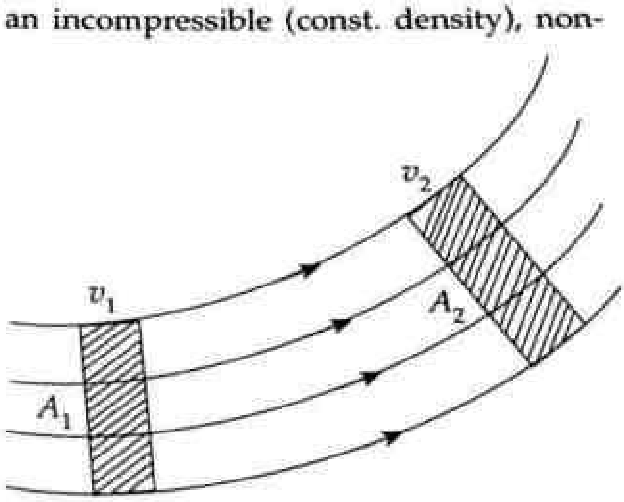
ρ = Density of the liquid

r = Radius of the tube in which liquid is flowing.

k = Reynold's number in which liquid is flowing.

This is called Reynolds formula. Here k is called Reynolds number, its value is very high and usually it is represented on a logarithmic scale. For a narrow tube the value of k is 1000. Obviously for the flow of liquids of higher viscosity and lower density through narrow tubes tends to be steady or orderly (streamlined) whereas that of liquids of lower viscosity and higher density through broader tubes tends to be turbulent.

Principle of Continuity : If an incompressible (const. density), non-viscous, fluid flows steadily through a tube of non-uniform cross-section, then the product of the area of cross-section and the velocity of flow is same at every point in the tube.



Thus, in a particular tube if A be the area of its cross-section and v be the velocity of flow of the liquid at a place (point), then according to the continuity principle; Av = Constant

Thereby, for two different places (points) in a tube as shown in the figure,

$$A_1 v_1 = A_2 v_2$$

Usually the principle of continuity is a fundamental law of fluid-flow and it is a special case of the general physical law of conservation of matter. Also we can conclude that in a steady compressible flow the velocity of flow varies inversely with the cross-sectional area, being larger in narrower parts of the tube and vice-versa.

Bernoulli's Theorem : This states that for all points along a streamline in an incompressible and non-viscous fluid flowing steadily, the sum of pressure energy, potential energy and kinetic energy per unit volume is constant.

Thus, if p be the pressure energy per unit volume, ρ be the density of the fluid, h be the height from the ground level, then by Bernoulli's theorem,

$$p + \frac{1}{2}\rho v^2 + \rho g h = \text{constant.}$$

Here, the term $(p + \rho gh)$ represents the pressure of the fluid even if fluid is at rest, so it is called static pressure of the fluid. The term $\frac{1}{2}\rho v^2$ represents the pressure of the fluid and by virtue of its velocity v it is called dynamic pressure of the fluid.

Thus, Bernoulli's theorem or equation can also be expressed as

Static Pressure + Dynamic Pressure = constant

In fact, *Bernoulli's theorem is nothing* but *the law of conservation of energy for an ideal fluid.*

Applications : (i) Venturimeter : This instrument is based upon Bernoulli's theorem by which the rate of flow (speed) of the liquid (say water) is measured through a pipe.

(ii) Pitot Tube : This instrument (device) is based upon Bernoulli's theorem which measures the rate of flow (speed) of the gas.

(iii) Dynamic Lift : This device operates on the principle of Bernoulli's theorem and in it the force acts on a body such as an air plane wing, a hydrofoil, a spinning ball, the spinning shot of a rifle by virtue of its motion through air.

(iv) Often in a sea if two water boats are moving parallel to each other and come close to each other, then the velocity of the water behind the two boats becomes larger than the individual relative velocities of the boat and consequently low pressure regions develop and the boats collide.

(v) If a Cyclonic storm comes, the roof of the tin foils are flown away because the pressure of the outer surface of the roof has low pressure (high velocity) than that of the air inside the roof in a closed room where no change in the pressure takes place.

Terminal Velocity and Stokes's theorem : When a solid body falls under gravity through a liquid (or gas), the layer of the liquid in contact with the body moves with the velocity of the body, while the liquid confined at the far distance from it is at rest. Thus, the body produces a relative motion between the layers of the liquid. This is opposed by the viscous force appeared between the layers of the liquid. The viscous force increases with the velocity of the body and ultimately becomes equal to the driving force of the body. The body then falls with a constant velocity and it is called *Terminal Velocity.*

Stokes observed dimensionally that when a small sphere moves slowly with a constant velocity through a perfectly homogeneous viscous fluid of an infinite extension, the resistive force experienced by the sphere is $F = 6\pi \eta r v$; where r is the radius of the sphere, v is its terminal velocity and η is the viscosity of the fluid. *This is called stokes law.* If this sphere of density ρ falls freely from rest under gravity through a fluid of density σ and acquires a terminal velocity v, then

$$6\pi \eta r v = \frac{4}{3}\pi r^3 (\rho - \sigma) g. \Rightarrow v = \frac{2}{9}\frac{r^2(\rho - \sigma) g}{\eta}$$

where, v = terminal velocity; This concludes that the terminal velocity of a small sphere is proportional to the square of its radius.

(G) ATMOSPHERIC PRESSURE

The gaseous layer which surrounds the earth is called atmosphere. It is held on the earth by the action of gravity. Atmosphere is a mechanical mixture of the gases namely nitrogen and oxygen and some other inert gases. The pressure of these gaseous mixture of atmosphere is called atmospheric pressure. As gravity is the only force acting on the atmosphere, the pressure on the atmosphere is obviously the weight of the vertical column of air of unit cross-section and height equal to that of atmosphere. Firstly the atmospheric pressure was evaluated and measured by Von Guericke. Normally, the atmospheric pressure is the pressure required which is exerted by the column of 76 cm of Hg at 0°C and at 45° latitude near the sea. Thus we can also say that atmospheric pressure is the pressure equivalent to the wt. of the column of 76 cm of Hg for unit cross-sectional area.

Unit of Atmospheric Pressure

Column of 1 cm of Hg	$= 1.33 \times 10^3$ Pascal
1 Pascal	= 1 Newton/meter^2
1 Bar	$= 10^5$ Newton/meter^2
1 Millibar	$= 10^2$ Pascal
1 ttor	= 1 milli Hg Pressure
	= 133.8 Pascal
More appropriately; 1 atmosphere	$= 1.013 \times 10^5$ N/m^2

Thus, the atmosphere exerts on us a pressure of 1600 kg, but we don't realise pressure. The osmotic pressure of the blood and mineral water of our body exerts an equivalent pressure that's why we don't feel external pressure. At the earth's surface (near sea level) on reaching a distance of 110 m upwards, atm. pressure decreases by 1 cm column of *Hg*.

In hilly area it is difficult to prepare food because of a fall in pressure on the hill and the boiling point of water correspondingly rises up. Consequently the latent heat of vaporisation of water decreases too and, that's why the difficulties occur. The phenomenon of ink overflowing from the pen of a man sitting in aircraft at higher altitudes, the phenomenon of bleeding through the nose etc. are common interesting incidents.

Barometer : The barometer is a device by which the atmospheric pressure is measured. Fortin fabricated and designed the barometer on the basis of Torricelli's theorem. It measures the atmospheric pressure accurately and by the help of Fortin barometer weather related activities are predicted. When the indicator of a barometer suddenly falls, it is the indicative prediction of the appearance of a cyclonic storm, but if its indicator falls slowly then the possibility is of the coming of rain and if the indicator inclines upward slowly then there is a possibility of the appearance of a clear day.

Due to large size and some other drawbacks, Fortin barometer was replaced by Aneroid barometer which is compact and convenient and in it no liquid is used. The frequent use of Aneroid barometer is customary to measure the altitude of various places. The device Altimeter operates on the basic principle of Aneroid barometer by which altitudes are measured.

The Standard Atmospheric pressure is the pressure required of 76 cm of *Hg* column or 760 mm of *Hg* column, which is equivalent to 1 atm.

6. Simple Harmonic Motion

Periodic motion and Oscillatory motion : Any motion that repeats in equal intervals of time is called periodic motion. The motion of the earth about its axis is a periodic motion. The motion of the piston of an engine, the motion of a pendulum, the motion of the electron in an atom etc. are the examples of periodic motion. The interval of time after which motion is repeated is called time period (T) or periodicity of the motion. In 1 sec repetition of the motion is called frequency (n). The relation between time-period (T) and frequency (n) is $n = \frac{1}{T}$.

If a particle in periodic motion moves back and forth over the same path, it is called an oscillatory (vibratory) motion. The oscillations of a simple pendulum, sonometer wire, atoms at the lattice sites of a solid, a mass attached to a spring etc. are the examples of periodic motion.

Simple Harmonic Motion : Simple Harmonic Motion (S.H.M.) is defined as motion in which acceleration is always directed towards a fixed point in the path of motion and is proportional to the displacement from that point.

Characteristics of Simple Harmonic Oscillator

(A) If an oscillator executing S.H.M passes through a fixed point (mean position) then

(i) No acceleration exists or acceleration is zero and thereby no force comes into existence and no work is done.

(ii) The potential energy of the oscillator is zero but the kinetic energy is maximum.

(B) If an oscillator executing S.H.M passes through the extreme point (end point) then

(i) The acceleration is maximum and thus acting restoring force will be maximum.

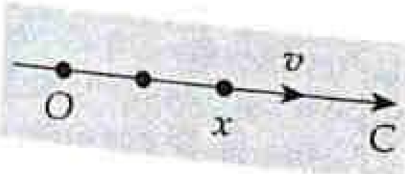
(ii) The oscillator instantaneously comes to rest (its velocity becomes zero) thus kinetic energy becomes zero. But its potential energy is maximum.

Equation of S.H.M. : If a particle of mass m moves in such a way about a fixed point (mean position) O then a force $F = -kx$ acts on the particle where k is a constant and x is the displacement of the particle from the fixed point O.

The acceleration of the particle at any instant is

$$f = \frac{F}{m} = \frac{-k}{m}x = -\omega^2 x \quad \text{... (i)} \quad (\because F = -kx)$$

where, $\omega = \sqrt{\frac{k}{m}}$ (say a constant)



But acceleration $= f = \frac{dv}{dt}$ and velocity $= v = \frac{dx}{dt}$

Thus, acceleration $= f = \frac{d}{dt}\left(\frac{dx}{dt}\right) = \frac{d^2x}{dt^2}$ ... (ii)

Now, from eqns. (i) & (ii)

$\Rightarrow f = \frac{d^2x}{dt^2} = -\omega^2 x$. The negative sign is the indication of particle's motion toward the mean position.

$\Rightarrow \frac{d^2x}{dt^2} + \omega^2 x = 0.$

This is the eqn. of a simple harmonic oscillator in differential form. The solution of this eqn. is given by $x = a \sin(\omega t + \phi)$.

where, x = instantaneous displacement at time t.

ω = a constant, called angular frequency.

ϕ = phase constant

a = max. displacement or amplitude.

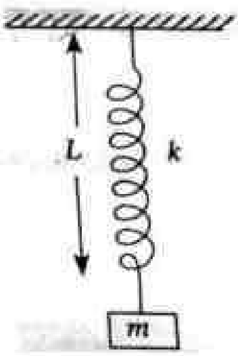
Thus, velocity of the particle executing SHM

$$v = \frac{dx}{dt} = a\omega \cos(\omega t + \phi)$$

$$= a\omega\sqrt{1 - \sin^2(\omega t + \phi)} = a\omega\sqrt{1 - \frac{x^2}{a^2}} \qquad \left[\because \frac{x}{a} = \sin(\omega t + \phi)\right]$$

$$= a\omega \frac{\sqrt{a^2 - x^2}}{a} = \omega\sqrt{a^2 - x^2}$$

$\Rightarrow$ velocity $= v = \omega\sqrt{a^2 - x^2}$



Time Period and frequency of a body suspended by a vertical spring : Let L be a natural length of a massless spring and a block of mass m be attached to it and the spring be vertically suspended by a rigid support. Now, let the spring be slightly extended from equilibrium, then the time period of oscillation of the block is given by

$T = 2\pi\sqrt{\frac{m}{k}}$. Here; k is called spring constant.

and frequency of oscillation $= n = \frac{1}{T} = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$

If the mass of the spring say m_s is also taken under consideration, then time period of the oscillating body (block).

$$= T = 2\pi\sqrt{\frac{m + \frac{m_s}{3}}{k}} \text{ and frequency of oscillation}$$

$$= n = \frac{1}{T} = \frac{1}{2\pi}\sqrt{\frac{k}{m + \frac{m_s}{3}}}$$

If a spring of length L and spring constant k be cut (or divided by breaking) into two equal parts or pieces each of length $L/2$ and spring constants k_1 and k_2, then $k_1 = k_2 = 2k$.

Thus, $k = \frac{k_1}{2} = \frac{k_2}{2}$

If n be the frequency of oscillation of a body of mass m attached to a massless spring, then frequency of oscillation $(n) = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$

But if the spring is cut into two equal pieces then each attached with a body of mass m will oscillate with frequency $(n') = \sqrt{2}\,\frac{1}{2\pi}\sqrt{\frac{k}{m}}$

$$\Rightarrow n' = \sqrt{2}\,n$$

In SI unit frequency of the oscillator is expressed in Hertz (Hz). Here angular frequency of a simple harmonic oscillator (ω) is related to frequency of n as $\omega = 2n$, but $n = \frac{1}{T}$,

Thus, $\omega = \frac{2\pi}{T}$,

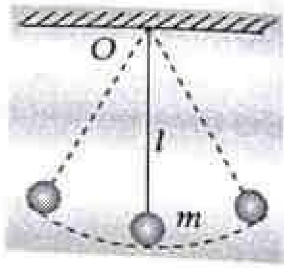
where T = Time period of the oscillator measured in seconds.

The maximum displacement of the oscillator (or particle) from the centre of oscillation (mean position) is called amplitude of the oscillation.

If a smooth straight tunnel is made diametrically opposite the points on the surface of the earth, then a body dropped to it executes S.H.M. and its period of oscillation is 84.2 minutes.

Simple pendulum and Some interesting incidents related to it :

A simple pendulum consists of a heavy particle suspended by a massless inextensible and perfectly flexible string (thread). The distance between the point of support (O) and the particle (bob) is called length (l) of the pendulum. An ideal simple pendulum defined as above can never be realised in practice, though in laboratories a small brass ball (bob) is suspended by a long thin cotton thread to construct a simple pendulum. The distance between the point of support and the centre of gravity of the bob is called the effective length of the pendulum.



The time period of the simple pendulum $= T = 2\pi\sqrt{\frac{l}{g}}$

(A) Obviously $T \propto \sqrt{l}$ i.e. on increasing the length of the pendulum the time period T will increase and vice-versa. For example when a girl be stand up during springing then the center of gravity (c.g.) of the body of the girl comes upward and the effective length is decreased smaller consequently the time period of the oscillation of the spring becomes small or lesser than that of initial value.

Also the time period of a simple pendulum doesn't depend upon its mass, so if another girl comes and seat gently then its time period doesn't change.

(B) As $T \propto \sqrt{\frac{l}{g}}$ and the value of g decreases either in going up or coming down inside the earth's atmosphere so a pendulum clock will become slowed down and will indicate a longer time period.

(C) If a pendulum clock is brought inside an artificial satellite, then due to the state of weightlessness inside the satellite ($g = 0$), the time period of the clock becomes infinite (∞). That's why such clock doesn't work inside the artificial satellites.

(D) In summer season the effective length of the pendulum clock is lengthened (increased length), so its time period is also increased and consequently the clock becomes slow. But in winter season the effective length is contracted thus time period is decreased and the clock becomes fast.

(E) As on the moon the value of acceleration due to gravity is $g/6$, where g is acceleration due to gravity on the earth's surface. Thus, the period of oscillation of the pendulum clock is increased on the moon's surface and so it (pendulum clock) is slowed down.

II. Sound (Acoustics)

1. Wave Motion

Wave motion : A wave motion is a process of transmission of disturbances created somewhere in an elastic medium in all directions around it and along with the disturbances energy transmits. Although the particles of the medium only vibrate about their mean position and do not leave their original respective positions.

Thus, three conditions are required for the formation of a wave—

(i) A vibrating body called the *source* is necessary to create the disturbance.

(ii) An elastic medium called the propagating medium through which the wave transmits.

(iii) Particles of the medium which take part in the process of onward transmission of the *disturbance* by executing successive similar vibrations in the source about their respective mean position.

Such wave (disturbance) progression along with energy transmission is called a wave-motion.

Broadly a wave is categorized into two types—

(i) Mechanical waves (Elastic waves)

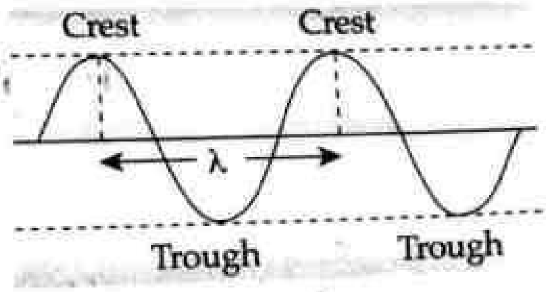
(ii) Non-mechanical waves (Electromagnetic waves).

(i) Mechanical waves *(Elastic waves)* : Waves which propagate in materialistic elastic medium like solid, liquid or gas are called mechanical waves. There are two essential features— elasticity and inertia for the existence of the mechanical waves.

Types of Mechanical waves :

(a) Transverse mechanical wave

(b) Longitudinal mechanical waves.



(a) Transverse mechanical wave : If in an elastic medium wave propagates (transmits) along the perpendicular direction of the particles vibration, then the wave is called transverse mechanical wave.

Transverse mechanical wave can be generated in solids and upper surfaces of the liquids. But it cannot be generated through gases and inside liquids due to lack of rigidity. The transverse wave propagates in the form of crest (max. upwards displacement) and trough (max. downwards displacement). The distance between two adjacent crests or troughs is called wavelength and it is represented by λ.

(b) Longitudinal mechanical wave : If in an elastic medium, a wave propagates (transmits) along the direction of particles vibration, then the wave is called longitudinal mechanical wave.

Longitudinal wave can be generated (produced) in all medium— solids, liquids and gases and such wave transmit through compression and rarefaction. In compression the pressure and the density of the medium is maximum, while in rarefaction the pressure and the density of the medium is minimum. Examples — Sound waves in air, earthquake waves, water waves etc. are longitudinal mechanical waves.

(ii) Non-mechanical waves (Electromagnetic waves) : Waves whose propagation (transmission) does not need any elastic medium and which is generated by the mutual oscillations of electric and magnetic fields perpendicular to each other. Such waves are called non-mechanical waves (electromagnetic waves). The electromagnetic waves propagate in a perpendicular direction to each electric field and magnetic field and it travels in vacuum with velocity of light $c = 3 \times 10^8$ m/s or 3 lakh km/sec. Each and every electromagnetic wave travels with the same velocity i.e. velocity of light c. The wavelength range of various electromagnetic waves lie between 10^{-14} meter to 10^{-4} meter. The examples of electromagnetic waves are radio waves, ultra violet rays, X-rays, γ-rays, thermal radiations etc.

In the early days light was also assumed to be an elastic wave and a hypothetical medium called ether was supposed to be its medium of propagation. But later after the negative result of ether drag by Michelson-Morely experiment, this concept was discarded (abandoned).

Spectrum of electromagnetic waves

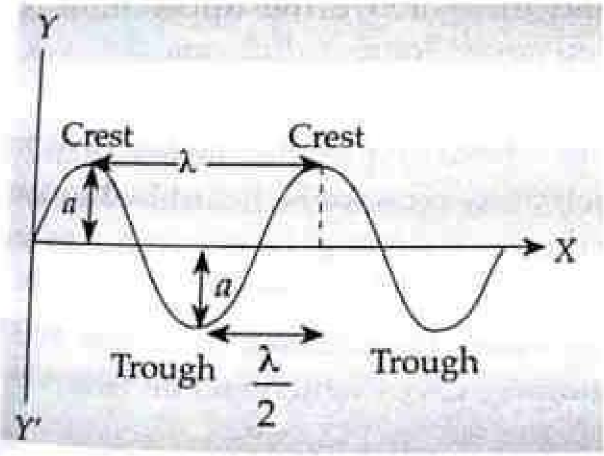
Electro-magnetic waves	Inventors	Wavelength range (m)	Frequency range (Hz)	Utilities
X-rays	Roentgen	10^{-10} m to 10^{-8} m (1A°–100A°)	10^{18} Hz to 10^{16} Hz	X-rays are extensively used in various surgical diagnosis like bone fractures, diseases of lungs, kidneys etc. and in various industrial purposes.

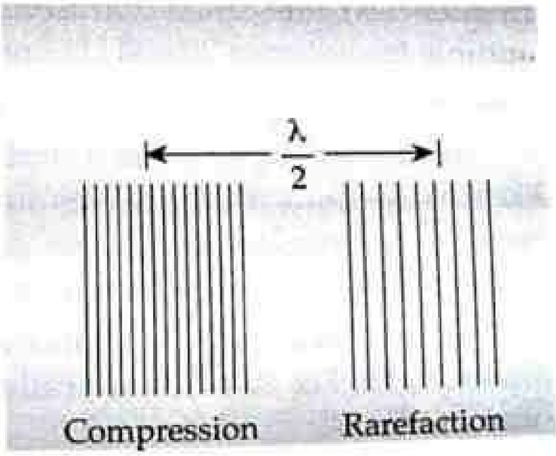
(1A° = 10^{-10} meter)

Scanned by CamScanner

Electro-magnetic waves	Inventors	Wavelength range (m)	Frequency range (Hz)	Utilities
γ-rays	H.Becquerl	10^{-14} m to 10^{-10} m	10^{20} Hz to 10^{18} Hz	γ-rays have max. penetrating power which is utilized in nuclear reaction and artificial radioactivity.
U/V-rays	Ritter	10^{-8}m to 10^{-7}m	10^{16}Hz to 10^{14}Hz	U/V rays are used in producing electric discharge, photoelectric effect and in destroying bacteria.
Visible radiation	Newton	3.9×10^{-7}m to 7.8×10^{-7}m	10^{14} Hz to 10^{12} Hz	By visible radiation objects become visible and by the illumination of the visible radiation objects are made distinctive.
Infra-red radiation	Hurssel	7.8×10^{-7}m to 10^{-3}m	10^{12} Hz to 10^{10}Hz	*I/R*–radiations are thermal radiations and on which object these incident raise the temperature. These are utilized in photography of the objects behind mist and fog. It is also used to warm patients in hospitals. In T.V. remote *I/R* is used.
Short radio waves	Henric Hertz	10^{-3}m to 1 m	10^{10}Hz to 10^{8}Hz	Short radio waves are used in radio, T.V. and Telephone etc.
Long radio waves	Marconi	1 m to 10^{4}m	10^{6}Hz to 10^{4}Hz	Longer radio waves are used in radio and T.V.

Terms related to wave motion





(i) Amplitude : The maximum displacement from the mean position of the vibration of the particles of the medium is called amplitude of the wave. Thus, maximum displacement on both sides from the equilibrium position is called amplitude which is represented by a.

(ii) Time-period : The time taken by the vibration of the particles of the medium in completing one oscillation is called time-period (T)

(iii) Frequency : The number of oscillations executed by the particles of the medium in one second is called frequency (n) of the wave and in SI unit it is expressed in hertz (Hz).

Thus; $n = \frac{1}{T}$

(iv) Phase : The state of motion of a particle of the medium at a given point of time is called phase of the wave. The state of motion of a particle at a time means where it is and what is its direction of motion at that instant ?

(v) Wavelength : The distance required to cover one complete oscillation of any particle of the medium is called wavelength (λ). In a transverse wave the distance between two consecutive (adjacent) crests or troughs is called its wavelength (λ) and in longitudinal wave it is the distance between two consecutive (adjacent) compressions or rarefactions

(vi) Wave speed : The rate of the distance travelled by the wave (disturbance) is called wave speed (v).

The relation among wave speed (v), wavelength (λ) and frequency (n) is

Wave speed (v) = frequency (n) × wavelength (λ).

2. Sound Wave

The sound wave is a longitudinal mechanical wave which is generated (produced) by the transmission of the disturbances in the form of compressions and rarefactions. This train of packets of compressions and rarefactions on reaching the listener's ears produces a variations of pressure on his or her ear-membranes. These pressure variations set up impulses on the auditory nerves which carry the message to the hearing centre of the brain.

In fact sound is produced by the rapid vibration of material bodies and its sensation is produced by a vibrating body, provided its frequency of vibration lies within the range 20 Hz to 20,000 Hz called audibility limit (range). The frequencies of less than 20 Hz (lower limit of audible frequencies) are called *infrasonics* and those above the upper limit of audible frequencies 20,000 Hz are called *super-sonics (ultrasonics)* waves.

Frequencies range of sound waves :

Infrasonic waves : The sound waves whose frequencies are less than 20 Hz are called *Infrasonic waves* and such waves cannot be heard by human ears. Such waves are produced inside the earth during the occurence of an earthquake. Heart beats of a human body are also infrasonics.

Audible waves : The sound waves whose frequencies lie between (20 Hz to 20,000 Hz 20 kHz) are called *audible waves* which can be heard by human ears.

(Supersonic) waves : The sound waves whose frequencies are more than 20,000 Hz are called ultrasonic waves and such waves cannot be heard by human ears. Ultrasonics were produced firstly by Galton and later these were produced in certain crystals of tourmaline, quartz, zinc oxide, etc. by Piezo electric method. Thus, Piezo electric crystals of quartz, rochelle salt, tourmaline etc. are generators of ultrasonics. As the frequencies of ultrasonics are too large so these waves are very energetic and have shorter wavelengths. Some animals like birds, bats, cats, dolphins etc. not only hear ultrasonics but also generate them. In the dark, the bats can fly freely without dashing against any obstacle (barrier) because during their course of flight they constantly send forward ultrasonic signals and if any obstacle is there, they hear the echoes (reflected sound wave) of the ultrasonics and at once change their course of flight. Bats can easily hear the ultrasonics of the frequencies of 1,00,000 Hz.

Utilities :

(i) In medical science ultrasonics are used in bloodless surgical operations, in detection of tumor and teeth cavity etc. By ultrasonic radiation various neurological disease and arthritis are being cured.

(ii) In western countries milk is purified by passing contaminated milk through ultrasonics. Generally contaminated (impure) milk has bacteria which are destroyed on passing through the ultrasonics.

(iii) Ultrasonics coagulate the dust particles in winter season. Thus mists and fogs at the airports are diminished and this facilitates in landing aircrafts (aeroplanes).

(iv) Ultrasonics are also used in measuring the sea depth, and in detecting or locating larger rocks, icebergs, bigger fishes etc. inside the sea SONAR (Sound Navigation And Ranging) is a technique through which objects located inside the sea are detected.

3. Speed of Sound

For the propagation of sound wave (mechanical longitudinal wave) a materialistic medium is needed. That's why sound doesn't propagate in vacuum. The speed of sound is different in different media. Newton firstly theoretically observed and propounded that the speed of sound is dependent on elasticity (E) of medium and its density (d) as given below;

$$v = \sqrt{\frac{E}{d}}$$

If the medium is solid then elasticity (E) = Young's modulus (γ)

$$\text{then } v = \sqrt{\frac{\gamma}{d}} \text{ (solid)}$$

Newton assumed (considered) that if sound wave propagates through a gaseous medium, then the disturbances transfer in the form of compressions and rarefactions in such a way that the temperature remains constant and the process is said to be isothermal.

Thus, elasticity (E) = Bulk's modulus (β)

= Pressure (p)

$$\Rightarrow \quad v = \sqrt{\frac{p}{d}} \text{ (gas)} = 280 \text{ m/sec}$$

where, $p = 1.013 \times 10^5$ N.m^{-2},

$d = 1.29$ kg.m^{-3}.

But this calculated value (280 m/sec) of the speed of sound by Newton himself was less than the actual value of the speed of sound (= 332 m/sec) which was globally acceptable.

Thus, a corrective modification was made by Laplace in this regard and he asserted that during the transmission of sound wave the compressions and rarefactions transfer so rapidly that temperature doesn't remain constant but the total thermal energy remains constant. Thereby Laplace assumed that the process of sound wave transmission is adiabatic (const. thermal energy) not isothermal (const. temperature) and it is called Laplace's correction.

Thus, elasticity (E) = Bulk's modulus $(\beta) = \gamma p$

$$\text{where,} \quad \gamma = \frac{C_p}{C_V} = \frac{\text{molar sp. heat at constant pressure}}{\text{molar sp. heat at constant volume}}$$

= 1.44 (for air diatomic gas)

$$\text{Thus, speed of sound} = v = \sqrt{\frac{\gamma p}{d}} = 332 \text{ m/sec.}$$

As the speed of light in air (c) is 3×10^8 m/s (300000 km/sec) which is very large than the speed of sound (332 m/sec). That's why during lightning in the sky both light and sound originate at the same time but light appears earlier to the eye and sound comes later to the ear.

Liquids are more elastic than gases but solids are the most elastic. Thus, speed of the sound is maximum in solids. Also speed of sound is more in liquids than gases. The speed of sound in air = 332 m/s

in water = 1493 m/s

and in iron = 5130 m/s

Speeds of sound in various media

Medium	Speed of sound in m/s at 0°C	Medium	Speed of sound in m/s at 0°C
CO_2	260	Water	1493
Air	332	Sea water	1533
Vapour (100°)	405	Iron	5130
Alcohol	1213	Glass	5640
Hydrogen	1269	Aluminium	6420
Mercury	1450		

If a sound wave propagates from one medium to another, then its speed and its wavelength changes but its frequency remains constant. Thus, the speed of sound doesn't depend on frequency. On moon no sound wave exists because of the absence of atmosphere (medium).

Variation in the speed of sound

Effect of pressure : At the same temperature the speed of sound in gas doesn't vary with pressure.

Effect of temperature : The speed of sound is directly proportional to the square root of its absolute temperature i.e. $v \propto \sqrt{T}$.

More appropriately as at 0°C the speed of sound is 332 m/sec and if at t°C speed be v_t then $v_t = 332 + 0.61t$. Obviously, for every 1°C increase in temperature the speed of sound increases by 0.61 m/sec.

Effect of humidity : The density of dry air is more than that of moist air. Thus, in moist air value of the speed of sound is more than in dry air. This is the reason why in rainy season the siren of the train is heard sharply up to a far distance than in summer season.

Effect of the speed of the medium : If the medium is speeded up then the speed of sound increases in the same direction and decreases in the opposite direction.

4. Characteristics of musical sound

Musical notes differ from each other in the respect of at least one of the three properties, namely– Intensity, Pitch and Quality. These three are called characteristics of a musical sound. A musical sound is bound to differ from another musical sound in at least one of these three properties and hence they provide a means to distinguish one musical note from another.

Intensity and Loudness : The intensity of a musical sound is defined as the rate of flow of energy per unit area of a plane perpendicular to the direction of wave propagation. The SI unit of intensity is Joule/sec-meter^2 or watt/meter^2.

The intensity of a simple harmonic wave is given by

$$I = 2\pi^2 \nu^2 a^2 \rho v.$$

where; a = amplitude of the wave
ρ = density of the medium
ν = frequency of the wave
v = wave speed

Obviously, the intensity of the musical sound is proportional to the square of the amplitude of the wave, the density of the medium, the square of the frequency of the wave, and wave speed. Apart from these the intensity of the musical sound varies inversely as the square distance of the source and varies directly to the elasticity of the medium. This intensity also depends on the size of the source and a larger source has larger intensity and vice-versa.

In fact intensity is a special feature (characteristic) of the musical sound by which feeble (weak) and loud (sharp) sounds can be identified. Though the absolute unit of intensity is watt/m^2 but it has no significance and another arbitrary unit is *bel* which is expressed on the logarithmic scale and it is used frequently to measure the relative intensity. This unit bel was a nobel honour to the inventor of the telephone *Graham Bel*. Generally, $\frac{1}{10}th$ of bel which is called *decibel* (db) is the most practical unit of the relative intensity.

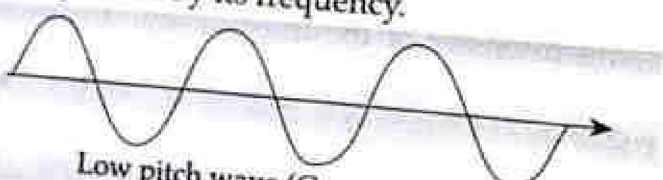
Thus, relative intensity of first relative to second on the logrithmic scale is expressed as $10 \log_{10} \frac{I_1}{I_2}$ decibel (db). The standard intensity level selected for expressing the relative intensity is 10^{-12} w/m^2.

Loudness is the sensation produced in the human ears and it is something that is not absolute and it varies from person to person although loudness depends upon the intensity. Thus intensity is the physical cause of the loudness. The unit of loudness is phon which is assumed to be the counterpart of the decibel (db).

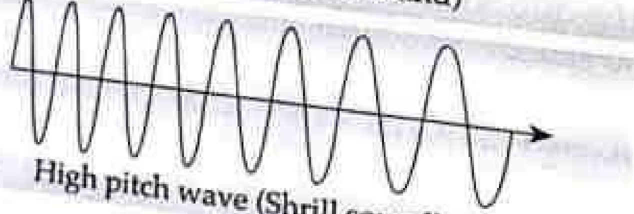
Source of sound	Intensity (db)	Source of sound	Intensity (db)
Whisper	15-20	Press	100-105
Ordinary conversation	40-60	Archestra	100-110
Loud speaker	70-80	Rocket	160-170
Hot discussion	70-80	Missile	180-190
Heavy motor vehicle, motor bike	90-95	Siren	190-200

For a sound sleeping man, 50 db sound is sufficient to wake him up. To dwell in the noise of 80 db is harmful and 90 db sound has its maximum limit to dare and if such noise be continued everyday 10 hours then the man would become deaf. World Health Organisation (WHO) has recommended 45 db sound good for the human ears, the sound of more than 75 db is assumed to be dangerous and the sound of 150 db can make human beings abnormal (mad).

Pitch and Frequency : The pitch of a musical note is that physical cause which distinguishes a shrill note from a grave note of the same intensity and coming from the same instrument. Thus the degree of shrillness of a musical note is its pitch. The pitch of a note emitted by a source depends upon its frequency of vibration. The greater the frequency of vibration of a source, higher the pitch of the note emitted and vice-versa. That's why the pitch of a note is expressed by its frequency.



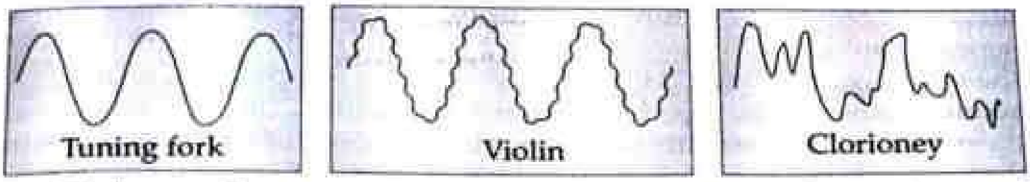
Low pitch wave (Grave sound)



High pitch wave (Shrill sound)

Children and women have shrill voice sound due to higher value of pitch but the grave sound of the man is due to low pitch. The horrified voice of lions have lesser pitch than that of mosquitoes. This shows that grave and shrill sounds are indicators of low and high pitches which has been displayed in the above diagram (graphical representation).

Quality or Timber : Quality or timber is a third feature of a musical note which distinguishes between two notes of the same intensity and pitch but produces two different musical instruments. The quality or timber of a note is appeared due to presence of different harmonics. The presence of harmonics affect the form of the wave emitted by the musical instrument.



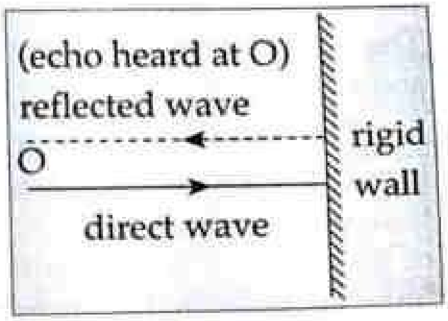
The harmonics present do not affect the frequency of the fundamental tone, but they simply reshape the form of the fundamental wave as shown in the diagram. On account of the different shaping of the wave form by the harmonics, the quality of different notes becomes different. Due to the difference in the quality we identify and detect the voices of well known persons.

5. Properties of sound wave and some acoustical applications.

(i) Reflection of sound wave : Like light wave, sound wave also returns to its original medium after incidence on any rigid surface and it is called reflection of sound wave. When reflection takes place from a rigid wall there is no change in the nature of the wave i.e. compression remains compression and rarefaction remains rarefaction. But when the reflection takes place on the open end of a pipe (organ pipe), then the nature of the wave changes i.e. compression changes into rarefaction and vice-versa. Due to a longer wavelength the sound wave reflects at large surface than light wave. In our daily life there are so many examples of sound wave reflection like reflected sound from walls, mountains, rivers, vallies etc.

(a) Echo : Echo is a natural phenomenon of reflection of sound and it is simply the repetition of a sound wave produced by the reflection from an obstacle like rigid wall, tower or mountain. The essential conditions for the formation of an echo is that the interval between the arrivals of the direct wave and the reflected wave must be at least $\frac{1}{10}$th of a second (0.1 sec) because a human ear cannot distinguish between two sounds arriving within $\frac{1}{10}$th of a second. Thus the minimum distance to hear (listen) an echo distinctly would be 16.6m (approx. 17m). Since speed of sound (v) = 332 ms^{-1} in air at NTP, time interval (t) = 0.1 sec.

$$\Rightarrow \text{ required distance } (x) = \frac{vt}{2} = \frac{332 \times 0.1}{2} = 16.6\text{m}$$



With the help of echo the depth of sea, the depth of wells, the altitudes of flying aircrafts etc. are measured. With the help of SONAR (Sound Navigation And Ranging) and producing (by the use of) ultrasonics we measure the sea-depth.

No mechanical wave can be produced on the moon due to the absence of the atmosphere. Also due to lack of an elastic medium, sound (longitudinal mechanical wave) cannot be produced. Thus no echo (reflected sound wave) can exist (be produced) on the moon.

(b) Reverberation : When the programmes of music, speech or concerts etc. are organized in lecture halls, cinema houses or auditoriums then a series of multiple reflections takes place from the walls, roofs and floors of the respective buildings. If the source of sound is stopped then up to a few seconds these music, speech or concerts are audible. This continuation of the original sound intensity level above the threshold of audibility is due to the multiple reflection of the source. Here, if source of sound is cut off then it is called reverberation and the time up to which this sound is sustained is called the time of reverberation.

The time of reverberation depends on various factors like material of the absorber, area of the absorbing material, volume of the building (like lecture hall, auditorium) etc.

Here, for the evaluation of reverberation time, Sabine gave a law as

$$T = 0.171\,\frac{V}{A} = 0.171\,\frac{V}{as}$$ (SI unit), called Sabine's law.

where, V = volume of the hall

and, $A = as$

where, a = absorption coeff.

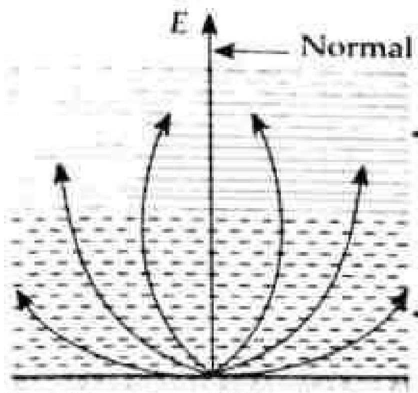
s = area of the absorbing material.

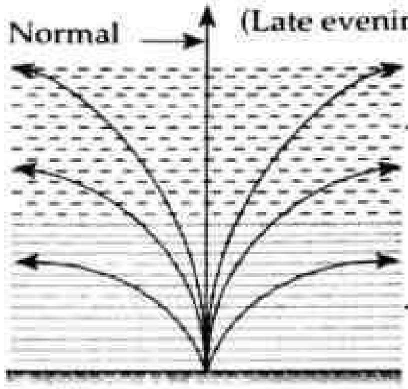
Thus, time of reverberation can be balanced (accommodated) by increasing or decreasing the area of the absorbing material. To sustain the reverberation in the lecture hall or auditorium the walls are made rough or they are covered by porous screens through which some sound is absorbed and original sound becomes clearly (distinctively) audible. The carpet of the floor is also utilised as sound absorber. Due to the reflection of sound *thunder in the cloud* appears.

The fitness of lecture halls, cinema houses, auditorium etc. for music, speech, concerts etc. depends largely on their design and construction. If the construction is such that there is uniformity in rendering of speeches, music, concerts etc. then these are said to be acoustically good, but if not they are said to be acoustically bad. There are two chief parameters echos and reverberation for the bad acoustics of the buildings.

(ii) Refraction of Sound : When a sound wave moves from one mechanical (elastic) medium to another mechanical (elastic) medium, the wave is refracted or transmitted. This phenomenon is called refraction and the refracted wave is deviated from the original path of the incident wave. The main reason for occurrence of refraction in sound is different speeds of sound in different medium at different temperatures.

The best example of refraction of sound or a natural consequence of acoustic (sound) refraction is the appearance of temperature gradient (variation of temperature due to variation of depth in different medium) near the surface of the earth. It is frequently observed that human voices are more clearly heard at dusk (in the late evening) than during day time. In the day time, the temperature of air is maximum near the ground surface and it diminishes upwards. Thus, the speed of sound is the largest near the surface of the earth ($v \propto \sqrt{T}$) and decreases upwards. So a ray of sound diverging upwards from a source on (or near) the earth's surface is refracted continuously towards the normal and hence less sound reaches the observer. At dusk the situation is just the opposite. Now, a ray diverging upwards from a source on (or near) the surface of the earth is refracted continuously away from the normal. Now, it is totally reflected when it begins to travel downwards with a continuous refraction to reach the observer towards vertically.





(iii) Free Vibration : When a body, which is capable of vibrating is displaced from its position of rest and then is left to vibrate itself, it will vibrate with its own time period or frequency. Such vibrations of the body are called its free vibrations, provided it is free from all type of resisting force, external or internal. Example - the prong of a tuning fork, the stretched string of a sonometer etc. are vibrations capable bodies. When these bodies are disturbed from their position of rest they vibrate and these vibrations are said to be free vibrations, and these are not resisted by frictional forces such as air resistance, viscosity or any other frictional forces etc.

Though vibrations of such bodies are free from the external forces namely air resistance, they are not free from internal frictional forces namely viscous force. In the course of vibrations, the different layers of the prong move relatively to one another and due to this relative motion between the layers a force comes into play which tries to diminish the relative motion. This force is called viscous force or internal frictional force. In practice vibrations of a body are resisted by some kind of frictional force and hence resisted vibrations are the natural vibrations. The frequency of free vibrations of a body is called its natural frequency.

(iv) Forced vibrations : Resonance : If a body can vibrate freely then due to resisting forces the natural frequency of the body starts to decay and thus an external periodic force is needed. A tussle starts between the frequency of the external force and the natural frequency of the body and ultimately the frequency of the external periodic force predominates and through this frequency the body vibrates which is called forced vibration.

But a unique situation arises when the frequency of the external periodic force becomes equal to the natural frequency of body of the free vibration. This is called *resonance*. Thus at resonance natural frequency of the body is equal to the frequency of the external periodic force.

Example : An 1939 Takoma bridge of USA was destroyed due to a mechanical resonance. The fast moving air confined to the outer surface across of the bridge had the same frequency as that of natural frequency of the bridge, consequently the phenomenon of resonance occurred. When military men move across any bridge in troops, then under precautionary measure the condition of resonance is said be avoided by walking troops in such a way that their feet do not fall in the same order.

A transistor (radio) is also tuned (switched on) by means of resonance. The frequency or wavelength of a particular radio station is made adjustable and a particular frequency is tuned by the same frequency on the antena.

(v) Superposition of waves : From a physical point of view it is necessary that when two or more than two waves meet in a medium a resultant wave must be formed. The basic necessity is called superposition principle of waves. The principle states that the resultant displacement due to a number of waves at any point in a medium is the vector sum of the displacements produced by the component waves. If $\vec{y}_1, \vec{y}_2, \vec{y}_3, ...$ be the instantaneous displacements produced by the component waves at a given point (place), then the resultant displacement (wave) at the same point by the superposition principle will be given by

$$\vec{y} = \vec{y}_1 + \vec{y}_2 + \vec{y}_3 + ...$$

In sound (acoustic) interference, beats and stationary waves are the direct outcome of this principle.

(a) Interference in Sound : Interference is the phenomenon of sustained cancellation or reinforcement of two waves, when they meet under certain specific conditions. When the effect of one wave is constantly neutralised by the other, the two waves are said to interfere destructively (destructive interference) and when their effects are reinforced they are said to interfere constructively (constructive interference). As usual Interference is a basic characteristic of the wave.

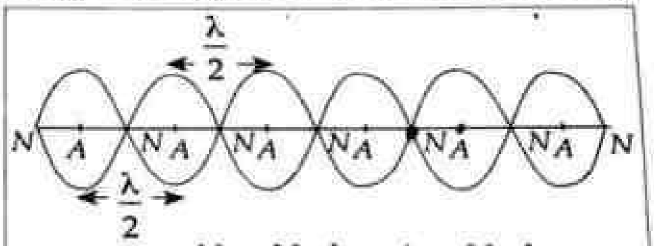
In sound when two sound waves trains meet at a point of a medium under certain suitable conditions stated below, then these two either interfere destructively producing a permanent *silence* or interfere constructively producing a permanent *anti-silence*.

Although total energy is conserved in the interference, here sound energy is transferred from the regions of *silence* to the regions of *anti-silence*.

(b) Beats : When two sound waves of the same amplitude but slightly different frequencies (not more than 16 Hz) travel along the same line, the loudness of the resultant sound wave formed by their superposition, fluctuates (varies) periodically and alternately which gives rise to a peak value with a waxing noise and then fading out with a waning noise. This phenomenon of waxing and waning in the loudness of the resultant wave is known as *beats*. Thus, the beats are formed due to the superposition of waves. Interferences and beats both occur due to the superposition of waves and these are concerned with the variation of the intensity of the wave. Interference is the phenomenon of sustained destruction or reinforcement of two identical waves and there is a spatial distribution of silence (destructive interference) and *anti-silence* (constructive interference) but in beats *silence* and anti-silence occur periodically at the same place, so it is also called *interference in time*. In producing interference the two interfering waves must be essentially coherent (having constant phase) but in producing beats any two sources can be taken.

(c) Stationary waves (standing waves)

When two identical progressive waves (waves having the same amplitude and frequency) travelling in the opposite directions meet along the same line with the same velocity, then the result of the superposition of such waves in the formation of a system of waves which alternately appear and disappear in the region where the two waves meet without advancing in either direction is called stationary (standing) waves.



N — Node, A — Node

In the formation of a stationary wave, the space confined has two types of points. The first is Node where no displacement takes place and another is Anti-node where maximum displacement occurs. The distance between two consecutive Nodes or Anti-nodes is $\frac{\lambda}{2}$; where λ is the wavelength of the waves undergoing for superposition.

(vi) Diffraction of sound : When sound waves originate by a vibrating source they spread in the medium and if the medium is homogeneous and isotropic (have uniform density), then these waves have spherical wave-fronts from the point source. Far from the source the wavefronts are nearly planes and the shape of the wavefront is changed when the wave meets an obstacle or an opening in its path. This leads to bending of the wave around the edges. Such bending of waves from an obstacle or an opening is called diffraction.

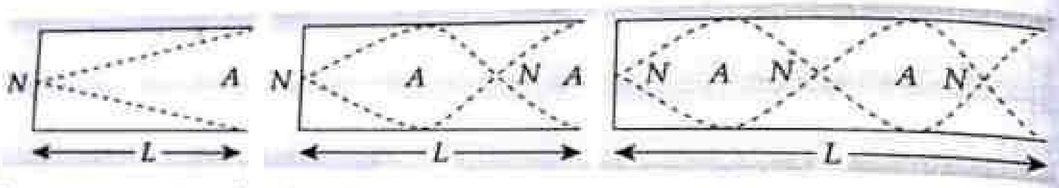
Diffraction is a characteristic property of the wave and all kinds of waves undergo diffraction. The effect of diffraction is appreciable when the dimensions of the obstacles are comparable or smaller than the wavelength of the wave. If the obstacle is large compared to the wavelength, the diffraction effect is almost negligible.

Example : The wavelength of the sound wave is approx. 1 meter and of the same order as the doors and windows of our houses. That's why sound wave is diffracted broadly and one person easily hears the voice of the another.

(vii) Vibration of air columns and organ pipes : Just as a string is used as a source of sound in various musical instruments, the vibration of air is used as source of sound in so many musical instruments like in chlorinet, sahnai, bansuri, organ pipe etc. A tuning fork is used as an exciter of vibrations in air and simultaneously performs two works— firstly it throws the air particles inside the pipe (open or closed) due to which forced vibrations are produced in the form disturbances which appear as a progressive wave and then a produced reflected wave is produced which interferes and forms a stationary wave.

It is observed that when a pulse of compressions through the tuning fork is incident on the closed end of a closed pipe, then the reflected wave appears as a pulse of compressions and similarly a pulse of rarefactions appears as a pulse of rarefactions. But in the open pipe a pulse of compressions is reflected as a pulse of rarefactions and vice-versa. Thus, in an open pipe compressions and rarefactions change into each other. Thus incident wave and reflected wave change their phase by π.

Closed organ pipe



In an organ pipe the closed end is essentially a *Node* and the open end is *Anti node*. The fundamental mode of vibration occurs when there is a Node at the closed end and an Anti node at the open end. As in the formation of a stationary wave, the distance between two adjacent Nodes or Anti nodes is $\frac{\lambda}{2}$. Thus, the distance between a Node and an Anti node $= \frac{\lambda}{4}$. $\Rightarrow L = \frac{\lambda}{4}$

The frequency of the fundamental mode is also called *first harmonic*.

$\because \quad n_1 = \frac{v}{\lambda} = \frac{v}{4L}$ = fundamental frequency. $\quad \left(\because L = \frac{\lambda}{4} \Rightarrow \lambda = 4L\right)$

But $v = \sqrt{\frac{E}{d}}$ where; E = Bulk modulus

d = density of the air.

$\Rightarrow n_1 = \frac{1}{4L}\sqrt{\frac{E}{d}}$ where; L = length of the pipe

Similarly, for the second mode of vibration, the frequency is called second harmonic or third overtone.

Here, $v = n_2 \lambda$ i.e. $n_2 = \frac{v}{\lambda}$ $\quad \left(\because L = \frac{\lambda}{2} + \frac{\lambda}{4} = \frac{3\lambda}{4}\right)$

$\Rightarrow \quad n_2 = \frac{3}{4L}\sqrt{\frac{E}{d}} = 3n_1$

Similarly, for the third mode of vibration; $v = n_3 \lambda$ ie., $n_3 = \frac{v}{\lambda}$

$\Rightarrow \quad n_3 = \frac{1}{\lambda}\sqrt{\frac{E}{d}} = \frac{5}{4L}\sqrt{\frac{E}{d}} \quad \left(\because L = \frac{\lambda}{2} + \frac{\lambda}{2} + \frac{\lambda}{4} = \frac{5\lambda}{4}\right)$

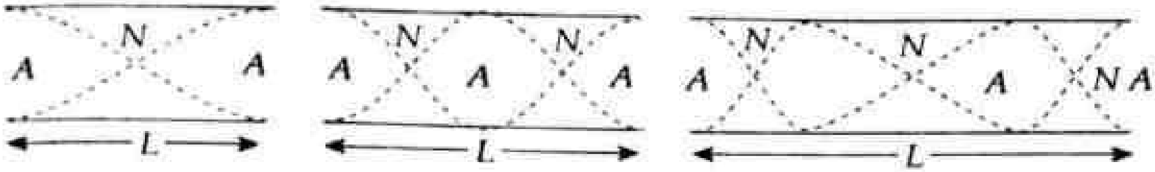
$\Rightarrow \quad n_3 = \frac{5}{4L}\sqrt{\frac{E}{d}} = 5n_1.$

Here, frequency is called third harmonic or fifth overtones.

Thus, $n_1 : n_2 : n_3 : ....$

$= 1 : 3 : 5 : ....$ Thus, possible tones of a closed pipe have frequencies in the ratio of odd integers. Notes emitted by the air column in a closed pipe have only alternate overtones and hence poor harmonics.

Open organ pipe



When the air column is contained in an open pipe, the two ends are essentially Anti nodes and then it is said to be in the fundamental mode of vibration of the air column.

Obviously, $L = \frac{\lambda}{2}$, and $v = n_1\lambda$

$\Rightarrow \quad n_1 = \frac{v}{2L} = \frac{1}{2}\sqrt{\frac{E}{d}} \qquad \left(\because v = \sqrt{\frac{E}{d}}\right)$

This is the fundamental frequency or first harmonic. Similarly frequency of second mode or second harmonic or first overtone

$= n_2 = 2\frac{v}{2L} = 2\frac{1}{2L}\sqrt{\frac{E}{d}} = 2n_1.$

and frequency of third mode or third harmonic or second overtone

$= n_3 = 3\frac{v}{2L} = 3\frac{1}{2L}\sqrt{\frac{E}{d}} = 3n_1.$

Thus, $n_1 : n_2 : n_3 : .... = 1 : 2 : 3 : ....$

Thereby it can be concluded that the possible tones of an open pipe have frequencies in the ratio of natural numbers. The note emitted by the air column in an open pipe will have the full series of overtones and hence it is very rich in harmonics. That's why the quality of a note emitted by an open pipe is always better and sweeter than that of a closed pipe.

6. Doppler's effect in sound

When there is a relative motion between an observer and a source, then the pitch of the note emitted by the source appears to be changed to the observer. This apparent change in pitch due to a relative motion between the observer and the source and also sometimes due to motion of the medium is called Doppler's effect in sound (acoustical Doppler's effect).

Actually Doppler firstly observed this effect in light waves. Thus, the optical Doppler's effect in fact firstly propounded the spectral lines of certain stars which were found to be shifted towards the red or violet end of the spectrum from their normal position by a very small distance. For the red and violet end stars recede from the earth and approach to the earth respectively. Doppler's effect is also a basic characteristic of the wave and it is to be found in all types of wave.

The acoustical (sound) Doppler's effect can be observed from a railway platform when a whistling locomotive engine passes the platform at a very high speed. Before passing the platform the pitch of the whistling appears higher and after passing the platform, its pitch appears lower

The formula derived for Doppler's effect in sound is—

Apparent pitch or frequency (n')

$$= \frac{\text{relative velocity of the observer with respect to velocity of sound}}{\text{relative velocity of the source with respect to velocity of sound}} \times \text{Actual pitch or frequency}$$

Thus, $n' = \dfrac{v \pm v_o}{v \pm v_s} \times n$

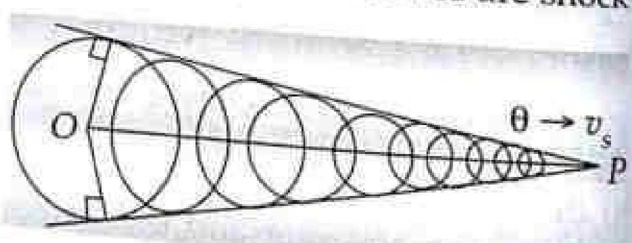
where, n' = apparent pitch or frequency.
n = actual pitch or frequency.
v = velocity of sound.
v_o = velocity of the observer.
v_s = velocity of the source.

Sonic booms, Shock waves and Mach-number :

When the velocity of a source exceeds the phase velocity of a sound wave, then Doppler's effect fails and it has no meaning. There are many instances in which, source moves through a medium at a velocity greater than the velocity of sound. A jet plane, a ballistic missile moves through the air at a velocity greater than the velocity of sound. In such cases the wavefront takes the shape of a cone with moving object at its apex. The Jet plane or the supersonic plane sends a cracking sound called *sonic boom* which can crack glass dishes, window panes and even damage buildings. The wave originated due to sonic boom is called *shock wave*. The spherical wavefront intersect over the surface of the cone with the apex at the source. Because of constructive interference of a large number of waves arriving at the same instant on the surface of the cone, pressure waves of very large amplitude are sent with a conical wave front. Such waves are shock waves.

Here, we can write $\sin\theta = \dfrac{v}{v_s}$

where, v = velocity of sound
v_s = velocity of source.



In aerodynamics, this ratio $\left(\dfrac{v}{v_s}\right)$ is called *Mach-Number*.

If Mach-Number $\left(\dfrac{v}{v_s}\right) > 1$, the velocity of the source like jet plane (supersonic plane) is called *Supersonic*.

If Mach-Number $\left(\dfrac{v}{v_s}\right) > 5$, then the velocity of the source is called *Hypersonic*.

III. Thermal Physics (Heat & Thermodynamics)

1. Heat & Temperature

The degree of hotness or coldness of a body is called its temperature and thus temperature is an indicator of the thermal stage of the body. Due to different temperatures of two bodies thermal energy transfers from the body having higher temperature to the body of lower temperature and at a particular temperature the process of energy transfer stops and now both bodies are said to be in *thermal equilibrium*. This thermal energy due to which the existence of the temperature in the body appears is called *heat*. In other words, heat is a type of energy by which mechanical work can be done. This was firstly detected by Rumford. Later, Davy confirmed this fact after rubbing two pieces of ice on melting. As no source of heat is available in the melting of the two pieces thus frictional forces came into existence due to the rubbing, which produce heat energy and consequently the two ice pieces melt. Later by Joule's experiment it was observed that heat is a form of energy by which various works can be performed. Joule also asserted that heat and mechanical work are inter-transferable to each other and the ratio of mechanical work and heat energy by which work is done is a fixed ratio called mechanical equivalent of heat and basically it is a conversion unit. If a mechanical work W is produced by an amount of heat H then

$J = W/H$ or $W = JH$, where; J = mechanical equivalent of heat.

= 4186 Joule / kilo cal.

= 4.186 Joule / cal.

= 4.186×10^7 erg / cal.

This implies that if work of 4.186 Joule is done then 1 kilo cal. heat would be produced.

Effect of heat :

(a) Physical changes : By the application of heat or thermal energy the physical structure of a body like its shape-size, volume, temperature and its state changes.

(i) Change in Temperature : Ordinarily temperature of a body increases with increase in heat or on supplying thermal energy to it.

(ii) Change in Volume : Ordinarily with increase in heat or thermal energy the volume of the body increases.

(iii) Change of state : Usually there are three states of matter— solid, liquid and gas and these states exist due to the difference of temperature thereby due to heat. Thus, change of state takes place due to heat.

(iv) Others changes: On heating a body its shape, size, electrical resistance, the ability to dissolve solute in the solvent etc. change drastically.

(b) Chemical changes : On heating a substance some changes occur permanently. One can observe free oxygen released on heating potassium chlorate with mangnese dioxide.

Units of Heat : The SI unit of heat is Joule and in C.G.S. its unit is calorie.

Calorie : The amount of heat required to raise the temperature of 1 g water by 1°C is called calorie.

International calorie : The amount of heat required to raise the temperature of 1 g water by 1°C (from 14.5°C to 15.5°C) is called International calorie.

British Thermal Unit (B.Th. U.) : The amount of heat required to raise the temperature of 1 pound water by 1°F is called 1 B.Th.U.

Relation among different units :

1 B.Th.U. = 252 cal.	1 Joule = 0.24 cal.
1 cal. = 4.186 Joule	1 kilo cal. = 4.186×10^3 Joule = 1000 cal.

Thermometry : The branch of thermal physics in which temperature is measured by various devices like thermometers, thermocouple, total radiation pyrometer etc is called thermometry.

All thermometers operate on the single principle by use of the substance whose volume expansion is directly dependent on the temperature. The thermometers are of various types which are fabricated and designed for the different means and purposes.

Thermometers are of many types—Liquid thermometer (based on the expansion of volume of the liquid by increase in temperature.), Gas thermometer (expansion in volume of the gas with increase in temperature), platinum resistance thermometer etc.

Liquid thermometer : In liquid thermometers mercury or alcohol is mainly used. Alcohol is used in those liquid thermometers which measure the temperature of below – 40°C. The freezing point of alcohol is – 115°C so alcohol thermometer doesn't work below-115°C. The freezing and boiling points of the mercury are – 39°C and 357°C respectively. Thus, mercury thermometer is fabricated and designed to remain operational from 30°C to 350°C.

Clinical thermometer : To measure the temperature of the human body a suitable thermometer has been fabricated and designed on Fahrenheit scale and it is called clinical thermometer. Since the temperature of the human body varies in very short span, thus in clinical thermometers lower fixed point is kept at 95°F (35°C) and upper fixed point at 110°F (43°C).

Gas thermometer : Constant volume hydrogen gas thermometer is a standard gas thermometer from which every other gaseous thermometers are fabricated. The temperature upto 500°C can be measured through it and if hydrogen is replaced by nitrogen then temperature up to 1500°C can be measured.

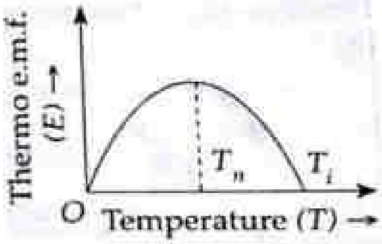
Platinum resistance thermometer : This thermometer is constructed on the basis that the resistance of a metal increases quite uniformly with the rise of temperature. The great advantage of this thermometer is that it measures very wide temperature ranges from – 200°C to 1200°C. The value of the temperature measured by platinum thermometer is so consistent, precise and accurate that this thermometer can be used to standardise the other thermometers.

The platinum resistance thermometer has a large thermal capacity and the protecting tube has low thermal conductivity so this thermometer doesn't attain the temperature of the bath quickly in which it is immersed.

Thus, this thermometer has an excessive time lag. Further, some time is also lost in balancing the bridge. That's why this thermometer is not suitable for measuring rapidly varying temperatures.

Thermo-couple : This is a special type of temperature measuring device in which two junctions are constructed by different metals— one junction is hot and another is cold and due to thermoelectric effect temperature is measured and this effect is called Seebek's effect.

In 1923 Seebek discovered that when two dissimilar metals are joined to form a closed circuit and a difference of temperature is established between their junctions, an e.m.f. is developed and hence an electric current flows through the circuit. The e.m.f. so produced is called thermoelectric e.m.f. and the phenomenon is called Seebek effect. Such an arrangement of connecting two dissimilar metals together is called a thermo-couple. The magnitude of thermo-electric e.m.f. depends upon the nature of two metals and on the temperature difference of their junctions.



At a particular temperature of hot junction thermo-e.m.f. becomes maximum. This temperature of the junction (at which e.m.f. in thermo-couple is maximum) is called *neutral temperature* T_n for the thermo-couple.

Neutral temperature is constant for a given pair of metals forming the thermo-couple. If the temperature of hot junction is raised further, the thermo e.m.f. decreases and becomes zero at a particular temperature which is called *temperature* of *inversion* T_i. Beyond inversion temperature T_i, thermo e.m.f. again increases but in reverse direction. Temperature of inversion is too much above than neutral temperature as the temperature of cold junction is below to it. Thus, inversion temperature is not constant for a given thermo-couple, but depends on the temperature of cold junction. Here, a relation between neutral temperature and inversion temperature is given by,

$$T_i - T_n = T_n - T_c \Rightarrow T_n = \frac{T_i + T_c}{2}$$

where, T_i = temperature of inversion.

T_n = neutral temperature.

T_c = temperature of cold junction.

Thermo e.m.f. in the circuit varies with temperature of hot junction is graphically obtained which is a parabolic curve given by a relation $E = AT + BT^2$ (a parabola). Here, cold junction is kept at 0°C, while A, B are constant and t is the temperature of hot junction.

Total radiation pyrometer : This is also a temperature measuring device through which the temperature of bodies like stars, sun etc. (which have very high order temperatures) are measured which are far away from us. Thus, radiation pyrometer is a device through which by the estimation of radiation without touching the bodies, temperatures are measured. Total radiation pyrometer operates on the principle of Stefan's law and according to which heat radiation emitted per second per unit area is proportional to the fourth power of the absolute temperature. The body having temperature less than 800°C doesn't emit a suitable (detective) radiation and that's why through the total radiation pyrometer the temperature of only those bodies are measured which have a temperature of more than 800°C.

Various scales of temperature measurement : In the construction of thermometers two fixed points are selected on various scales in which there is a maximum point called Upper Fixed Point (U.F.P.) and there is a minimum point called Lower Fixed Point (L.F.P.). There are various scales like Celsius (or centrigrade), Fahreneit, Reaumur, Kelvin and Rankin.

Generally; the freezing point of ice is taken as L.F.P. and the boiling point of pure water at 76 cm of Hg is taken as U.F.P. The difference between the U.F.P and L.F.P. is called Fundamental difference or Interval (F.I.)

Scale	L.F.P.	U.F.P.	F.I.
Celcius	0° C	100° C	100
Fahrenheit	32° F	212° F	180
Reaumur	0° R	80° R	80
Kelvin	273 K	373 K	100
Rankin	492 R_n	972 R_n	180

For any thermometer;

$$\frac{\text{Reading} - \text{L.F.P.}}{\text{U.F.P.} - \text{L.F.P.}} = \text{a constant}$$

Thus, $$\frac{C-0}{100-0} = \frac{F-32}{212-32} = \frac{R-0}{80-0} = \frac{K-273}{373-273} = \frac{R_n - 492}{672-492}$$

or, $$\frac{C}{100} = \frac{F-32}{180} = \frac{R}{80} = \frac{K-273}{100} = \frac{R_n - 492}{180}$$

Absolute zero : Theoretically there is no limit of maximum temperature but there is a limit or restriction on the minimum temperature. The lowermost temperature is – 273.15°C and it is called *absolute temperature.*

On Kelvin scale absolute temperature is expressed as 0 K and it is the required temperature on which molecular motion of the body is ceased.

Thus, 0 K = – 273.15°C ⇒ 273.15 K = 0°C

⇒ 0°C = 273.15K.

K = (273.15 + °C)

It is a convention in Physics (which is strictly followed) that the temperature of the kelvin scale is never represented in degree.

Some temperature on various scales :

Temperature	**Celsius (°C)**	**Fahrenheit (°F)**	**Kelvin (K)**
Freezing of water	0°C	32°F	273 K
Normal temperature of the room	27°C	80.6°F	300 K
Normal temperature of the human body	37°C	98.6°F	310 K
Boiling point of water	100°C	212°F	373 K

2. Thermal expansion of solids, liquids and gases

Ordinarily the volume of a substance increases with the supply of heat (thermal energy) resulting from the increase of intermolecular distances in the substance. But there are some exceptions also for instance, in water volume contracts on increasing its temperature from 0°C to 4°C. Similarly in Silver Iodide (AgI) volume contracts on increasing the temperature if it has temperature between 80°C to 140°C. On supplying heat expansion occurs in all solids, liquids and gases, but gases expand more than liquids and liquids expand more than solids.

Expansion of solids : Usually if any solid body is heated, it expands in length, breadth and thickness and if the expansion, in length is only substantial then it is called linear expansion but if both length and breadth expand substantially it is called superficial expansion and ultimately if the length, breadth and thickness all expand, then it is called volume expansion (cubical expansion).

Coefficient of linear expansion—It is defined as increase in per degree celsius temperature with unit length of the body and it is represented by α.

Thus, coefficient of linear expansion

$$= \frac{\text{increase in length}}{\text{original length} \times \text{increase in temp.}} \quad \Rightarrow \alpha = \frac{\Delta L}{L \times \Delta\theta}$$

Coefficient of linear expansion is represented by α and its unit is per degree celsius.

Coefficient of superficial expansion : It is defined as increase in per degree celsius temperature with increase in unit area of the body and it is represented by β.

Thus, coefficient of superficial expansion

$$= \frac{\text{increase in area}}{\text{original area} \times \text{increase in temp.}} \quad \Rightarrow \beta = \frac{\Delta s}{s \times \Delta\theta}$$

Coefficient of cubical expansion—It is defined as increase in per degree celsius temperature with increase in unit volume of the body and it is represented by γ.

Thus, coefficient of cubical expansion

$$= \frac{\text{increase in volume}}{\text{original volume} \times \text{increase in temp.}} \quad \Rightarrow \gamma = \frac{\Delta V}{V \times \Delta\theta}$$

Here, it is observed that $\beta = 2\alpha$ and $\gamma = 3\alpha$

Thus, $\alpha : \beta : \gamma = 1 : 2 : 3$

Application related to expansion of solids :

(i) Railway tracks are constructed from iron and steel and these are made adjustable to sustain tremendeous load and the thermal expansion. That's why some free space is left at the joints of two such tracks.

(ii) If we pour or keep hot water inside a thick glass (jar) then the inside surface of the jar suffers thermal expansion while outer surface of the jar remains unaffected due to its thickness that's why glass jars crack.

Today good quality glass jars are constructed through pyrex glass whose thermal expansion is negligible and jars can be protected from cracking.

(iii) As time period of a pendulum clock is given by $T = 2\pi\sqrt{\frac{l}{g}}$, from its time period obviously depends on the length of the pendulum. In summer the length of a pendulum increases, so its time period increases and consequently the pendulum clock slows down. But in winter the length of the pendulum contracts so the time period decreases and pendulum clock oscillates fast. Today pendulum clocks are constructed through those metallic bodies which have negligible thermal expansion and contraction.

Expansion of liquids : As there is no shape of liquids like solids, liquids are always kept in a container (vessel). So linear expansion and superficial expansions in liquids have no relevancy and significance. So cubical expansion (volume expansion) in the liquids has only the appropriate meaning. As soon as heat (thermal energy) is supplied the liquid starts to expand but along with it, its container (vessel) also starts to expand. Actually up to what extent liquid originally expands it doesn't perceive and its expansion is slightly less than the original because some thermal energy is used up in expanding the container.

This shows that there are two types of thermal expansions one is apparent and the other is real. Thereby coefficient of apparent volume expansion (γ_a)

$$= \frac{\text{apparent increase in volume}}{\text{original volume} \times \text{change in temp.}}$$

and coeff. of real volume expansion (γ_r)

$$= \frac{\text{real increase in volume}}{\text{original volume} \times \text{change in temp.}}$$

Thus, if γ_g be the coeff. of volume expansion of the glass the vessel (container) then, γ_r (coeff. of real volume exp.)

$= \gamma_a$ (coeff. of apparent volume exp.)

$+ \gamma_g$ (coeff. of volume expansion of glass)

The density of substance is defined as the ratio of the mass of the substance and its volume. As the volume of a substance increases on heating, its density would correspondingly decrease, its mass being constant. But this effect is negligible for solids and prevailents in liquids because change in volume in solids are very small.

Anomalous expansion in water : Ordinarily the volume of most liquids increases with supply of heat (thermal energy) while its density decreases. But the behaviour of water is just opposite. If water at 0°C is to be heated up to 4°C, its volume decreases and density increases. At 4°C the volume of water is minimum and its density is maximum but with increase in temperature water behaves like an ordinary liquid. Thus if water of 4°C is to be heated further then its volume increases and density decreases. This is called *anomalous expansion of water*. There are so many incidents of anomalous expansion of water in our aquatic life. In the winter season specially in cold regions when atmospheric temperature falls, the upper layer of the water of the lakes and ponds are frozen and consequently density increases while the lower layer of the water is comparatively warmer and this process continues until the total volume of water attains the temperature of 4°C. If the atmospheric temperature falls more sharply, the density of the outer layer of water starts to diminish due to the anomalous expansion of water. Consequently the outer layer is remained frozen at 0°C and the lower layer of the water is in liquid state of 4°C. That's why in the lower layer of the water of the lakes and ponds the fishes and others aquatic organisms live. Due to the anomalous expansion of water the water pipes in the cold regions burst (crack). Since at 0°C water freezes and on transforming it into the ice its volume increases which brusts the tanks (pipes).

Expansion of gases : Gases are the most active substances which take part in thermal expansion. On supplying heat to the gases not only their temperature increase but the pressure and volume also change under the suitable condition. Boyle's law, Charle's law etc. were derived from these conditions.

Boyle's law - pV = a constant (at constant temperature).

Charle's law - $\frac{V}{T}$ = a constant (at constant pressure).

Boyle's and Charle's law together give gas equation.

$$\frac{pV}{T} = \text{a constant, called gas constant } (R)$$
$$= 8.31 \text{ joule/mole-kelvin.}$$

Calorimetry : The branch of thermal physics in which heat is measured by the principle of heat lost and heat gained is called calorimetry and the apparatus used for the purpose is called calorimeter. The calorimeter is made of copper. The principle of calorimetry states that the total heat lost is equal to the total heat gained and this is based upon energy conservation principle.

The heat lost or gained by a body depends on the mass of the body and on the rise or fall in its temperature.

Thus; $\Delta Q = ms\Delta\theta$.

where; s is a constant called specific heat capacity of the body

m = mass, $\Delta\theta$ = rise or fall in temperature.

Specific heat capacity : This is defined as the amount of heat required to raise the temperature of 1 kg of a substance through 1 K thus

$$\Delta Q = ms\Delta\theta \qquad \Rightarrow s = \frac{\Delta Q}{m\Delta\theta}$$

If $m = 1$ kg and $\Delta\theta = 1$ kelvin then $s = \Delta Q$

S.I. unit of specific heat capacity is $J\ kg^{-1}\ K^{-1}$ and in CGS it is cal. $gm^{-1}\ {}^{o}C^{-1}$.

Thermal capacity : It is defined as the amount of heat required to raise the temperature of a given amount of a substance through 1 kelvin, thus thermal capacity = ms Joule/kelvin or cal. $^{o}C^{-1}$.

Specific heat capacity of some important substances

Substance	Sp. heat (cal./gm°C)	Substance	Sp. heat (cal./gm°C)
Lead	0.03	Water	1
Brass	0.09	Ice	0.50
Iron	0.11	Alcohol	0.60
Carbon	0.17	Tarpin	0.42
Silica (sand)	0.20	Magnesium	0.25
Aluminium	0.21	Zinc	0.092

Specific heat capacities and Molar heat capacities of the gases

On supplying a substantial amount of thermal energy to gases the temperature of the gases increase and both volume and pressure change along with it. Thus, it can also be interpreted as the temperature variation with pressure at constant volume and the temperature variation with volume at constant pressure. That's why gases have two specific heat capacities— one at constant pressure indicated by C_p and another at constant volume indicated by C_v. Here it is also observed that specific heat at constant pressure is greater than specific heat at constant volume.

Specific heat capacity at constant pressure (C_p) : The amount of heat required to raise the temperature of 1 kg mass of a gas through 1 K at constant pressure is called specific heat capacity of the gas at constant pressure (C_p).

Specific heat capacity at constant volume (C_v) : The amount of heat required to raise the temperature of 1 kg mass of a gas through 1 k at constant volume is called specific heat capacity of the gas at constant volume (C_v).

Molar heat capacity at constant pressure (C_p) : The amount of heat required to raise the temperature of 1 mole (gm-molecule) of a gas through 1K at constant pressure is called molar heat capacity at constant pressure (C_p).

Molar heat capacity at constant volume (C_v): The amount of heat required to raise the temperature of 1 mole (gm-molecule) of a gas through 1K at constant volume is called molar heat capacity at constant volume (C_v).

Relation between C_p and C_v :

(i) C_p is greater than C_v and Mayer established a relation; $C_p - C_v = R$, called Mayer's relation.

Here R is called gas constant and its value $= 1.99 \simeq 2$ cal/mole-K

$= 8.31$ Joule/mole-K

(ii) $\frac{C_p}{C_v} = \gamma$ = ratio of specific heat capacities.

Water equivalent : This is quantity of water in kg which will require the same amount of heat to raise its temperature through 1K as it is required by the body when heated through the same temperature. Thus, its unit is gm or kg.

If m be the mass of a body in kg and s be the specific heat in SI unit, then water equivalent of the body $= W = \frac{ms}{4200}$

Obviously; water equivalent (in gm) and thermal capacity (in cal./°C) are numerically equal.

Latent heat of fusion : The latent heat of fusion of a substance is defined as the quantity of heat required to convert 1 kg of the substance from solid to liquid state without change of temperature at its melting point. It is expressed in cal/gm in CGS unit and in Joule/kg in SI unit.

Thus, $Q = mL$

where, Q = heat required

m = mass of the substance (solid)

L = Latent heat of fusion.

Latent heat of ice (latent heat of fusion of ice) = 80 cal/gm

$$= \frac{80 \times 4.2}{10^{-3}} \text{ Joule/kg.}$$

$$= 336 \times 10^3 \text{ J/kg}$$

Latent heat of vaporisation : The latent heat of vaporisation of a substance is defined as the quantity of heat required to convert 1 kg of the substance from liquid to vapour state without change of temperature at its boiling point. It is also expressed in cal/gm in CGS unit and in Joule/kg in SI unit.

Thus, $Q = mL$,

where, Q = heat required

m = mass of the substance (liquid)

L = latent heat of vaporisation

Latent heat of water (latent heat of vaporisation of water)

$$= 536 \text{ cal/gm} = \frac{536 \times 4.2}{10^{-3}} \text{ J/kg} = 2250 \times 10^3 \text{ J/kg}$$

Change of state of matter : A substance can be found only in three states of matter– solid, liquid and gas. If a certain amount of thermal energy be supplied to the solid state then at a particular temperature (melting point of the solid) it is converted into liquid and this thermal energy is latent heat of fusion and conversely if such energy be withdrawn from the liquid it would be transformed back into the solid state. Similarly the liquid is converted into the gas (vapour) at a particular temperature (boiling point of the liquid) and the thermal energy supplied is latent heat of vapourisation. Conversely by withdrawing required thermal energy, the gas could be again transformed back into the liquid state.

Steam at 100°C is hotter than water at 100°C though water is boiling. This is strange but true because boiling water has only thermal energy whereas steam has thermal energy plus latent heat of vaporisation. Because of this steam is more painful than boiling water.

Most metals are found to be in solid state but mercury (*Hg*) exceptionally is the only metal found in liquid state.

Melting point of a solid : A constant temperature at which a solid is transformed into liquid by the supplied heat energy of latent heat of fusion is called its melting point (m.p).

Effect of pressure : When a solid melts, there may be an increase or decrease in volume with the application of pressure. The melting point of certain solids like wax and sulphur increases with increase in pressure, while the melting point of certain solids like ice, gallium and bismuth decreases with increase in pressure. Thus, ice will melt at a temperature lower than 0°C when the pressure is higher than that of the normal pressure.

Effect of Impurity : Normally the m.p. of solid decreases more sharply on mixing impurity. Example- If some salts or perfumes are added to ice of 0°C then its melting point decreases upto - 22°C.

Freezing point : At a fixed temperature the transformation of a liquid into the solid by lowering the temperature or withdrawing the thermal energy (latent heat of fusion) is called freezing point. The freezing point coincides with the melting point of the solid.

Boiling point of a liquid : A constant temperature at which a liquid is transformed into gas (vapour) by the supplied heat energy of latent heat of vaporisation is called boiling point (b.p).

Effect of pressure : When a liquid boils i.e. changes from liquid to gas there is an increase in its volume. Thus the boiling point of a liquid rises with increase in pressure and vice-versa. Thus a liquid will boil at lower temperature under reduced pressure. Hence; water will boil at a temperature lower than 100°C when the pressure applied is less than normal pressure.

Effect of Impurity : On mixing the impurity boiling point of the liquid increases.

Condensation point : At a constant temperature the transformation of vapour into the liquid is called condensation point and usually the condensation point and boiling point of the liquid coincides.

Difference between vapour and gas : If the liquid boils at a particular temperature (b.p) then after a few seconds latter latent heat of vaporisation generates the vapour. But a few seconds latter vapour increases its temperature which is called critical temperature (T_c) above which vapour is called gas.

3. Transmission of heat

Due to substantial temperature difference the heat is transferred from one place to another in a substance then it is called transmission of heat. There are three processes (modes) of the transmission of heat—

(i) Conduction (ii) Convection and (iii) Radiation.

(i) Conduction : By the process of conduction heat is transferred from one place to another by the particles vibrations of the substance but these particles do not leave their occupied position. In fact when a substance is being heated then the molecules (particles) start to vibrate rapidly (vigorously) and this kinetic energy of vibration of the particles is transferred which appears as heat energy and it is called the phenomena of thermal conduction. In solid, heat is transmitted by the process of thermal conduction only but this process is not relevant and significant in liquid and gas. The process of transmission of heat in the substance is called thermal conductivity. The rate of thermal (heat) energy transmitted through the substance (conductor) depends on various parameters like area of cross section, temperature difference between the faces of the substance and the thickness of the substance and it is given as— the rate of thermal energy transmitted $= \left(\frac{Q}{t}\right) = \frac{k A \Delta\theta}{\Delta l}$

where k is a proportionality constant called coefficient of thermal conductivity whose value is different for different substance (conductor) and depends on its material.

A = area of cross-section

$\Delta\theta$ = difference in temperature

Δl = thickness

Δt = change in time

Also here, $\frac{\Delta\theta}{\Delta l}$ is called temperature gradient

On the basis of thermal conductivity the substances are classified in the following types—

(a) Good conductor : The substances through which heat is transmitted very easily and conveniently are called good conductors or conductors. Most of the metallic solids are good conductors.

Examples : Metals, acidic water, human body etc. are good conductors.

(b) Bad Conductor : The substances through which heat is not transmitted easily and conveniently and a little amount of heat transfers are called bad conductors. Examples– Wood, fiber, glass, rubber, air etc. are bad conductors.

(c) Thermal Insulator : The substances through which heat is not transmitted by any means (methods) are called thermal insulators. In fact bad conductors are sometimes synonymously used as thermal insulators. Thus, we can say bad conductors are good insulators. In garments and cloths air is trapped which provides a good insulating characteristic.

Examples— Abonite, asbestos etc are insulators.

(ii) Convection : In the process of convection heat is transmitted in the substance by transfer of molecules (particles) of the substance and thus a current due to the molecules transfer is generated which is called convectional current.

In liquid and gas heat is transmitted by the process of convection and as molecules of solid are not free to move, so heat cannot be transmitted in solid by the process of convection. Whenever a liquid or a gas is heated, the molecules (particles) of these substances become lightened and move upwards and then cooler molecules settle downwards and heated. Now a convectional current is formed and heat is transmitted throughout in the liquid or gas. The atmosphere of our earth is heated by the process of convection.

(iii) Radiation: In the process of radiation there is no need of any medium for the transmission of heat, while in conduction and convection a medium is necessarily needed. In fact thermal radiation is an electromagnetic wave which can transmit even in vacuum. Thus we can say that in the process of radiation thermal energy transmits anywhere without interfering with and heating the medium through which it passes. We obtain heat (thermal energy) from the sun by the process of radiation on the earth's surface. Thus, thermal radiations (simply radiation) are the electromagnetic waves which on being absorbed by the certain bodies manifest themselves as heated. But there are also other electromagnetic waves that stimulate the sensation of vision and these are called luminous radiations, while those producing chemical changes are called actinic radiations.

Difference between thermal radiation and light radiation : Thermal radiation (heat radiation) and light radiation (optical radiation) both have the same form of radiant energy and the difference between them is a difference of frequency or wavelength, but not of kind.

Sources of thermal radiations : Any hot body maintained at a constant temperature may serve as a source of thermal radiations. The earliest source of thermal radiations suitable for simple experiments on radiation is a leslie cube which is simply a hollow cube of metal blackened on one side with lamp-soot. When the boiling water is poured into it, radiations are emitted from blackened surface. But now at present two special devices have been designed by Fery and Wien's black bodies which are usually used as the source of thermal radiations. The ideas of these radiations came from the concept of black body and the theoretical fact is that the quality of radiations inside a uniformly heated enclosure is exactly the same as that of black body radiations (radiations from a hot black body).

Black body : A perfectly black body is one which absorbs completely all the radiations of whatever wavelength incident upon it. Since it neither reflects nor transmits any radiation, it appears black whatever the colour of the incident radiation may be. If a black body is placed inside a uniform temperature enclosure, it will absorb the full radiation of the enclosure. The quantity and quality of the radiation inside a uniform temperature enclosure is not affected by the presence of any body inside it, the black body will emit the full radiation of the enclosure on attaining equilibrium temperature with it. Thus, the radiation emitted by a black body is also the full radiation consisting of all possible wavelength.

But there is no surface available in practice which will absorb all the radiation falling upon it. Even the lamp-blacked surface which is assumed to be a perfectly black body and which absorbs practically all the visible and infra-red radiations, reflect the far infra-red radiation.

Emissive power and Absorptive power : The emissive power of a body at a given temperature and for a given wavelength is defined as the radiant energy emitted per second per unit surface area of the body per unit wavelength range. It is symbolically represented by e_{λ}.

The absorptive power of a body at a given temperature and for a given wavelength is defined as the ratio of the radiant energy absorbed per second by the surface of the body to the total energy falling per second on the same area. It is symbolically represented by a_λ.

Kirchhoff's law : It states that the ratio of emissive power to absorptive power for a radiation of a given wavelength is the same for all the bodies at the same temperature and it is equal to the emissive power of a perfectly black body at that temperature.

Thus $\dfrac{\text{emissive power of any body } (e_\lambda)}{\text{absorptive power of that body } (a_\lambda)}$

= emissive power of black body at the same temperature (E_λ).

This law also concludes that if a body absorbs radiation of a particular wavelength strongly, it also emits the same radiations strongly. Thus, the alternate statement of Kirchhoff's law is *good absorbers are good emitters.*

Red glass appears red because from the thermal radiation incidents upon it red colour is totally reflected and other colours are absorbed. If the red colour from the white light is withdrawn, then this would seem to appear green. That's why when a red glass is heated for a long time, it appears green and conversely on heating a green glass it appears red.

Stefan's law : It states that the total radiant energy (E) emitted per second from unit surface area of a black body is proportional to the fourth power of its absolute temperature (T)

Thus, $\boxed{E \propto T^4}$ $\Rightarrow E = \sigma T^4$, Here, σ is called Stefan's constant.

Boltzmann established this law theoretically from a thermodynamical consideration and hence an extended form of Stefan's law is called Stefan Boltzmann's law which is stated as below—

If a black body at an absolute temperature T is surrounded by another black body at an absolute temperature T_o, then it will lose an amount of energy σT^4 per sec per unit area and will gain an amount of energy σT_o^4 per sec per unit area from the surroundings. Hence the net loss of energy per sec per unit area of the body will be $E = \sigma(T^4 - T_o^4)$ which is called Stefan–Boltzmann's law.

Newton's law of cooling : It states that the rate of loss of heat energy of any hot body by the process of thermal radiation is proportional to the difference between the mean temperature and the surroundings.

Thus the rate of heat energy lost $\left(\dfrac{Q}{t}\right) = k\left(\dfrac{\theta_1 + \theta_2}{2} - \theta_0\right)$

where, k = a proportionality constant

θ_1, θ_2 = two temperatures of small time interval.

θ_0 = temperature of the surrounding.

t = time

It is observed that if a hot body loses its heat energy in such a way that its temperature falls from 70°C to 60°C in particular time t min, then it will take more than t min. in the temperature falling from 60°C to 50°C. By the process of radiation the heat energy lost not only depends upon the temperature difference of the body and the surroundings, but also on the nature of the surface of the body and its surface area.

For a small temperature difference of the body and surroundings Newton's law of cooling becomes just an approximation of Stefan-Boltzmann's law of radiation.

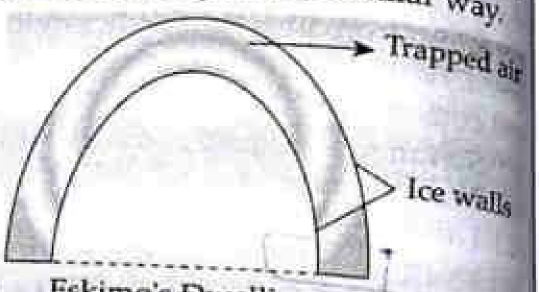
Utilities and Applications of transmission of heat in our daily life

(A) Utilities and Applications of conduction

(i) When we touch a piece of iron and wood placed in the same room, we feel iron to be colder than the wood. The reason behind it is good conduction of heat by the iron in comparison to the piece of the wood.

Our body temperature (normally 37°C) is generally greater than that of the room. When we touch an iron piece, heat is rapidly conducted from the hand (hotter body) to the iron but wood being a bad conductor conducts very little amount of heat. So we lose more heat by touching iron than wood. That's why an iron piece appears colder. But when both are kept in the open sky under the sun, then on touching the iron piece it appears hotter than the wooden piece. This can also be explained exactly in the similar way.

(ii) Eskimos live in the houses of double walls of ice as shown in the figure. Such houses keep people warmer and comfortable because air molecules are being trapped between the ice walls of the house which is bad conductor of heat.



Eskimo's Dwelling

(iii) To drink tea in a metallic cup is painful than to drink tea in a ceramic or fiber cup. The simple reason behind it is that heat from the tea goes into the metallic cup which becomes hot and ones lips have painful and bitter experience due to good conduction of heat. But due to bad conduction of heat, in ceramic or fiber cup heat doesn't travel from tea to the cups and does not warm.

(B) Utilities and Applications of convection

(i) Ventilation : The ventilation of a room is the process of expulsion of warm and impure air and induction of cold and fresh air into the room. For proper ventilation an outlet is necessary near the top of the room and an inlet near the bottom of the room. The hot and impure air being lighter escapes from the top outlet and fresh air enters into the room through the inlet at the bottom of the room.

(ii) Chimney : Smoke issuing from chimneys is a common phenomenon and in a chimney the process of convection occurs. Hot air and smoke being lighter move up through the chimney while the cold and heavier air is continuously drawn inside the bottom. Thus, a convectional current is set up. In the tall chimney the difference in the density of air between the top and the bottom is large. Narrow chimneys are being preferable to wide ones because they can prevent downward currents of air more effectively.

(iii) Winds and breezes : Trade winds, land breeze and sea breeze are natural consequences of convection. The equatorial belt of the earth is hotter than other regions. Air of this belt thus becomes lighter and rises up. Cold air from North and South rushes to take up the place of the hot air. Due to the rotation of the earth from West to East, this natural air current actually flows from the North-East direction in the northern hemisphere and from South-West direction in the southern hemisphere. These are called trade winds.

Land is a better absorber of heat and has a higher thermometric conductivity than water. Consequently land attains a higher temperature during the day time in comparison to the water. Air over land becomes lighter and rises up. Cold air from seas, oceans or lakes rushes to the land. This is called sea-breeze.

As a body which is a good absorber of heat is also a good radiator of heat, so in night the temperature over land goes on falling down much earlier than that over the water. Air over water being hotter rises up and cold air from land flows into the sea. This is called land breeze.

(iv) To fillup inert gases inside the electric bulbs : To avoid the burning of the filaments of the electric bulbs which are made of tungsten (high atomic wt. and high m.p.) the bulb is evacuated (creation of vacuum). Also to avoid the melting of filaments in the bulb some inert gases like argon or krypton are filled up and thus thermal radiations generated by filaments form a convectional current inside the bulb and a tremendous quantity of thermal energy produced doesn't melt the filament.

(C) Utilities and applications of radiation

(i) Cloudy night of winter is warmer than that of night of free and clear sky : In the night of free and clear sky the thermal energy (thermal radiation) produced from the earth's surface goes upwards uninterruptedly into the space through the sky. But during cloudy nights these radiations do not go into the space as the cloud is a bad conductor of heat which prevents these radiations get reflected back and our surrounding becomes warmer.

(ii) In desert area day is too hot and night is too cold : Since sand (silica) is a good absorber of thermal radiations and by Kirchhoff's law a good absorber of heat is also a good emitter (radiator). During the day the sand absorbs the thermal radiations from the sun and so day becomes too hot but at night all such radiations are emitted thus night becomes too cold.

(iii) Outer layers of a tea container (jar) are made bright : The bright layer neither permits inner thermal energy to go out nor absorbs or accepts outer thermal energy (radiation). It simply reflects and thus the container remains hot a longer time.

Prevost's theory of heat exchange : The most basic and fundamental concept about the radiation process was propounded by Prevost at Geneva in 1792. Before this theory it was assumed that there are two types of radiations – hot and cold. Cold bodies emit cold radiations and hot bodies emit hot radiations. A block of ice was supposed to emit cold radiations, because it produces a sensation of coldness and a red hot iron ball was supposed to emit hot radiations, as it produces the sensation of warmness. If this is a fact then there must be a basis to define hot and cold bodies. But we have no such basis of thinking and no scientific background. The correct explanation was given by Prevost.

Prevost asserted that all bodies, irrespective of their temperature, emit only one type of radiation and temperature is the only core factor regarding its rate of emission. At low temperature, the total emission (radiation of all wavelengths) is poor and at high temperature the emission of radiation is very high. The rise or fall of temperature, which is observed in a body is due to its exchange of radiant energy with surrounding bodies, which goes on uninterrupted in equal amount even after the attainment of thermal equilibrium. This is called Prevost's theory of heat exchange. When we stand near a fire, we have the sensation of warmness, because our body which is also a radiator receives more energy from the fire than what it loses through radiation. But when we stand near a block of ice, we feel a sensation of coldness because our body emits more radiant energy than what it receives from the ice.

By the devices pyrometers and bolometers the thermal radiations were detected earlier but at present thermopiles are the appropriate devices operated on the basis of variation of temperature with resistance of platinum wires. Thus, the temperature of the sun, stars etc. can be measured by pyrometers and bolometers.

4. Kinetic theory of gases

The theoretical analysis of the behaviour of gases was first explained by J. Bernoulli in 1738. Later, Maxwell, Boltzmann and Clausius consensusly and comprehensively gave the theory of the nature, character and behaviour of gases and propounded various models and consequently a theory was concluded which is called kinetic theory of gases. The following assumptions (postulates) were given as below—

(i) Each and every particle of gases has identical mass and volume and these particles are called molecules.

(ii) The molecules of the gas are in random motion and they obey Newton's laws of motion. The molecules move in all directions with all possible velocities from zero to infinity and collide constantly with each other. Collision also takes place on the walls of the container. Though the molecules are constantly having their velocities changed in magnitude and direction due to mutual collisions, yet a particular temperature and its over-all distribution in volume element remains unaffected.

(iii) The volume of the molecules is negligibly small in comparison to the volume occupied by the gas.

(iv) The collisions are perfectly elastic and are of negligible duration. The collisions of the molecules occur to each other and with the walls of the container in which both momentum and kinetic energy remain constant. The time of the collision is negligible in comparison to the time spent in traversing the paths between two collisions.

(v) The gas exerts pressure on the walls of the container. This pressure arises due to collisions of the molecules with the walls. As a molecule collides, it suffers a change in momentum. The rate of change of momentum is equal the force exerted on the wall (Newton's Second law of motion). Since a ge number of molecules collide frequently, they exert a steady force given by the average rate of change of momentum. This force measured per unit area of the wall is called the 'pressure' of the gas.

The pressure exerted by the gaseous molecules on the walls of the container $= p = \frac{1}{3} \rho \overline{C}^2$

where ρ = density of the gas

$\overline{C}^2$ = mean-square speed.

5. Thermodynamics

Thermodynamics is that branch of Physics in which we are mainly concerned about the transformation of heat into mechanical work. With the advancement of time thermodynamics covers all the branches of Physics as well as Chemistry and we deal now today a relationship between the heat and energy associated with any form of energy like-electrical, mechanical, chemical etc. Thus, thermodynamics is an emprical or experimental science and the laws of thermodynamics have been developed by means of observation and experiments since long.

Thermodynamic system : A thermodynamic system is one which may interacts with its surroundings in at least two distinct ways and one of these is necessarily a transfer of heat in or out of the system. The other may be some other means of transfer of energy, say by performance of mechanical work by or on the system or through electromagnetic interaction such as magnetisation.

Example: A gas contained in a cylinder, a vapour in contact with its liquid, a stretched wire, tyre containing air etc. are examples of thermodynamical system.

Thermal equilibrium : A thermodynamic system is said to be in thermal equilibrium if all parts of it are at the same temperature and this temperature is the same as that of the surroundings.

Zeroth law of thermodynamics : If two independent thermodynamical systems are in thermal equilibrium with a third thermodynamical system, then they must be in thermal equilibrium to each other. This is called Zeroth law of thermodynamics and it becomes a base for the definition of temperature. All these systems can be said to possess a characteristic to remain in thermal equilibrium and this characteristic is called temperature. Thus, we can define the temperature of a system as the property by virtue of which we determine whether the system is in thermal equilibrium or not with other neighbouring systems.

Mechanical equilibrium : For a system (thermodynamical) to be in mechanical equilibrium, there must be no unbalanced forces between different parts of the system or between the system and the surroundings.

Chemical equilibrium : For a system to be in chemical equilibrium, the composition of the system must remain fixed (constant) and system must have a definite physical configuration.

Thermodynamical equilibrium : If a thermodynamical system is in thermal equilibrium, mechanical equilibrium and chemical equilibrium then the system is said to be in thermodynamical equilibrium. In the condition of thermodynamical equilibrium no change occurs in the state of system or in the surroundings.

Thermodynamical definition of Ideal gas (perfect gas) : An ideal gas (perfect gas) is one whose internal energy is entirely kinetic and depends on its temperature only and it is independent of its volume. This definition has been concluded from Joule's experiments which simply showed that there is no intermolecular attractions among the gaseous molecules. Thus, total internal energy is entirely kinetic and it depends upon the temperature only.

Thermodynamical definition of real gas : A real gas has intermolecular attractions among gaseous molecules and thus the internal energy is both potential and kinetic. Thermodynamically real gas is called Vanderwaal's gas whose nature, character and behaviour are determined by Vanderwaal's gas equation $(p + a/v^2)(v - b) = RT$, where a, b are called Vanderwaal's constants.

First law of thermodynamics : The first law of thermodynamics is simply the law of conservation of energy applied to the thermodynamical system. According to this law if a substantial amount of thermal energy is supplied to a thermodynamical system, then it is partially used in changing its internal energy (temperature dependent) and partially used in doing external work.

If dQ is the thermal energy supplied and dU and dW are change in internal energy and external work done respectively, then according to the First law of thermodynamics.

$$dQ = dU + dW.$$

All are expressed in same unit and it is called differential form of the First law of thermodynamics.

In thermal physics practically all mechanical works can be transformed into thermal energy (heat energy) but its converse is not true. The First Law of thermodynamics simply explains it, as equivalency of both mechanical work and quantity of heat being extracted mutually and nothing else.

Second law of thermodynamics : To extract a certain quantity of heat from a body and to convert it completely into work is permitted by the First law of thermodynamics. But in actual practice it is found to be impossible. If this was possible, we could drive ships across an ocean by extracting heat from the water of the ocean. Thus the First law simply tells that if a process takes place, energy will remain conserved. It doesn't tell us whether the process is possible or not. Similarly, if a hot body and a cold body are brought in contact, the First law is not violated whether the heat flows from hot to cold or cold to hot. But experience has shown that heat never flows from cold to hot body.

The Second law of thermodynamics explains the possibility of the thermodynamical process, its direction and its relevancy. In this regard two important statements are given :

Kelvin-Planck's statement : It is impossible to construct a device which operates in a cycle that will take heat from a body and convert it completely into the work without leaving any change anywhere.

Clausius's statement : It is impossible to construct a self acting device which operates in a cycle that will transfer heat from a cold body to a hot body without expenditure of work by an external energy source or without any aid of external agency. In other words heat cannot flow spontaneously from a colder to a hotter body.

Third law of thermodynamics : The entropy of any system at absolute zero (lowermost temperature) is a universal constant, which may be taken to be zero. This is called Third law of thermodynamics or *Nernst heat theorem.*

Here two important consequences of this law are :

(i) Specific heat capacities of a system vanish at absolute zero.

(ii) Coefficient of volume expansion of any substance vanishes at absolute zero.

An alternate statement of third law of thermodynamics is the unattainability of absolute zero. A fundamental feature of all cooling processes is that if the temperature achieved is lower, it is difficult to go still lower. Thus, Third law of thermodynamic can also be stated as it is impossible to reduce any system to the absolute zero by a finite number of operations by any procedure, no matter how the system is idealised.

Entropy : If a substance takes or gives up an amount of heat Q in a reversible process at constant temperature T, then $\frac{Q}{T}$ is called an increase or a decrease in the entropy of the substance. Thus change in entropy is denoted by $\Delta S = \frac{Q}{T}$. Obviously its SI unit is Joule/kelvin and its C.G.S. unit is Cal/kelvin. But the Second law of thermodynamics imposes the restriction in which only those processes are possible for a system in which entropy of the system plus surroundings always increases. Thus, on account of the processes occurring in nature the entropy of the universe is continuously increasing. That's why entropy doesn't obey the law of conservation.

Our every day experience tells us that chaos (disorder) must probably exist in nature as usual while the orderness is the least probable. Thus, in all natural processes there is a tendency to proceed towards a state of great disorder. As entropy of a system increases due to natural process taking place in the system, the degree of molecular disorder of the system also increases. Thus entropy of a system is a measurement of the degree of molecular disorder existing in the system. That's why we conclude that gas has more entropy than liquid and liquid has more than solid.

i.e. $(\text{gas})_{\text{entropy}} > (\text{liquid})_{\text{entropy}} > (\text{solid})_{\text{entropy}}$.

Some important thermodynamical processes

(i) Cyclic process : The thermodynamical system which operates in such a way that its initial and final conditions are the same, then it is said to be in a cyclic process.

By the First law of thermodynamics

$dQ = dU + dW = U_f - U_i + dW = dW \quad (\because U_f = U_i)$

Thus, total thermal energy would be utilised in doing mechanical work and change in internal energy would be zero.

(ii) Quasi-Static process : A process in which a system never works more than infinitesimal (very small) from the equilibrium state and it is called a quasi-static process. Thus, the quasi-static process is an ideal process which can never be exactly obtained but can be approximated under some specific circumstances.

(iii) Reversible and Irreversible process : A reversible process is one which can be reversed in such a way that all changes taking place in the direct process are exactly repeated in the reverse order (opposite sense) and no changes are left in any of the bodies taking part in the process or in the surroundings. The conditions of reversibility are never realised in practice, hence a reversible process is only an ideal conception.

Any process which is not reversible exactly is an irreversible process. All natural processes such as conduction, radiation, radioactive decay etc. are irreversible processes. Thus, irreversibility is a rule.

(iv) Isothermal and Adiabatic process : When a thermodynamic system undergoes through a process in which its temperature remains constant, then the process is said to be isothermal. The essential condition for an isothermal process is that the system must be contained in a perfectly conducting chamber and it occurs extremely slowly in which the heat produced or absorbed during the process at once goes out or comes in from outside. Hence, temperature will remain constant but as there is no perfect conductor, so isothermal process cannot be performed exactly but can only be approximated. Ideal gas equation $PV = RT$ is directly applicable for an isothermal process.

But when a thermodynamic system undergoes a process under the condition that no heat comes into or goes out of the system, then the process is said to be adiabatic. Such process can occur when the system is perfectly insulated from the surroundings. But since no perfect insulator is available, perfect adiabatic change is impossible. Thereby, an approximate adiabatic process can be obtained (achieved). It is an extremely rapid or fast process because there is a very little time for the heat to go out or to come into the system. The equation PV^{γ} = constant is directly applicable and relevant for an adiabatic process, where γ = specific heat capacities ratio of the ideal gas.

Examples : If a gas is suddenly compressed, the heat of compression is added to its internal energy and its temperature rises. That's why the bicycle pump is heated when the air in it is suddenly compressed. Similarly, if a gas is suddenly expanded, then the external work done during it against the surroundings draws energy (equivalent to the work done) from its internal energy and its temperature falls. When a motor tyre bursts, the sudden expansion of air into the atmosphere is an adiabatic process in which the tyre is cooled down. As in an adiabatic process no heat exchange takes place, so entropy also remains constant. That's why the adiabatic process is also called isentropic (constant entropy) process.

To prepare dry ice (solid CO_2) carbon dioxide is suddenly expanded and consequently it converts into ice, called dry ice.

On shaking a thermos containing tea becomes warm, because on shaking the existing viscous forces among various layers of the tea do external works and these works are transformed into thermal energy. So its internal energy increases and consequently the temperature rises.

(v) Isobaric and Isochoric process : A thermodynamic process taking place at constant pressure is called an isobaric process.

Example—The boiling of water to steam or the freezing of water to ice taking place at a constant pressure (also at constant temperature) are isobaric processes.

A thermodynamic process taking place at constant volume is called isochoric process. Obviously, in such a process the work done on or by the process is zero ($dW = 0$).

Thus, in an isochoric process, the heat added to (or taken from) the system only increases or decreases the internal energy of the system.

If an ideal gas is assumed to be a thermodynamic system, then work done by the gas or on the gas are different for different processes and which can be compared as given below;

$W_{Isobaric} > W_{Isothermal} > W_{Adiabatic} > W_{Isochoric}$ → Thermal Expansion.

$W_{Isochoric} > W_{Adiabotic} > W_{Isothermal} > W_{Isobaric}$ → Thermal Compression

Miscellaneous topics

(I) Cooling process (Mechanism)

(a) Evaporation (Vaporisation) : From the outer surface of any liquid at any temperature slowly and steadily the transformation of liquid into vapour is called *evaporation*. In the process of evaporation (vaporisation) the heat energy is supplied by the inner molecules of the liquid and when a sufficient heat energy is acquired by the molecules of outer surface then these molecules start to detach from the liquid. Thus, vapour is formed and along with themselves molecules have lower heat energy and ultimately temperature falls. Thus evaporation is a process of obtaining the cooling from the liquid. The evaporation depends on various factors like amount of vapour present in atmosphere, the area of the liquid surface, the temperature of the liquid etc. If the water vapour present in the atmosphere is large then the rate of evaporation is least and vice-versa. That's why in summer wet clothes are dehydrated soon and made dry in short interval of time, while in rainy season the process of drying takes a longer time. In summer, surahi (water container made of ceramic) by the evaporation process lowers the temperature and water becomes cool. If the body temperature of a man/women due to suffering of a severe fever becomes extremely high then on keeping the weted cloth on his/her forehead such high temperature can be lowered down through the process of evaporation.

A room/hall or any closed space (region) cannot be cooled down by opening the door of the refrigerator but ultimately it will be warmed up. As the refrigerator removes heat from its interior and expels it into the surrounding air, it ultimately warms up the room/hall or closed space.

The refrigerator also produces cooling by the process of evaporation. In the process of refrigeration the liquid freon is filled up in the vapoured coil of copper and by the process of evaporation cooling is achieved.

(b) Adiabatic Demagnetisation : At present by the mechanical process the lowest temperature is obtained by the method of adiabatic demagnetisation. When a paramagnetic substance is magnetised, its molecules are set in the direction of the magnetising field. The necessary work done in this process is added to the internal energy of the substance which suffers a rise in temperature. If the substance is allowed to cool and then demagnetised under an adiabatic condition, the molecules return to their original random distribution and there is a corresponding fall in temperature. This effect is too much pronounced at a very low temperature.

Giauque and McDougall used gadolinium sulphate (a paramagnetic salt) and a magnetic field of 8000 Gauss in order to obtain the temperature of $0.25\ K$.

(c) Joule-Thomson (Joule-kelvin) effect : Joule and Thomson experimentally observed that when a gas under constant pressure is forced through an insulated porous plug (compressed porous material like cotton-wool or silk fibres) to a region of lower constant pressure, its pressure changes. This is called *Joule-Thomson effect*. All gases when pass through the porous plug, suffer a change in temperature and this temperature change is directly proportional to the pressure difference of two sides of the plug. At ordinary temperature all gases, except hydrogen and helium, suffer a fall in temperature (cooling effect), while hydrogen and helium suffer a slight rise in temperature (heating effect).

The temperature of inversion $\left(T_i = \frac{2a}{Rb}\right)$ is characteristic of the particular gas and below this temperature cooling is observed, while above it heating is observed and at the inversion temperature neither heating nor cooling takes place.

The inversion temperatures for H_2 and He are $-80°C$ and $-240°C$, hence these gases show heating effects at ordinary temperature. If the initial temperatures of H_2, He is brought below $-80°C$ and $-240°C$ these gases will also show cooling effect.

(d) Adiabatic expansion : If a compressed gas is suddenly released to the atmosphere, then it does an external work against the molecular attractions. Since the expansion is sudden and no appreciable amount of heat flows into it from the surroundings, the external work is drawn from the internal energy of the gas itself which therefore cools. Thus, in adiabatic expansion the cooling is mainly due to the external work done.

Four processes are common to achieve the cooling and the chronological order of the processes of these cooling are; adiabatic expansion, evaporation, Joule-Thomson effect and adiabatic demagnetisation in their increasing order.

i.e. $(\text{adi. demag.})_{\text{cooling}} > (\text{Joule-Thomson})_{\text{cooling}} > (\text{evaporation})_{\text{cooling}} > (\text{adi. expan})_{\text{cooling}}$

(II) (a) Humidity : The amount of water vapour present in the atmosphere is called humidity. The amount of water vapour in atmospheric air is different for different places. Generally, the amount of water vapour near the sea-level is large thus, humidity is also large. In rainy season usually humidity is found to be more.

(b) Relative humidity : The relative humidity is the ratio of the amount of water vapour in the air of a given volume at a particular temperature to the required water vapour in air to saturate the same volume at the same temperature.

$$\text{Thus, relative humidity} = \frac{\text{The water vapour in air of any volume at any temperature}}{\text{The water vapour required of the same volume at the same temperature}}$$

The relative humidity is measured by a device called *Hygrometer.* On increasing temperature relative humidity is increased.

Saturated vapour : If at a given temperature air absorbs a definite amount of water vapour, then at this state air is said to be in the state of saturated water vapour.

(c) Air-conditioning : The climate of any place on the earth's surface is determined by various parameters like temperature, relative humidity, the wind flowing direction etc. Usually for a hygienic and comfortable climate the following conditions should be fulfilled.

(i) The temperature should lie between 23°C to 25°C.

(ii) The relative humidity should lie between 60% to 64%.

(iii) The speed of wind should lie between 0.0125 m / sec to 0.01417 m / sec.

Such climate usually doesn't exist naturally specially in the urban areas. Thus it is prepared artificially and on this principle air-conditioning operates.

IV. Light

1. Nature and Speed of Light

Light : Light is an external cause due to which any object becomes visible for human eye. For the illumination or visibility of an object light incidents upon it (up to 1/6th second). Then after reflection it comes to the eye and then the object is seen. At present light is defined in the form of an energy which transmits (propagates) as an electromagnetic wave and whose energy is confined in the form of a small packet called photon.

Dual nature of light : In early time it was believed that light consists of a stream of corpuscles, emitted by various light sources travells outward from the sources in straight lines. This was the idea of Newton's Corpuscular theory. The corpuscles directly penetrate through the transparent materials butreflectbackfromthesurfacesofopaquematerials. When they (corpuscles) enter the eye, they cause the sense of illumination.

But during the middle of 17th century the idea of light as a wave was perceived. Huygens in 1670 showed that the laws of reflection and refraction could be explained on the basis of wave theory. But it was objected that if the light exhibits the wave motion, then one should be able to expose it around the corners, as waves can bend around the obstacles in their path. It is well known that the wavelengths of light waves are so small that on the bending, which actually takes place is so small that it is not ordinarily observed. In fact, the bending of light waves around the edges of an object (a phenomenon called diffraction) was noted by Grimaldi before 1663 and interpreted by Hooke in 1665 in terms of wave picture, but its significance was not recognized at that time.

After 1827 the experiments of Young and Fresnel on the interference and the measurement of the velocity of light in liquids by Foucault demonstrated the phenomenon which could not be correctly explained by the corpuscular theory, and it could be explained only by the wave theory. Young's experiments enabled him to measure the wavelength of the waves and Fresnel showed that the rectilinear propagation of light as well as the diffraction observed by Grimaldi and others, could be explained if light is assumed to be waves of shorter wavelength.

The next forward step in the theory of light was taken by Maxwell who showed theoretically that an oscillating electrical circuit radiates electromagneticwavespropagatingwiththevelocityoflight. Approximately fifteen years later, Hertz succeeded in producing short-wavelength waves of electromagnetic origin and showed that they possessed all the properties of light waves like reflection, refraction, polarisation etc. Thus, Maxwell's electromagnetictheoryoflightwasexperimentallyverified. Butunfortunately the phenomenon of photoelectric effect (the ejection of electrons from a metallic conductor by the incident of light on its surface), Compton's effect, Raman effect etc. couldn't be explained on the basis of wave theory. Einstein explained these on the basis of Plank's quantum theory

At present the dual nature of light (both as a wave and a particle) is acceptable. The phenomenon of propagation of light may best be explained by the electromagnetic wave theory, while the interaction of light with matter in the process of emission and absorption is a corpuscular phenomenon.

Speed of light : Firstly Romer (an astronmer) obtained the value of the speed of light with the help of motion of the sattelite of the planet (Jupiter). In different media the speeds of light are different and it depends upon the refractive index of the medium. The medium which has larger refractive index has smaller speed of light.

The refractive index or index of refraction $(\mu) = \dfrac{\text{speed of light in vacuum}}{\text{speed of light in medium}}$

The speed of light is maximum in vacuum and it is 3×10^8 meter/sec. (1,86,310 mile/sec or 2, 99,776 km/sec). In any denser medium the speed of light is always smaller than that of vacuum. In air the value of the speed of light is 0.03% lesser than the value of the speed of vacuum, in water it is smaller than 25% and in glass it is lesser than 35%.

Values of the speeds of light in various media

Medium	Speed of light (m/s)	Medium	Speed of light (m/s)
Vacuum	3×10^8	Glass	2×10^8
Water	2.25×10^8	Rock salt	1.96×10^8
Oil of tarpin	2.04×10^8	Nylon	1.96×10^8

Light from the sun reaches the earth's surface in 8 minutes 19 seconds and the reflected light from the moon takes 1.28 seconds to reach the earth's surface.

Rectilinear propagation of light: In an isotropical (having same density) materialistic medium the rays of light move in straight line. This is called rectilinear propagation of light. The formation of various types of shadows, the formation of image through a pin hole camera, occurrence of solar and lunar eclipses etc. are the examples of rectilinear propagation of light.

Miscellaneous

(i) Firstly Newton asserted that light is made of micro particles or corpuscules and it moves in a straight line. Newton also speculated that white light is made of all the seven colours.

(ii) Huygens propounded the wave theory of light. Which asserted that light can be displayed in the form of waves.

(iii) Young propounded the theory of Interference of light. Young's experiment was the base of the verification and confirmation of wave theory for the physicists.

(iv) Maxwell propounded the theory of electromagnetism in 1864. According to Maxwell the oscillating electric and magnetic fields generate an electromagnetic wave perpendicular to each other and its direction of propagation is perpendicular to each electric and magnetic field. This theory was verified by Hertz and later on commercial level too much work was done by Marconi in this regard.

(v) Max. Planck in 1900 gave the famous quantum theory by the help of an equation $E = h\nu$, where h is called Planck's constant and ν is the frequency of emitted photon. He also explained that the energy in the electromagnetic wave is quantized and appears descretly in the form of packet called quantum and this energy is confined in the form of a pocket called photon. This concept became the origin of Quantum mechanics later.

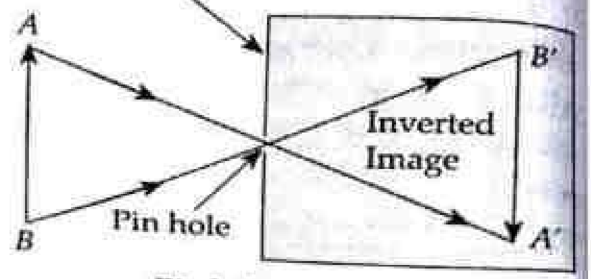
(vi) Einstein on the basis of a comperhensive observation and speculation in 1905 declared that the light is quantized and the energy is divided into a small group called quanta and the corpuscule of the light is called photon.

Sources of light: The sun, stars and other celestial bodies in our universe are the natural sources of light. In stellar or solar system, hydrogen atoms regularly transform themselves into helium and tremendous amount of solar energy or stellar energy is produced.

Apart of such energy is received by our earth's surface. The sun is supplying 4×10^{26} Joule energy per second and according to Einstein's mass energy equivalent relation ($E = mc^2$), the rate of mass decay is 4×10^9 kg/sec. It is predicted that our sun will supply its energy upto approxmately one thousand crores years. There are some artificial sources of light like electric bulbs, matches, candles etc.

Shadow : When an opaque body (body through which light rays are obstructed on passing) is placed in the front of a source of light, then behind the opaque body a black or dark region appears which is called shadow. The formation of shadows depends on the types of source of light. If the source of light is a point source, then the shadow formed is called umbra while for an extended source of light is called *penumbra*.

Pin hole camera : In it a rectangular wooden box whose inner walls are painted black and a pointed hole is made in the front wall of the box and rear wall has a cover of rubbed glass or a piece of oily paper are taken. Whenever an object is kept in front of a camera then an inverted image is formed near the rear wall of the box. If more than one pointed hole is made in the front wall, then a number of inverted images are formed which are equal to the number of holes.



Pin hole camera

This also proves the rectilinear propagation of light. The size of image depends on the distance between the pointed hole and screen and the distance between the object and the pointed hole. If on behalf of the screen the photographic plate is taken, a distinct and decent (perfect) image is formed.

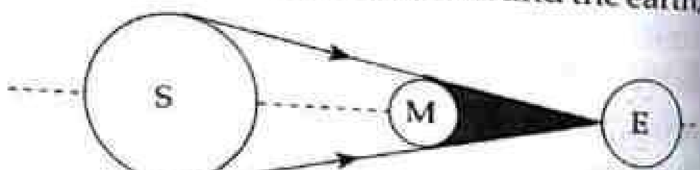
$$\text{Here, magnification} = \frac{\text{Height of the object}}{\text{Height of the image}}$$

$$= \frac{\text{Image distance from the hole}}{\text{Object distance from the hole}}$$

Obviously, for a substantial magnification the object distance from the pointed hole should be small.

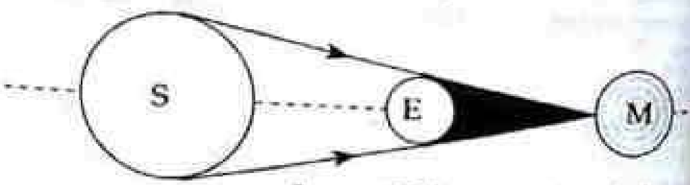
Eclipse :

(A) Solar Eclipse : When the moon comes between the sun and the earth, then the shadow of the moon falls upon the earth and from the shadow region the sun is not visible and this position is called *solar eclipse*. This eclipse may be full or partial. Full solar eclipse occurs on the day of *full moon*.



Solar Eclipse

(B) Lunar Eclipse : When the earth comes between the sun and the moon, then the shadow of the earth falls on



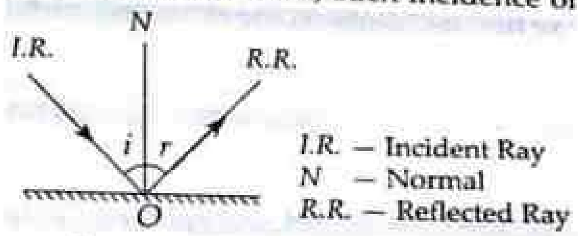
Lunar Eclipse

the moon then the shadow region of the moon is not visible and this position is called *lunar eclipse*. This eclipse may also be full or partial. Full lunar eclipse occurs on the day of *new moon*.

Eclipses are not visible and do not occur each and every month because the equatorial orbit of the earth makes an angle of 5° to 7° from the axial axis of the moon.

2. Reflection of light

When a light ray incidents on a smooth and polished surface, then it undergoes (comes) back almost in a different direction, such incidence of light ray is called reflection of light. A plane mirror is assumed to be the best reflector. The straight line perpendicular to the reflected surface is called normal. The angle between incident ray and normal is called angle of incidence and between the normal and reflected ray is called angle of reflection.



There are two laws of reflection—

(i) Incident ray, normal and reflected ray all lie in the same plane.

(ii) Angle of incidence and angle of reflection both are equal. Thus $i = r$

Plane mirror : One surface of the mirror is plane and another surface has a sharp metallic polish which is pasted. This is done to avoid the polish decay. The backside of the mirror with silver or mercury layers (metallic polish) works as reflector surface. The object and image both are located at equal distance. In a plane mirror the formed image is always imaginary and it is equal to the size of the object laterally inverted.

Some more facts related to plane mirrors

(i) If a body having a speed v moves forward with this speed then its image through a plane mirror appears to be moving with speed $2v$.

(ii) For showing the full image of an object, the size of the plane mirror should be at least half of the object.

(iii) If the incident ray is kept constant and the plane mirror is rotated by an angle θ, then the reflected ray is rotated by angle 2θ.

(iv) If two plane mirrors are inclined to each other at an angle θ, then total number of images formed between the two mirrors $= \frac{360^\circ}{\theta^\circ} - 1$.

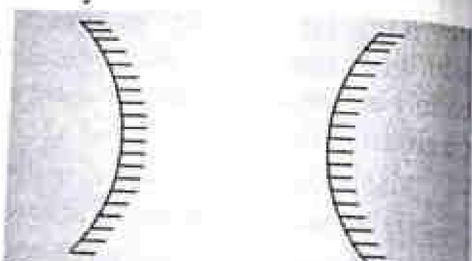
Thus, if two plane mirrors are inclined at right angle to each other then three images will be formed between them. Similarly, between two parallel plane mirrors infinite images would be formed.

Utilities : The plane mirror is utilised in the form of kaleidoscope, periscope, looking glass etc.

(i) Kaleidoscope : In it three rectangular plane mirrors of equal length and equal breadth are attached to each other in such a way that the angle between two mirrors is of 60°. The reflecting surfaces of all these mirrors are inwardly confined and in the space confined by the mirrors, the pieces of the colour glasses are kept. These three mirrors are kept inside a thick long pipe. The spherical piece of glass is attached to the first end of the pipe and at another end the piece of rubbed glass is attached. When we look inside the pipe through the transparent glass end, then on rotating the pipe new colour images are seen. These images are of the pieces of the colour glasses, which have been formed due to the multiple reflections of the plane mirrors. On moving the pipe location of the pieces of the colour glasses and the colour of images are changed.

(ii) Periscope : In it two plane mirrors are attached to each other at 45° in such a way that the reflecting surfaces are oppositely directed. Light ray first incidents on the reflecting surface of the first (upward) mirror and the reflected beam now incidents upon the second (downward) mirror so that after reflection it enters the eye. That's why during war time the arms uses periscope to detect the enemies who are hidden in bunkers. Also in submarines periscopes are frequently used today.

Spherical mirror : In spherical plane the constructed mirror is called spherical mirror in which one side of the mirror has a layer of mercury or coating of lead oxide. A thin layer is painted and pasted to one side and another side is used as a reflecting surface.

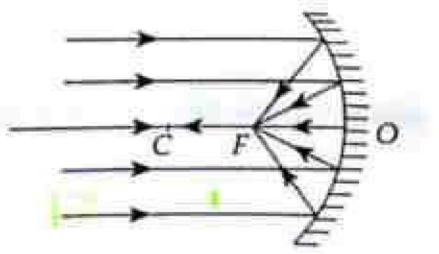


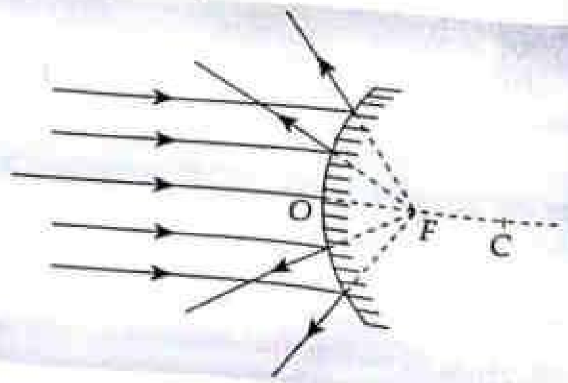
Concave mirror   Convex mirror

The spherical mirror is of two types—

(i) Concave mirror : The spherical mirror whose reflecting surface is inwardly leaned is called concave mirror. It is also called converging mirror because it converges the coming rays from infinity.

(ii) Convex mirror : The spherical mirror whose reflecting surface is outwardly leaned is called convex mirror. It is also called diverging mirror because it diverges the rays coming from infinity.





As both concave and convex mirrors are constructed through the same spherical glass.The centre of the glass sphere is called centre of curvature (C) and the middle point (O) of the spherical mirror is called pole. The line passing through the centre of curvature and pole is called principal axis. The middle point of the straight line drawn from the pole to the radius of curvature is called focus (F).

Thus focal distance $(f) = \frac{\text{radius of curvature}}{2}$

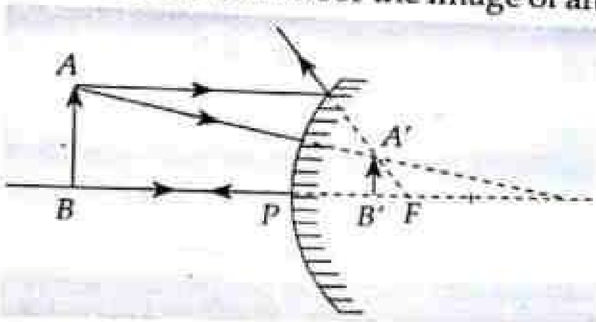
The focal distance (f) of concave and convex mirrors is evaluated by the following formula

$$\frac{1}{v}+\frac{1}{u}=\frac{1}{f}$$ where u = Object distance
v = Image distance
f = Focal length of the mirror.

Magnification : The ratio of image distance to object distance or the ratio of the length of image to the length of the object is called magnification of the mirror and is represented by m.

$$\text{Thus magnification } (m) = \frac{\text{Length of Image}}{\text{Length of object}} = \frac{\text{Image distance } (v)}{\text{Object distance } (u)}$$

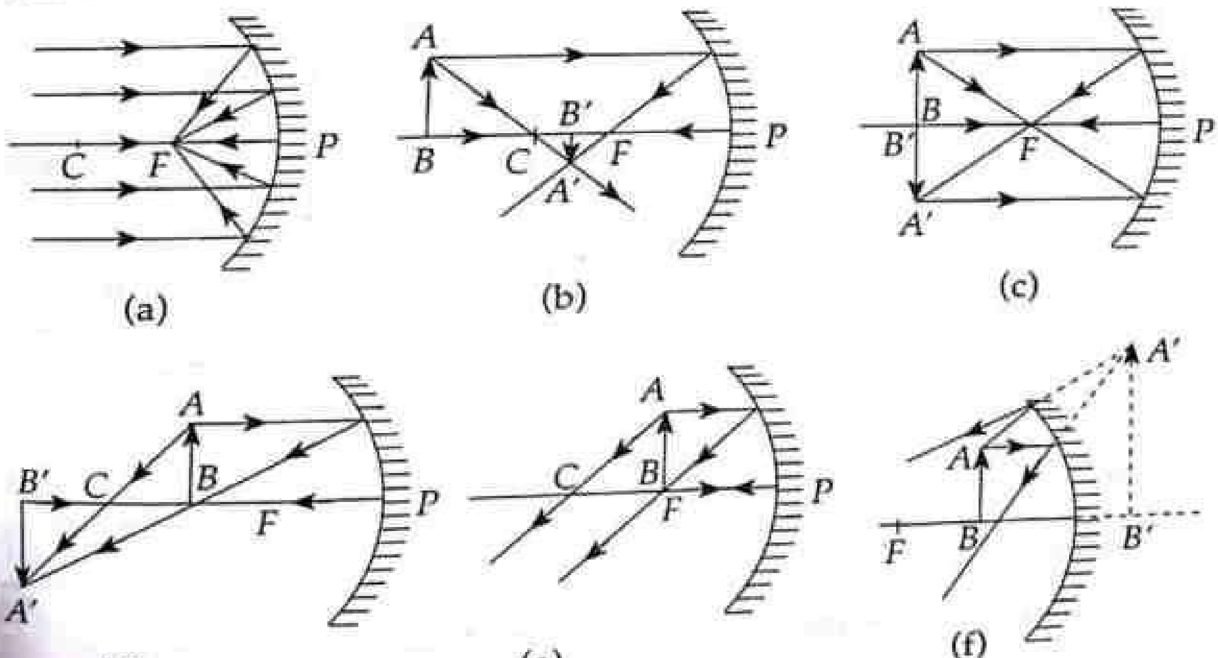
The image formed by convex mirror : In convex mirror the image of an object is formed behind the mirror between the pole and the focus and the image formed is smaller than the object and it is erect and virtual.



If the position of the object is changed and if it shifts from the pole, then the virtual erect image becomes smaller and shifts towards the focus.

Use : Since convex mirror is diverging in nature, so the objects of a large region are being diverged into a smaller region. That's why the convex mirror has a vast field-view and so these mirrors are utilised in motor cars, trucks etc. as a rear view mirror. Due to large field view these are utilised in the reflecting lamps installed near the roads and streets.

The images formed by concave mirror : The position of the object may vary according to our choice and so the images which are real and inverted can be formed at various locations tabulated as given below.

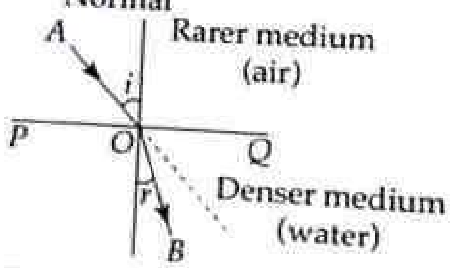


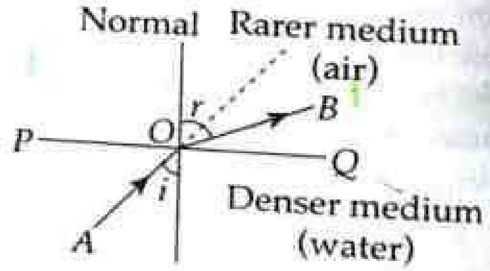
(a) (b) (c) (d) (e) (f)

Position of object	Position of image	Size of image with comparison to object	Nature of image
(a) At infinity (∞)	At focus	Very small	real and inverted
(b) Between centre of curvature and infinity	Between focus and centre of curvature	Small	real and inverted
(c) At centre of curvature	At centre of curvature	Equal in length	real and inverted
(d) Between focus and centre of curvature	Between centre of curvature and infinity	Large	real and inverted
(e) At focus	At infinity (∞)	Very large	real and inverted
(f) Between pole and focus	Behind the mirror	Large	virtual and erected

3. Refraction of light

When a light ray passes from one transparent medium to another transparent medium perpendicularly at any point on a line dividing both the mediums, then the ray passes directly without any deviation. But if they incident inclinedely then they deviate from the original path and this phenomenon of light is called refraction of light.





If a light ray enters from a rarer medium to a denser medium (say, air to water) then this ray leans towards the normal drawn on the dividing line of both the mediums, but in the reverse case it escapes far away from the normal. Also if a ray passes from any medium to any other medium parallel to the normal, then it also passes directly without any deviation.

Laws of refraction :

(i) Incident ray, Normal and Refracted ray all lie in the same plane.

(ii) For any two mediums the ratio of sine of the angle of incidence and sine of the angle of refraction is constant and it is called refractive index of second medium with respect to first and this statement is also called *Snell's law*.

Thus $\frac{\sin i}{\sin r} = \mu$ or ${}_1\mu_2$.

Now, if ${}_1\mu_2 = \frac{\sin i}{\sin r}$, ${}_2\mu_3 = \frac{\sin r}{\sin r'}$ and ${}_3\mu_1 = \frac{\sin r'}{\sin i}$

where; 1 → 1st medium, 2 → 2nd medium, 3 → 3rd medium then ${}_1\mu_2 \cdot {}_2\mu_3 \cdot {}_3\mu_1 = \frac{\sin i}{\sin r} \cdot \frac{\sin r}{\sin r'} \cdot \frac{\sin r'}{\sin i} = 1$, similarly; ${}_a\mu_w \cdot {}_w\mu_g \cdot {}_g\mu_a = 1$

Where 1 → air (a), 2 → water (w), 3 → glass (g)

If refraction takes place from vacuum or air to any medium then the above ratio of sine of angle of incidence and sine of angle of refraction is called absolute refractive index or simply index of refraction. This is Snell's law.

Thus, absolute refractive index $(\mu) = \frac{\sin i}{\sin r}$

It is also observed optically that the ratio of velocity of light in vacuum to velocity of light in any medium is equal to the absolute refractive index of the medium.

Thus; $\mu_0 = \frac{\text{velocity of light in vacuum } (c_0)}{\text{velocity of light in medium } (c_m)}$ i.e., $\mu_0 = \frac{c_0}{c_m}$

The refractive index of different colours (different wavelengths) of the light are different. On increasing wavelength refractive index decreases. That's why the red colour of visible light has the least value of refractive index and the voilet colour has the largest value of refractive index, as the red colour has longer wavelength and the violet colour has shorter wavelength. Also with rise in temperature index of refraction slightly decreases.

Some interesting incidents related to refraction of light :

(i) Twinkling of stars at night : Atmospheric air has various layers of different densities. Whenever light rays coming from stars incident on air surface (layer) then refract from various layers because air layers are not static. Thus we observe that stars are twinkling due to their various positions in different time intervals.

(ii) The coin kept at the bottom of a container having water seems upwardly uplifted : Whenever a coin is kept inside a water container, then the phenomenon of refraction takes place and the coin kept in the container seems upwardly uplifted.

(iii) A fish inside water seems uplifted from its original position.

(iv) A straight rod partially sunk inside water seems to be bent.

(v) Whenever the sun is below the horizon then before sunrise and after sunset the region around the sun appears red due to refraction.

4. Total Internal Reflection of light

When any light ray enters from an optically denser medium to an optically rarer medium then due to refraction the light ray bends away from the normal. But as well as the values of angles of incidence are increased, the light bending from the normal becomes more and more away. Thus, the value of angle of refraction is in increasing order. But for a definite angle of incidence the angle of refraction becames 90° and here the angle of incidence is called critical angle.

Thus index of refraction $(\mu) = \frac{1}{\sin C}$

$\Rightarrow \sin C = \frac{1}{\mu}$, where C = critical angle.

If the angle of incidence is increased by more than a certain value, then the light ray doesn't refract at all. Thus the angle of incidence can not be greater than 90°. In this situation incident light ray reflects back into denser medium and this incident in geometrical optics is called *total internal reflection*. Also the region (space) where the phenomenon of total internal reflection takes place becomes extremely bright.

Thus, for the occurrence of total internal reflection two conditions are required—

(i) The light ray must enter from an optically denser to an optically rarer medium.

(ii) The angle of incidence should always be greater than critical angle.

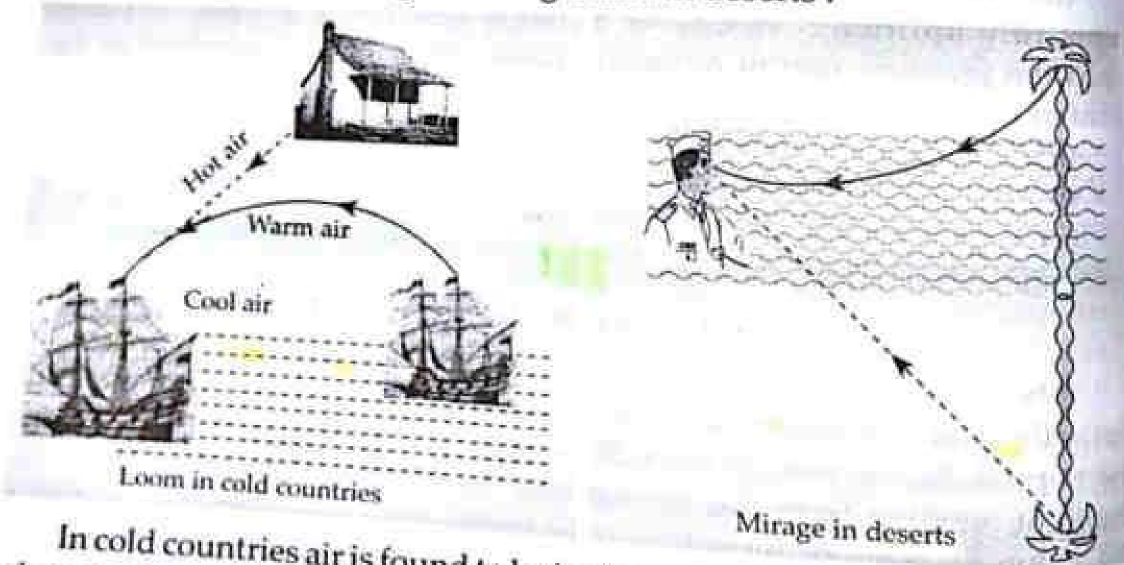
Critical angles of some important substances :

Substance	Index of refraction	Critical angles	Substance	Index of refraction	Critical angles
Water	1.33	48.5°	Flint glass	1.65	37.4°
Crown glass	1.52	41.1°	Diamond	2.42	24.4°

Some interesting incidents related to total internal reflection—

(i) Over brightness in diamond : The critical angle is very low (approximately 24°) for a light ray coming from diamond to air. When light rays enter into the diamond, then from various layers multiple reflections take place and if the angle of incidence of the rays becomes less than 24°C then light rays come out from the diamond. Thus, light rays entering from every side into the diamond, only appear to come from certain side and that's why the diamond appears overbrightend.

(ii) Ships hang inverted (looming) in the air in cold countries and trees hang inverted (mirage) underground in deserts :



Loom in cold countries

Mirage in deserts

In cold countries air is found to be in the most densed state at the surface of sea-water and it gets gradually rarer upwards. So the rays diverging upwards from an object on the surface of sea-water say, a ship are refracted continuously away from the normal. Now it is totally reflected when the light rays begin to travel downwards with continuous refraction towards

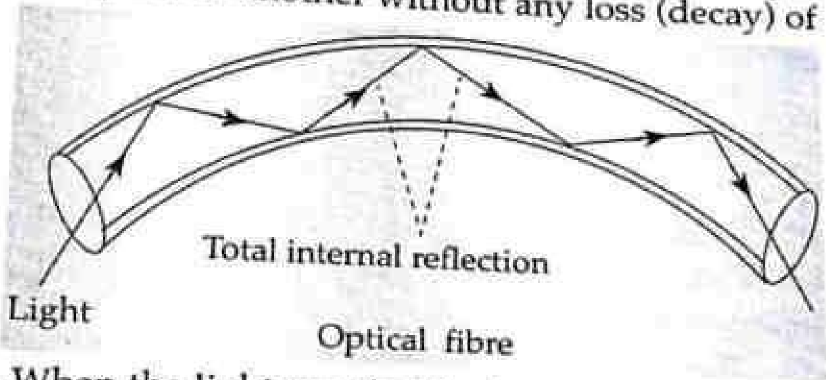
... eye of the observer in the upward direction. That's why the ship appears inverted in air, and it is said to be the position of loom.

In deserts the situation is just the reverse. Here air is the rarest at the ground level and gets gradually denser as we go upwards. So the light rays diverging downwards from an object above the ground, say the leaf of a tree, are refracted continuously away from the vertical. Now it is totally reflected when the light rays begin to travel upwards with a continuous refraction towards the vertical and soon reach the eye of the observer in the downward direction. The leaf so appears underground and it is called *Mirage*. In fact, the ship and the tree are not inverted but they seem to be inverted. These are simply optical illusions.

(iii) The cracked part of glass appears to be brightend : The cracked part of glass contains air, which acts like a rarer medium with respect to it. When light rays enter through the glass (cracked) to air then they refract in which the angle of incidence becomes greater than the critical angle, and the phenomenon of total internal reflection takes place. That's why cracked part of glass appears to be brightend.

(iv) A test tube filled with water appears to be brightend due to the similar reason.

(v) Optical fibre : Rectilinear propagation of light which is a well known optical phenomenon and by the use of total internal reflection light can also be passed through the curved optical path. A fibre is an optical system based upon the basic principle of total internal reflection and through which light signal is transferred from one place to another without any loss (decay) of amplitude or intensity.



Optical fibre

An optical fibre is basically composed through a long, large and compact quartz fibre and each fibre is 10^{-4} cm thick. Around the optical fibre a substance whose index of refraction is about 1.6 is wrapped out. When the light rays incident on one side of this fibre by making a very small angle, then these are refracted inside it. Thus incident rays after being totally internally reflected collide with the other end of the fibre. On this limiting surface upto which optical fibre is confined again the angle of incidence becomes greater than the critical angle and total internal reflection takes place again.

Thus, the phenomenon of total internal reflection takes place repeatedly and the light ray reaches from one end to another end.

Use of optical fibre :

(i) To send an electric signal by transforming it into a light signal and vice-versa.

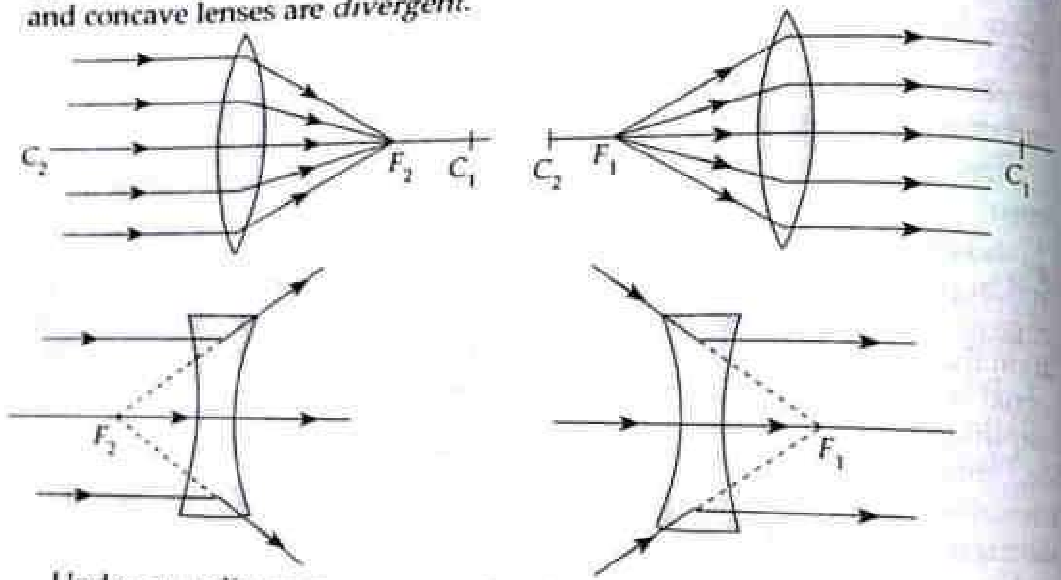
(ii) To send laser light rays inside the human body.

(iii) Today optical fibres are frequently used in telecommunication. Old copper cables are being replaced today by optical fibres whose capacity is large and they are convenient in use and which are noise free.

5. Refraction of light through a lens

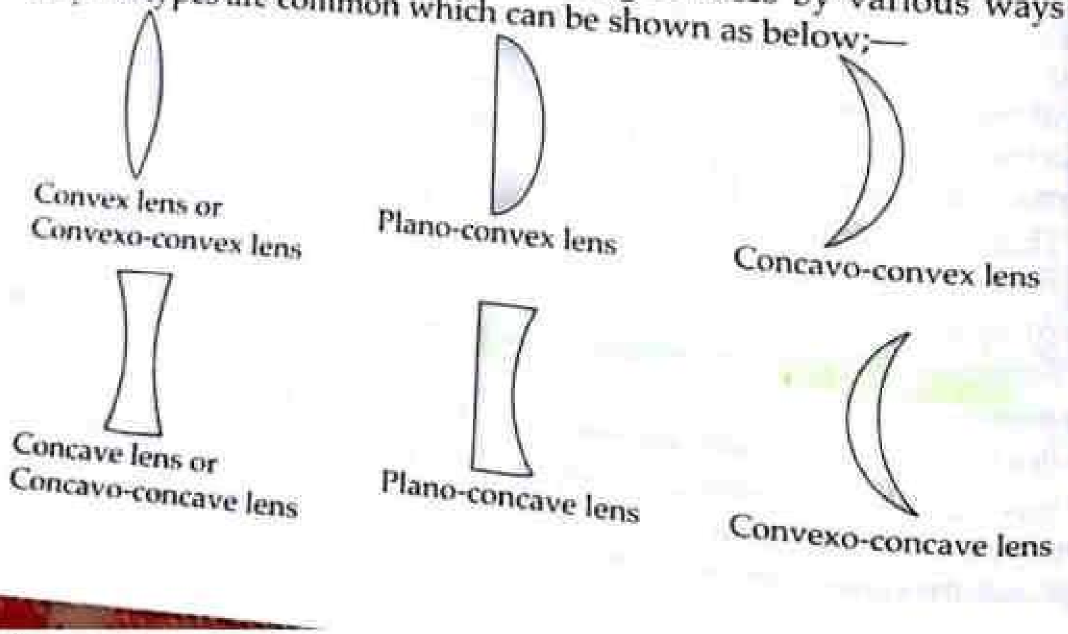
Lens : A lens is a transparent medium bounded by two spherical surfaces.

The line joining the centres of curvature of the two bounding surfaces is called principal axis of the lens. The section of a lens by a plane passing through its principal axis is called principal section of the lens. A lens is shown by its principal section. The point on the principal axis of the lens through which rays pass undeviated through the lens is called its *optical centre*. Lenses bound by two convex spherical surfaces are called *convex lenses* and those bound by two concave spherical surfaces are called *concave lenses*. Lenses which converge a parallel beam of rays to a point are said to be convergent in nature and those which diverge the rays from a virtual point are said to be divergent in nature. Generally, convex lenses are *convergent* and concave lenses are *divergent*.



Under co-ordinate sign convention (which is updately acceptable) the focal length of the convex lens is taken positive and that of concave lens is taken negative.

The lenses are generally constructed by the good quality hollow spherical glasses which act like refracting surfaces by various ways but only six types are common which can be shown as below;—



two spherical
ding surfaces
plane passing
ns. A lens is
is of the lens
d its optical
lled convex
led concave
re said to be
irtual point
convergent

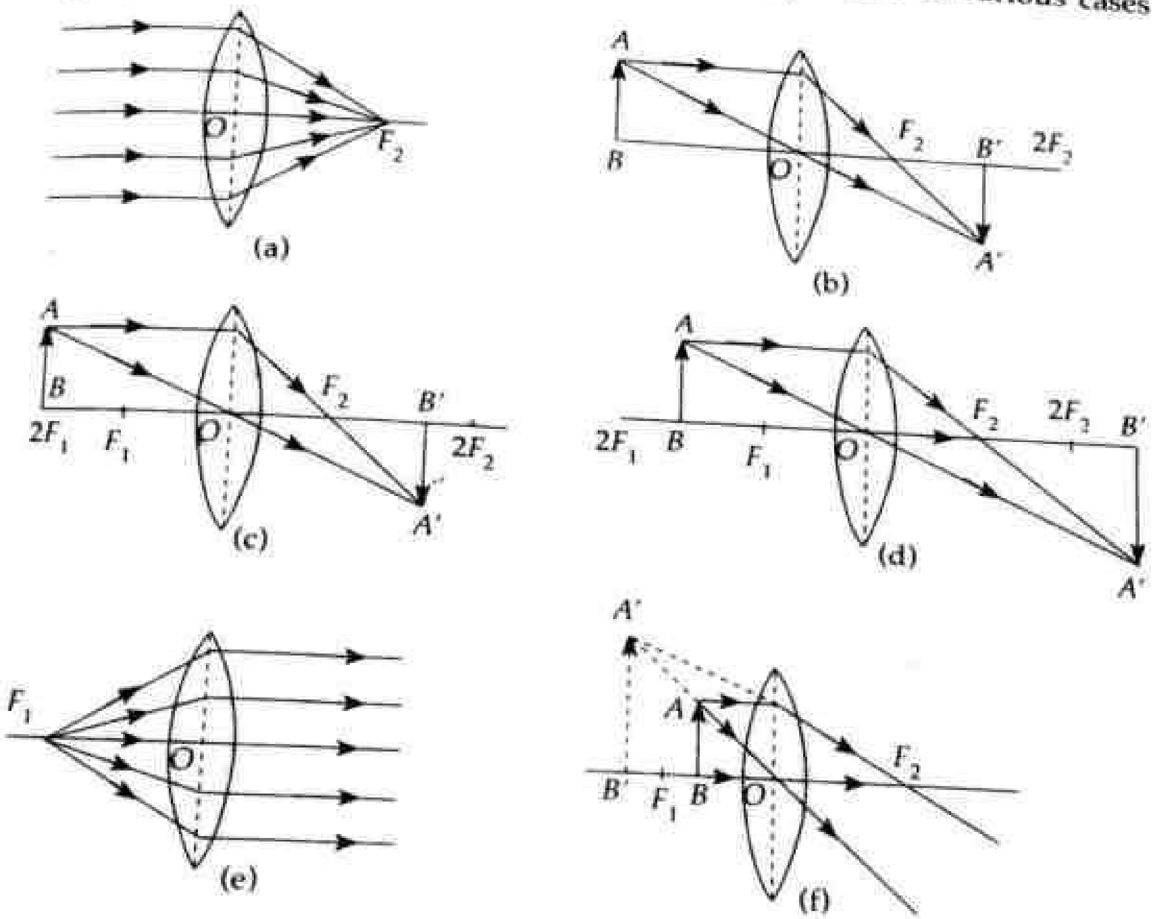
Terms related to lens

Optical centre : It is a mid point in a lens and any light ray which passes through it doesn't deviate.

Focus : The point at which the light rays coming parallel to the principal axis meet or appear to meet after refraction is called focus.

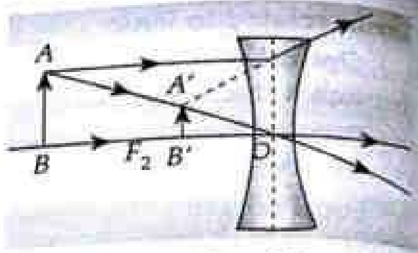
Focal length : The distance between the optical centre and the focus is called focal length.

The Image formation by convex lens : The nature of image formed, its size and position etc. depend on the distance of the object kept from the focus. There may be following positional configuration in various cases given as below—



) the
ns is
low
but

Position of object	Position of image	Nature, Size, Position of image
(a) At infinity (∞)	At F_2	real, very small and inverted
(b) Left near $2F_1$	Between F_2 and $2F_2$	real, small and inverted
(c) At $2F_1$	At $2F_2$	real, equal and inverted
(d) Between $2F_1$ and F_1	Right from $2F_2$	real, large and inverted
(e) At F_1	At infinity (∞)	real, very large and inverted
(f) Between O and F_1	Towards objects	Virtual, erected and magnified



The image formation by concave lens : By concave lens often the image is formed towards the object side (left) between the focus and lens and it is virtually erected and small.

Object can be kept at various position and image can be obtained.

Relation among object distance, image distance and focal length of the lens.

$\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$ is called lens formula and it is the required relation between the distance of object and image with focal length.

Here, f = focal distance, $+ve$ for convex lens and $-ve$ for concave lens.

u = object distance

v = image distance.

Relation among focal distance, index of refraction and radius of curvature.

(a) Thin lens formula : $\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$

where μ = index of refraction of the lens.

f = focal length

R_1, R_2 are radii of curvature of two surfaces.

If the lens is a plano-convex then $R_2 = \infty$

Thus, by lens formula $\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{\infty}\right)$

$$= (\mu - 1)\left(\frac{1}{R_1} - 0\right) = \frac{\mu - 1}{R_1} \Rightarrow \frac{1}{f} = \frac{\mu - 1}{R_1}$$

(b) Thick lens formula : If t be the thickness of the lens then

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

Equivalent focal length of two lenses :

(a) If two lenses are kept in contact then equivalent focal length of these two lenses is the sum of the focal lengths of the lenses.

Thus if F is the equivalent focal length of two lenses whose respective focal lengths are f_1 and f_2 then $\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2}$

(b) But if these two lenses are kept apart at d distance, then its equivalent focal length is given by

$$\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2} - \frac{d}{f_1 f_2}$$

Power of a lens : The inverse of the focal length of any lens is called *power of the lens.* If the focal length of a lens is in meter, then its inverse which is called power of the lens is expressed in *Dioptre.* Thus, SI unit of the power of the lens is dioptre. Since the focal lengths of convex and concave lenses are +*ve* and –*ve*. That's why convex lens has +*ve* power and concave lens has –*ve* power.

Equivalent power of the combination of lenses : As from the formula of equivalent focal length of two lenses when these two are in contact.

$$\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2} \Rightarrow P = P_1 + P_2$$

If first lens is concave, say $P_1 = -1.5$ (dioptre)

and second lens is convex, say $P_2 = f = +2.5$ (dioptre)

then $P = -1.5 + 2.5 = +1$ dioptre

Also, if d is the distance between two lenses, then $P = P_1 + P_2 - d\,P_1\,P_2$.

Variations in the power of lenses : Whenever a lens is kept inside a liquid its focal length and power both change. If a lens of refractive index μ is kept inside a liquid of refractive index μ′ then here three cases arise;

(a) When $\mu > \mu'$ **:** Here power of the lens decreases and thus focal length increases. The nature of the lens remains the same.

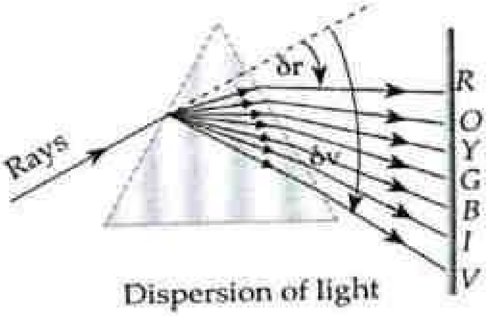
(b) When $\mu = \mu'$ **:** Here focal length of the lens becomes infinite and thus power of the lens vanishes or becomes zero. Thus lens behaves like a plane parallel plate and inside the liquid lens doesn't look.

(c) When $\mu < \mu'$ **:** Here power of the lens again decreases and thus focal length increases. Thus a convex lens acts like a concave lens and vice-versa.

An air bubble inside the water acts like a concave lens but as usual (without water) acts like a convex lens. A convex lens of glass when kept inside the carbon disulphide appears like a concave lens and vice-versa.

6. Dispersion of light

When a light ray incidents upon a prism, it gets refracted through it and bends towards the base of the prism and this ray splits into various colours. This group of component colours is called spectrum. Also the process of splitting of a white light is called *dispersion of light*. In all the colours of white light, violet ray (colour) deviates the most and red ray (colour) deviates the least. The white light has seven colours **VIBGYOR** (Violet, Indigo, Blue, Green, Yellow, Orange and Red).



Dispersion of light

Newton observed that different colours of white light deviate on different angles. The optical dispersion takes place because different colours of white light have different speeds for any transparent material. As well as the refractive indices of various colours of the light increase correspondingly their speeds decrease.

For example : The violet ray (colour) has the largest refractive index and the least speed in glass and red ray (colour) has the least refractive index and the largest speed. Other colours have their speeds between these two colours—violet and red.

Also the wavelength of violet colour is the least and that of the red colour is the largest. The wavelength of light is expressed in *Angstrom* (Å) and 1Å = 10^{-10}m.

Wavelength of important colours :

Colour	Wavelength (in Å)	Colour	Wavelength (in Å)
Violet	3969 Å	Yellow	5893 Å
Blue	4861 Å	Red	6563 Å

Rainbow : When the phenomena of refraction, reflection and total internal reflection take place coincidentally and in which a comprehensive optical dispersion also takes place then a rainbow is formed.

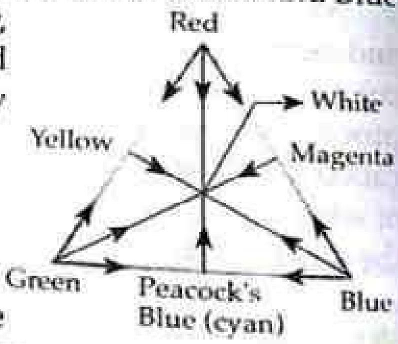
The rainbow is of two types—

(i) Primary rainbow : Whenever rainfall occurs then after its complete end some rain drops remain suspended in the sky and in the meantime if any light ray (from the sun) incidents on a particular drop in such a way that it reflects one time and refracts two times then primary rainbow is formed. In it red colour is located outwardly and violet colour is located inwardly. Inwardly located violet ray makes an angle of $40^\circ.8$ and outwardly located red ray makes an angle of $42^\circ 8'$ at the eye.

(ii) Secondary rainbow : As above if the light ray (from the sun) incidents on a particular drop in such a way that reflects two times and refracts two times then secondary rainbow is formed. In it violet colour is located outwardly and red colour is located inwardly. Outwardly located violet ray makes an angle of $54^\circ 52'$ and inwardly located red ray makes an angle of $50^\circ 8'$ at the eye.

The secondary rainbow is less distinctive and clear than the primary rainbow.

Primary, secondary and complementary colours : Red, Green and Blue colours are called *primary colours,* while Yellow, Magenta and Peacock Blue (cyan) colours are called *secondary colours.* These colours are prepared by mixing two primary colours as below :



Red + Blue → Magenta.

Green + Blue → Peacock Blue (Cyan)

Red + Green → Yellow

If two colours mutually meet to form a white light, then the colour is called complementary colour.

Example : Red + Peacock Blue (Cyan) → White.

Green + Magenta → White.

Yellow + Blue → White, Red + Peacock Blue (Cyan) → White.

Such type of colours cannot be achieved in our daily life because colours which we use are practically impure.

Colour TV utilises primary colour—red, green and blue.

Colour of Objects : The colour of any object is the reflected colour and all other colours are absorbed. The object which reflects all the incident colours looks white but if all the incident colours the are absorbed then the object appears black. The white colour of an object is the composite effect of all the colours.

Example : When a red rose is seen through a green glass then the rose appears black because red colour is not available for reflection and green colour is absorbed by it.

The colours effect on various type of objects

Name of objects	In white rays	In red rays	In green rays	In yellow rays	In blue rays
White paper	white	red	green	yellow	blue
Red paper	red	red	black	black	black
Green paper	green	black	green	black	black
Yellow paper	yellow	black	black	yellow	black
Blue paper	blue	black	black	black	blue

7. Interference of light waves

In general interference is the phenomenon of sustained cancellation or reinforcement of two waves when they meet under certain specific conditions. When the effect of one wave is constantly neutralised by the other, two waves are said to interfere destructively and when their effects are reinforced they are said to interfere constructively. Thus, we can say that when two waves of the same frequency travel in same direction and have a phase difference that remains constant with time, the resultant intensity of light is not distributed uniformly in space. The non-uniform distribution of light intensity due to superposition of two waves is called *interference.* At some points intensity is maximum and interference at these points is called *constructive interference.* At some other points intensity is minimum (possibly even zero) and interference at these points is called *destructive interference.* Usually when two light waves are made to interfere, we get alternate dark and bright bands of a regular or irregular shape. These are called *interference fringes.*

Interference is the most fundamental characteristic of a wave and there is no loss of energy in it, there is only redistribution of energy from maxima to minima. The phenomenon of interference was firstly demonstrated by Thomas Young in his experiment called *Young's double slit experiment.*

Examples related to interference

(i) The kerosene oil spread on the water surface seems to have a decent colour because of interference of the light.

(ii) The soap bubbles have a brilliant colour in the sunlight because of interference of the light.

Coherence : A wave which has a pure sine wave for an infinitely large period of time or for an infinitely extended space is said to be a *perfectly coherent wave.* In such a wave there is a definite relationship between the phase of the wave at a given time and at a certain time or distance later at a given point same condition is again satisfied.

No actual light source however emits a perfectly coherent wave. Light waves which are pure sine waves only for a limited period of time or in a limited space are partially coherent waves.

Thus there are two different criteria of coherence–criteria of time and criteria of space. This gives rise to the phenomena of *temporal coherence* and *spatial coherence*.

8. Diffraction of light

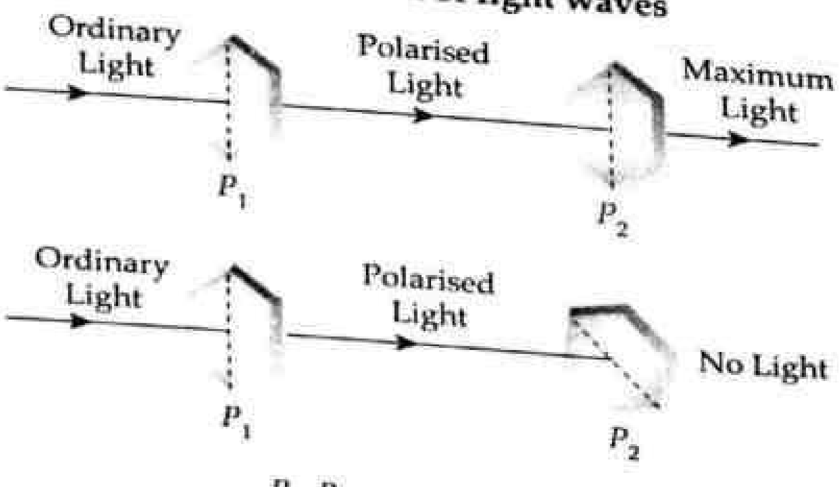
If an opaque obstacle (aperture) is kept between a source of light and a screen, a sufficiently distinct shadow (or an illuminated region) is obtained on the screen. This shows that light which travels the obstacle (aperture) is small (comparable to the wavelength of the light), there is a departure from straight line propagation and so the light bends round the corners of the obstacle (aperture) and enters in the geometrical shadow. This bending of the light is called *diffraction*. Consequently, the edges of the shadow (or illuminated region) are not sharp, but the intensity is distributed in a certain way depending upon the nature of the obstacle (aperture). Thus, if the size of the obstacle is in the order of the wavelength of light, then diffraction will be appeared which is clear and distintive. The phenomenon of diffraction confirms the wave character of the light. Sound wave has longer wavelength, that's why acoustical diffraction takes place clearly in which sound wave bends from obstacle and we listen. While the wavelength of light wave is shorter than common barrier (obstacle) we use in our daily life, that's why the phenomenon of optical diffraction is rarely observed.

There are two types of optical diffractions—

(a) Fresnel's diffraction : In Fresnel's class of diffraction, the source of light or screen on which diffraction pattern is observed, are usually at finite distances from the diffraction obstacle (aperture). In this case no lenses are used and the wavefront (wave shape) is either spherical or cylindrical.

(b) Fraunhofer diffraction : In Fraunhofer's class of diffraction, the source of light and the screen are effectively at infinite distances from the diffracting obstacle (aperture). This is achieved by keeping the source and screen in the focal planes of two lenses. Here the incident wavefront (wave shape) is plane.

9. Polarisation of light waves

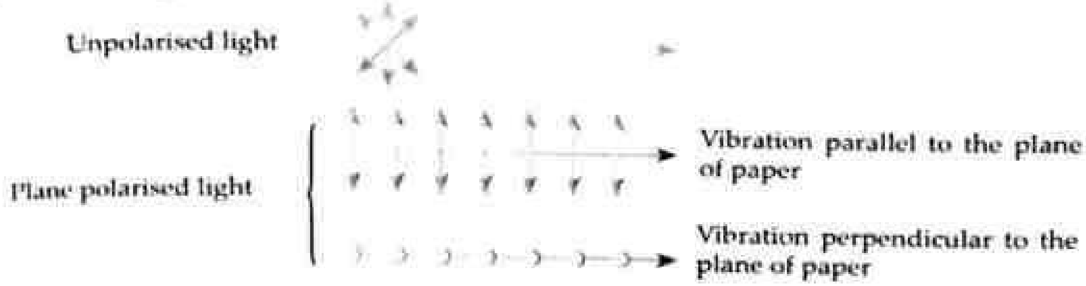


$P_1, P_2 \rightarrow$ tourmaline crystals

When an ordinary light incidents normally upon a pair of parallel tourmaline crystal plates P_1 and P_2 as shown in the figure which have been cut parallel to their crystallographic axis, the emergent light shows a variation in intensity as P_2 is rotated. The intensity is maximum when the axis of P_2 is parallel to that of P_1, and minimum when it is at right angles. This shows that the light emerging from P_1 is not symmetrical about the direction of propagation of light, but its vibrations are confined only to a single line in a plane perpendicular to the direction of propagation. Such light is called *plane-polarised* or *linearly-polarised* light.

According to the electromagnetic theory of light, a light wave consists of electric and magnetic vectors vibrating in mutually perpendicular planes, both being perpendicular to the direction of propagation of light. The electric vector acts like a light vector. Hence, the plane-polarised light is a light in which the light vector vibrates along a fixed straight line in a plane perpendicular to the direction of propagation.

Symbolical representation



As in an unpolarised beam of light all directions of vibration at right angles to that of propagation of light are possible, hence it is represented by a star.

In a plane-polarised beam of light the vibrations are along a single straight line. If the vibrations are parallel to the plane of the paper, they are represented by the arrows. If they are along a straight line perpendicular to the plane of paper, they are represented by dots.

Light waves are transverse : In tourmaline experiment, the variation in intensity of the emergent light on rotation of P_2 (First section of the polarisation) shows that light waves are transverse. But if the waves were longitudinal i.e. having vibration along the direction of propagation of light, they will have passed through P_2 in all positions of it.

Thus, polarisation of light takes place with transverse waves only and doesn't occur with longitudinal waves. That's why sound (longitudinal) wave doesn't exhibit the phenomenon of polarisation.

Doubly-Refracting crystals : There are certain crystals which split a ray of light incident upon them into two refracted rays. Such crystals are called *doubly-refracting crystals*. These are of two types : uniaxial and biaxial. In uniaxial crystals there is one direction called *optic axis* along which the two refracted rays travel with the same velocity. The examples of such crystals are calcite, tourmaline and quartz. In biaxial crystals there are two optic axes. The examples of biaxial crystals are topaz and arogonite.

Double refraction : When a ray of unpolarised light incidents on a calcite (or quartz) crystal, it splits up into two refracted rays. The phenomenon is called *double refraction*.

One of these two refracted rays is found to obey the laws of refraction i.e. it always lies in the plane of incidence and its speed in the crystal is same in all directions. This ray is called an *ordinary ray* (O-ray). The other refracted ray doesn't obey the laws of refraction. It travels in the crystal with different speeds in different directions. Hence it is called an extraordinary ray (E-ray). Along the optic axis, however, O-ray and E-ray both have the same velocity and hence the same refractive index. An ordinary ray (O-ray) and an extraordinary ray (E-ray) obtained through the double refraction are plane-polarised.

Nicol's prism : It is an optical device made from a calcite crystal which is used in producing and analyzing the plane-polarised light.

Dichroism : Some doubly-refracting crystals have the property of absorbing strongly one of the two refracting rays, while allowing the other to emerge with a little loss. This selected absorption by the crystal is known as *dichroism*. The best example of such a crystal is tourmaline.

When a ray of unpolarised light is sent through a 1 mm thick, tourmaline plate then it splits up into plane-polarised light in which O-ray and E-ray vibrate in mutually perpendicular planes. O-ray is completely absorbed while E-ray is totally transmitted. Thus, the light emerging through the plate is plane-polarised. This is the basic principle of the commercial polarising devices called *polaroids*.

Polaroid : It is a large-sized polarising film mounted between two glass plates, and is used to obtain plane-polarized light for the commercial purposes. The film consists of a thin sheet of nitro-cellulose packed with ultra microscopic crystals of the organic compound iodosulphate quinine (also called herapathite) with their optic axes all parallel. These crystals are highly dichroic, absorbing one of doubly-refracted beams completely. Hence when a beam of unpolarised light passes through the polaroid film, the emerging light is plane-polarised.

Recently large-sized polaroids have been made by stretching a film of polyvinyl alcohol. The stretching orients the complex molecules with their long axes in the direction of stress and makes them doubly-refracting. Then the film is impregnated with iodine which makes it dichroic. Such polaroids are called *H*-polaroids. If instead of iodine impregnation, the stretched film is heated with a dehydrating agent, then it slightly darken and becomes strongly dichroic. It is called *K*-polaroid.

Uses of polaroids

(i) Polaroids are used in the laboratory to produce and analyse a plane-polarised light. These are cheaper than Nicols.

(ii) K-polaroids are used in head-lights and wind-screens of cars to cut off the dazzling light of a car approaching from the opposite side. They are fitted in the head-light and wind-screen of the car with their vibration-planes parallel to each other but inclined at 45° to the vertical. When two cars approach each other from the opposite sides then through the vibration-plane of polaroids light is sent out to each other and hence light coming from the head light of one car is completely cut off by the wind-screen of the another car and thus the driver is able to see the other car by the light sent out from his (or her) own car.

(iii) Polaroids are used to control the intensity of light in entering trains and aeroplanes. A polaroid is fixed outside the window, while the other is fitted inside it which can be rotated and the intensity of light can be adjusted by rotating the inner polaroid.

(iv) Polaroid glasses are used in viewing three-dimensional pictures.

(v) The polaroids are today frequently used in sun-glasses to cut off the glare of light reflected from the horizontal surfaces such as moist roads, cover glasses of the paintings, polished table, pavements etc.

Plane, Circularly and Elliptically polarised light : According to Maxwell's electromagnetic theory, a light wave consists of electric and magnetic fields (vectors) vibrating in mutually perpendicular planes, both being perpendicular to the direction of propagation of light. The electric vector is responsible for the optical effect of the wave and which is also called *light vector.* In unpolarised light, light vector takes all the possible directions of vibration in a plane perpendicular to the directions of propagation. If however, light vector vibrates along a fixed straight line in the plane, the light is said to be *plane-polarised or linearly-polarised.*

When two plane-polarised waves are superimposed, then under certain conditions the resultant light vector rotates with a constant magnitude in a plane perpendicular to the direction of propagation. The tip of the vector traces a circle and the light is said to be *circularly-polarised.* If, although the magnitude of the resultant light vector varies periodically during its rotation, the tip of the vector traces an ellipse, the light is said to be *elliptically-polarised.* Thus, there are usually three types of polarised light which exist in nature.

10. Scattering of light

When light waves fall on extremely small bodies (particles) such as dust particles, very small suspended water droplets, suspended particles in colloidal solution etc then these are thrown out in all directions. This phenomenon of light is known as *scattering.* Here bodies are small in the sense of their sizes and are smaller than the sizes (wavelengths) of the incident waves. Thus, the strength of scattering depends upon the wavelength of the light beside the size of the bodies (particles) which cause scattering. If these particles are smaller than the wavelength of the incident light, then the scattering is proportional to $\frac{1}{\lambda^4}$. This is called *Rayleigh's law* of *scattering.* Thus, red light is scattered least and violet is scattered most. That's why red signals are used to indicate dangers. Such a signal appears to be visible at a larger distances without an appreciable loss due to scattering.

Incidents of the scattering of light in our daily life—

(i) Due to the scattering of light sky appears blue : When we look at the sky it is scattered light from the atmosphere that enters the eyes. Among the shorter wavelength the colour blue is present in larger proportion in the light. Light of short wavelengths are strongly scattered by the air molecules and the suspended water droplets and it explains the blue colour appearance of the sky.

(ii) At sunset and sunrise sun appears red : At such occasion the sunlight has to travel a large distance through the atmosphere. The blue and neighbouring colours are scattered away in the path and the light reaching the observer is predominantly red. Thus, at sunset and sunrise sun appears red and it occurs due to the scattering of light.

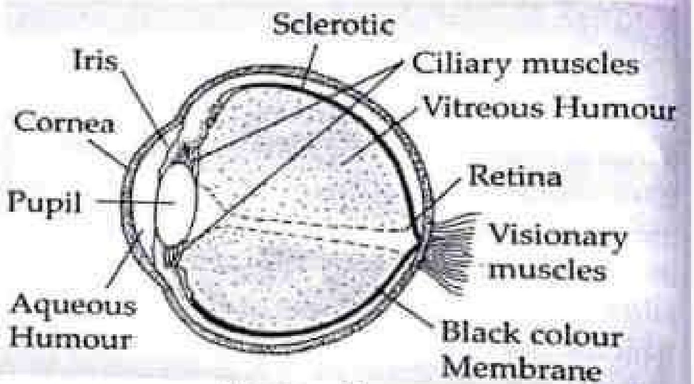
(iii) If there were no atmosphere of the earth, then the sky would appear black and stars would be seen during the day.

(iv) On a humid day before rains, the sky appears light blue, while on a clear day it appears deep blue. The change in the quality of colour of the sky results from the fact that the water droplets and the dust particles may have a size larger than the wavelength of light. Rayleigh's law of scattering doesn't apply in this case and colours other than blue may be scattered in larger proportion.

(v) The seas also appear blue due to the scattering of light.

11. Human eye

The human eye is like a camera with the help of which we see the objects. Human eye is externally very hard and it is covered with a opaque white membrane which is called *sclerotic*. The front part of sclerotic is concave which is called *cornea*. During eye donation this part (cornea) is donated.



Human Eye

A light ray enters the eye through cornea. Behind the cornea a colour opaque membrane is located which is called Iris. In the middle of the *Iris* there is a sharp hole, which is called *pupil*. Iris controls the amount of light which enters the eye. If more light comes into it, then automatically iris compresses itself. Also in dark or insufficient light it (iris) automatically expands. Behind the pupil the eye lens is located. The eye lens is made from many layers whose index of refraction increases from outside to inside and its mean index of refraction is approximately 1.44. The eye lens is confined within the musclular region and it is capable of adjusting its focal length. That's why human eye has a variable nature of focal length. Between cornea and eye lens a saline transparent fluid is filled up which is called *aqueous humour,* and its index of refraction is 1.336. Behind the eye lens another transparent fluid is also found which is called *vitreous humour* and whose index of refraction is also 1.336. Behind sclerotic there is a black coloured membrane which is called *choroid*. It absorbs the light and stops the process of internal reflection. Inside this membrane and in the innermost part of the eye there is a transparent membrane which is called *retina*. The retina is basically a film of optical nerves and these nerves produce the sensation of the image formed in the mind (brain). Thus, shape, size and colour of the object's image is observed by the human eye. When a light ray incidents on an object, then by reflection it passes through the cornea and aqueous humour reaches to the retina. At retina (used as screen for the glass lens) a real and inverted image of the object is formed and this message is sent to the human brain by the visionary (optic) nerves and the brain realises the real erected image. There is no effect of light is found the place (point) where optic nerves by making the hole in the retina goes upto brain. This place is called *blind spot*. There is a mid-point in the retina which is of yellow colour. Here the obtained image is very sharp and distinctive. It is called *yellow spot*.

Power of accommodation of eye : To see any object distinctly (clearly) it is necessary that the light ray reflected from object be totally confined on the retina. In usual condition the light rays coming from far flung object are assumed to be confined on the retina by which the muscles of the eye is not stretched as normally and the object looks. At this position the eye lens has the maximum focal length. But if the eye looks at any nearer object, then eye muscles start to shrink and reduce the radii of curvature of the lens surfaces. Here the focal length of the eye lens is reduced and again image starts to form on the retina. This adjustment of the focal length of the eye is called Power of accommodation of the eye. As we try to look at the nearest object more and more power of accommodation of the eye is required and it has also a limit. If any object is kept very close to the eye it doesn't look distinct. Thus the maximum accommodation power of eye is applied to the nearest object which looks sharp and distinct. This distance of distinct vision is called the least distance of distinct vision and for a normal human eye it is 25 cm. But inversely the eye without applying the power of accommodation can see distinctly any object located at far point and for a normal human eye it is infinity (∞).

Colour vision : There are two types of cells found in the retina of the eye which are optically sensitive. These are called cones and *rods*. Cone shaped cells react according to the consistency of the colours by which we realise about the colours. Rod shaped cells react according to the consistency of the intensity of light. This is very sensitive for the dim light. That's why we also speculate (guess) about the object in the dark. When light is of shining (dazzling) type then rods cells stop to act and cones cells become active. A normal human eye's retina has three types of cones cells—

(i) **First type**–Sensitive to the light of shorter wavelength (blue colour)

(ii) **Second type**–Sensitive to the light of middle range wavelength (green colour)

(iii) **Third type**–Sensitive to the light of longer wavelength (red colour)

Chromatic adaptation : If a piece of glazed (shined) colour paper is taken and half part of it is covered, then on looking up to approximately 30 seconds at the rest of the piece and if the covered part is now made open then on looking at the entire piece the covered part appears more glazed. This optical incident is called chromatic adaptation.

Successive contrast : If we look at a coloured image up to approximately 30 seconds and a white surface is seen then a post-image appears, whose shape and size is equal to that of the real image, but its colour is different. If the real image is red then its post-image is green and vice-versa. If the real image is blue then its post-image in yellow and vice-versa and for the white real image its post-image is black and vice-versa. Such optical incident in technical form is called successive constrast.