## UNIT – 01 NATURE OF PHYSICAL WORLD AND MEASUREMENT

## TWO MARKS AND THREE MARKS:

**01. Briefly explain the types of physical quantities.**

.1. Fundamental or base quantities are quantities which cannot be expressed in terms of any other physical quantities. These are length, mass, time, electric current, temperature, luminous intensity and amount of substance.

2. Quantities that can be expressed in terms of fundamental quantities are called Derived quantities. For example, area, volume, velocity, acceleration, force.

**02. Write the rules for determining significant figures.**

i) All non-zero digits are significant. Ex.1342 has **four** significant figures

ii) All zeros between two non zero digits are significant.
Ex. 2008 has **four** significant figures

iii) All zeros to the right of a non-zero digit but to the left of a decimal point are significant. Ex. 30700. has **five** significant figures

iv) The number without a decimal point, the terminal or trailing zero(s) are not significant. Ex. 30700 has **three** significant figures
All zeros are significant if they come from a measurement
Ex. 30700 m has **five** significant figures

v) If the number is less than 1, the zero (s) on the right of the decimal point but to left of the first non zero digit are not significant. Ex. 0.00345 has **three** significant figures

vi) All zeros to the right of a decimal point and to the right of non-zero digit are significant. Ex. 40.00 has **four** significant figures and 0.030400 has **five** significant figures

vii) The number of significant figures does not depend on the system of units used 1.53 cm, 0.0153 m, 0.0000153 km, all have **three** significant figures

**03. What are the limitations of dimensional analysis?**

1. This method gives no information about the dimensionless constants in the formula like 1, 2, ……..π,e, etc.
2. This method cannot decide whether the given quantity is a vector or a scalar.
3. This method is not suitable to derive relations involving trigonometric, exponential and logarithmic functions.
4. It cannot be applied to an equation involving more than three physical quantities.
5. It can only check on whether a physical relation is dimensionally correct but not the correctness of the relation. For example using dimensional analysis, $s = ut + \frac{1}{3}at^2$ is dimensionally correct whereas the correct relation is $s = ut + \frac{1}{2}at^2$

**04. Define Physical quantity. Write its example.**

Quantities that can be measured, and in terms of which, laws of physics are described are called physical quantities. Examples are length, mass, time, force, energy, etc.

**05. Define SI standard for length**

One metre is the length of the path travelled by light in vacuum in 1/299,792,458 of a Second.

**06. Define SI standard for mass**

One kilogram is the mass of the prototype cylinder of platinum iridium alloy (whose height is equal to its diameter), preserved at the International Bureau of Weights and Measures at Serves, near Paris, France.

**07. Define SI standard for time**

One second is the duration of 9,192,631,770 periods of radiation corresponding to the transition between the two hyperfine levels of the ground state of Cesium-133 atom.

**08. Define one radian**

One radian is the angle subtended at the centre of a circle by an arc equal in length to the radius of the circle.

**09. What is the principle of screw gauge? Write its least count.**

The principle of the instrument is the magnification of linear motion using the circular motion of a screw. The least count of the screw gauge is 0.01 mm

**10. Define light year**

Light year (Distance travelled by light in vacuum in one year)

1 Light Year = $9.467 \times 10^{15}$ m

**11. Define astronomical unit**

Astronomical unit (the mean distance of the Earth from the Sun)

1 AU = $1.496 \times 10^{11}$ m

**12. What is relative error or fractional error?**

The ratio of the mean absolute error to the mean value. Relative error = $\frac{\Delta a_m}{a_m}$

**13. What is percentage error?**

The relative error expressed as a percentage . Percentage error = $\frac{\Delta a_m}{a_m}$ x 100%

**14. Define significant figure or digits.**

The digits that are known reliably plus the first uncertain digit are known as significant figures or significant digits.

**15. Define dimensions.**

The dimensions of a physical quantity are the powers to which the units of base quantities are raised to represent a derived unit of that quantity.

Velocity = Displacement / Time = [L] / [L] = $M^0LT^{-1}$

**16. Define dimensional constant and dimensionless constant**

**Dimensional Constant**

Physical quantities which possess dimensions and have constant values are called dimensional constants. Examples are Gravitational constant, Planck's constant etc.

**Dimensionless Constant**

Quantities which have constant values and also have no dimensions are called dimensionless constants. Examples are π, e, numbers etc.

**17. Define dimensional variable and dimensionless variable**

**Dimensional variables**

Physical quantities, which possess dimensions and have variable values are called dimensional variables. Examples are length, velocity, and acceleration etc.

**Dimensionless variables**

Physical quantities which have no dimensions, but have variable values are called dimensionless variables. Examples are specific gravity, strain, refractive index etc.

**18. What are the uses of dimensional analysis?**

(i) Convert a physical quantity from one system of units to another.

(ii) Check the dimensional correctness of a given physical equation.

(iii) Establish relations among various physical quantities.

**19. Write principle of homogeneity of dimensions.**

The principle of homogeneity of dimensions states that the dimensions of all the Terms in a physical expression should be the same. For example, in the physical expression $v^2 = u^2 + 2as$, the dimensions of $v^2$, $u^2$ and 2 as are the same and equal to $[L^2T^{-2}]$.

## FIVE MARKS QUESTIONS

**20. i) Explain the use of screw gauge and vernier caliper in measuring smaller distances.**

**ii) Write a note on triangulation method and radar method to measure larger distances.**

**Measurement of small distances:**

1) **Screw gauge:** The screw gauge is an instrument used for measuring accurately the dimensions of objects up to a **maximum of about 50 mm**. The principle of the instrument is the magnification of linear motion using the circular motion of a screw. The **least count of the screw gauge is 0.01 mm**
2) **Vernier caliper:** A vernier caliper is a versatile instrument for **measuring the dimensions of an object namely diameter** of a hole, or a depth of a hole.

**Measurement of large distances :**

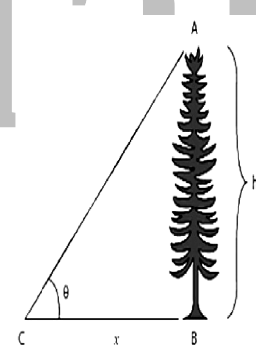
3) For measuring **larger distances** such as the **height of a tree, distance of the Moon or a planet from the Earth**, some special methods are adopted. Triangulation method, parallax method and radar method are used to determine very large distances.



**Triangulation method for the height of an accessible object**

i) Let AB = h be the height of the tree or tower to be measured. Let C be the point of observation at distance $x$ from B. Place a range finder at C and measure the angle of elevation, $\angle ACB = \theta$ as shown in Figure. From right angled triangle ABC, $\tan\theta = \frac{AB}{BC} = \frac{h}{x}$ (or) height $h = x \tan\theta$

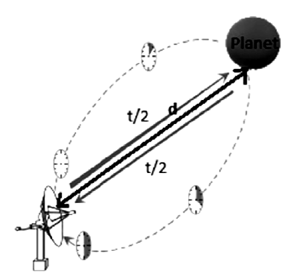
Knowing the distance $x$, the height h can be determined.




**RADAR method**

i) The word RADAR stands for radio detection and ranging. Radar can be used to measure accurately the distance of a nearby planet such as Mars. In this method, radio waves are sent from transmitters which, after reflection from the planet, are detected by the receiver.

ii) By measuring, the time interval (t) between the instants the radio waves are sent and received, the distance of the planet can be determined as $d = \frac{v \times t}{2}$




**where v is the speed of the radio wave**. As the time taken (t) is for the distance covered during the forward and backward path of the radio waves, it is divided by 2 to get the actual distance of the object. This method can also be used to determine the height, at which an aeroplane flies from the ground.

**21. Explain in detail the various types of errors.**

Random error, systematic error and gross error are the three possible errors

**Systematic errors:**

Systematic errors are reproducible inaccuracies that are consistently in the same direction.

**Instrumental errors**

1) When an instrument is not calibrated properly at the time of manufacture, These errors can be corrected by choosing the instrument carefully.

**Imperfections in experimental technique or procedure**

2) These errors arise due to the limitations in the experimental arrangement. To overcome these, necessary correction has to be applied.

**Personal errors**

3) These errors are due to individuals performing the experiment, may be due to incorrect initial setting up of the experiment or carelessness of the individual making the observation due to improper precautions

**Errors due to external causes**

4) The change in the external conditions during an experiment can cause error in measurement. For example, changes in temperature, humidity, or pressure during measurements may affect the result of the measurement.

**Least count error**

5) Least count is the smallest value that can be measured by the measuring instrument, and the error due to this measurement is least count error.

**Random errors**

6) Random errors may arise due to random and unpredictable variations in experimental conditions like pressure, temperature, voltage supply etc.
7) Errors may also be due to personal errors by the observer who performs the experiment. Random errors are sometimes called **"chance error"**
8) It can be minimized by repeating the observations a large number of measurements are made and then the arithmetic mean is taken.

**Gross Error**

9) The error caused due to the shear carelessness of an observer is called gross error. These errors can be minimized only when an observer is careful and mentally alert.

**22. Write the rules for rounding off.**

i) If the digit to be dropped is smaller than 5, then the preceding digit should be left unchanged.

**Ex.** i) 7.32 is rounded off to 7.3 ii) 8.94 is rounded off to 8.9

ii) If the digit to be dropped is greater than 5, then the preceding digit should be increased by 1

**Ex.** i) 17.26 is rounded off to 17.3 ii) 11.89 is rounded off to 11.9

iii) If the digit to be dropped is 5 followed by digits other than zero, then the preceding digit should be raised by 1

**Ex.** i) 7.352, on being rounded off to first decimal becomes 7.4

ii) 18.159 on being rounded off to first decimal, become 18.2

iv) If the digit to be dropped is 5 or 5 followed by zeros, then the preceding digit is not changed if it is even

**Ex.** i) 3.45 is rounded off to 3.4 ii) 8.250 is rounded off to 8.2

v) If the digit to be dropped is 5 or 5 followed by zeros, then the preceding digit is raised by 1 if it is odd

**Ex.** i) 3.35 is rounded off to 3.4 ii) 8.350 is rounded off to 8.4



**Remarks :**

# UNIT – 02 KINEMATICS

## TWO MARKS AND THREE MARKS:

**01. Define a vector. Give examples**

It is a quantity which is described by both magnitude and direction. Geometrically a vector is a directed line segment. **Examples** Force, velocity, displacement, position vector, acceleration, linear momentum and angular momentum

**02. Define a scalar. Give examples**

It is a property which can be described only by magnitude. In physics a number of quantities can be described by scalars. **Examples** Distance, mass, temperature, speed and energy

**03. Define displacement and distance.**

**Distance** is the actual path length travelled by an object in the given interval of time during the motion. It is a positive scalar quantity.

**Displacement** the shortest distance between these two positions of the object and its direction is from the initial to final position of the object, during the given interval of time**.** It is a vector quantity**.**



**04. Define velocity and speed.**

**Velocity:** The rate of change of displacement of the particle.

Velocity = Displacement / time taken. Unit: $ms^{-1}$. Dimensional formula: $LT^{-1}$

**Speed:** The distance travelled in unit time. It is a scalar quantity.

**05. Define acceleration.**

The acceleration of the particle at an instant is equal to rate of change of velocity. It is a vector quantity. SI Unit: $ms^{-2}$. Dimensional formula: $M^0L^1T^{-2}$

**06. What is the difference between velocity and average velocity?**

Velocity is the rate at which the position changes. But the average velocity is the displacement or position change per time ratio.

**07. Write down the kinematic equations for angular motion.**

1. $\omega = \omega_0 + \alpha t$  2. $\theta = \omega_0 t + \frac{1}{2}\alpha t^2$  3. $\omega^2 = \omega_0^2 + 2\alpha\theta$  4. $\theta = \frac{(\omega + \omega_0)t}{2}$

**08. What is meant by equal vectors?**

Two vectors $\vec{A}$ and $\vec{B}$ are said to be equal when they have equal magnitude and same direction and represent the same physical quantity.

**09. Define parallel and anti-parallel vectors.**

Two vectors $\vec{A}$ and $\vec{B}$ act in the same direction along the same line or on **parallel lines**, then the angle between them is $0^0$

Two vectors $\vec{A}$ and $\vec{B}$ are said to be anti–parallel when they are in opposite directions along the same line or on parallel lines. Then the angle between them is $180^0$

**10. What is retardation?**

If the velocity is decreasing with respect to time then the acceleration.

**11. Define momentum**

The linear momentum or simply momentum of a particle is defined as product of mass with velocity. It is denoted as '$\vec{p}$'. Momentum is also a vector quantity.

**12. Write the kinetic equations for linear motion.**

i) $v = u + at$ ii) $s = ut + ½ at^2$ iii) $v^2 = u^2 + 2as$ iv) $s = \frac{(u+v)t}{2}$

**13. What is meant by projectile?**

When an object is thrown in the air with some initial velocity and then allowed to move under the action of gravity alone, the object is known as a projectile

**14. Give some examples for projectile motion.**

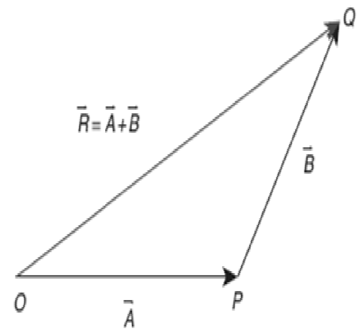
1. An object dropped from window of a moving train
2. A bullet fired from a rifle.
3. A ball thrown in any direction.
4. A javelin or shot put thrown by an athlete.
5. A jet of water issuing from a hole near the bottom of a water tank.

**15. Write the assumptions need to study about the projectile motion.**

i) Air resistance is neglected.
ii) The effect due to rotation of Earth and curvature of Earth is negligible.
iii) The acceleration due to gravity is constant in magnitude and direction at all points of the motion of the projectile.

## FIVE MARKS QUESTIONS

**16. Explain in detail the triangle law of addition.**

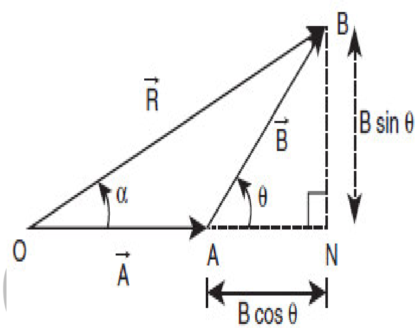



1) $\vec{A}$ and $\vec{B}$ by the two adjacent sides of a triangle. Then the resultant is given by the third side of the triangle taken in the opposite order.

2) The head of the first vector $\vec{A}$ is connected to the tail of the second vector $\vec{B}$. Let θ be the angle between $\vec{A}$ and $\vec{B}$. $\vec{R}$ is the resultant vector connecting the tail of the first vector $\vec{A}$ to the head of the second vector $\vec{B}$.

3) The magnitude of $\vec{R}$ (resultant) is given geometrically by the length of $\vec{R}$ (OQ) and the direction of the resultant vector is the angle between $\vec{R}$ and $\vec{A}$ Thus we write $\vec{R} = \vec{A} + \vec{B}$. $\because \overrightarrow{OQ} = \overrightarrow{OP} + \overrightarrow{PQ}$

**Magnitude of resultant vector :**




4) Consider the triangle ABN, which is obtained by extending the side OA to ON. ABN is a right angled triangle.

Cos θ = $\frac{AN}{B}$ ∴ AN = B Cos θ *and*

Sin θ = $\frac{BN}{B}$ ∴ BN = B Sin θ

For ΔOBN,

we have $OB^2 = ON^2 + BN^2$

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

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

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

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

which is the magnitude of the resultant of *A* and *B*

**Direction of resultant vectors:**

5) If θ is the angle between $\vec{A}$ and $\vec{B}$, then $|\vec{A} + \vec{B}| = \sqrt{A^2 + B^2 + 2AB\cos\theta}$

If $\vec{R}$ makes an angle α with $\vec{A}$ , then in ΔOBN,

$$\tan\alpha = \frac{BN}{ON} = \frac{BN}{OA+AN}$$

$$\tan\alpha = \left(\frac{B\sin\theta}{A+B\cos\theta}\right)$$

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

**17. Discuss the properties of scalar and vector products.**

**Properties of scalar products**

1) The product quantity $\vec{A} \cdot \vec{B}$ is always a scalar. It is positive if the angle between the vectors is acute (i.e., < 90°) and negative if the angle between them is obtuse (i.e. 90°<θ< 180°).
2) The scalar product is commutative, i.e. $\vec{A} \cdot \vec{B} = \vec{B} \cdot \vec{A}$
3) The vectors obey distributive law i.e. $\vec{A} \cdot (\vec{B} + \vec{C}) = \vec{A} \cdot \vec{B} + \vec{A} \cdot \vec{C}$
4) The angle between the vectors $\theta = \cos^{-1}\left[\frac{\vec{A} \cdot \vec{B}}{AB}\right]$
5) The scalar product of two vectors will be maximum when Cos θ = 1, i.e. $\theta = 0^0$, i.e., when the vectors are parallel; $(\vec{A} \cdot \vec{B})_{max} = AB$
6) The scalar product of two vectors will be minimum, when Cos θ = –1, i.e. $\theta = 180^0$ $(\vec{A} \cdot \vec{B})_{min} = -AB$ when the vectors are anti-parallel.

**Properties of vector (cross) product.**

i) The vector product of any two vectors is always another vector whose direction is perpendicular to the plane containing these two vectors, i.e., orthogonal to both the vectors $\vec{A}$ and $\vec{B}$, even though the vectors $\vec{A}$ and $\vec{B}$ may or may not be mutually orthogonal.

ii) The vector product of two vectors is not commutative, i.e., $\vec{A}x\vec{B} \neq \vec{B}x\vec{A}$ But., $\vec{A}x\vec{B} = -[\vec{B} \times \vec{A}]$. Here it is worthwhile to note that $|\vec{A}x\vec{B}| = |\vec{B}x\vec{A}|$ = AB Sin θ. i.e. in the case of the product vectors $\vec{A}x\vec{B}$ and $\vec{B}x\vec{A}$, the magnitudes are equal but directions are opposite to each other

iii) The vector product of two vectors will have maximum magnitude when sin θ = 1, i.e., $\theta = 90^0$ i.e., when the vectors $\vec{A}$ and $\vec{B}$, are orthogonal to each other. $(\vec{A} \times \vec{B})_{max} = AB\hat{n}$

iv) The vector product of two non–zero vectors will be minimum when sin θ = 0, *i.e.*, $\theta = 0^0$ *or* $180^0$ $[\vec{A} \times \vec{B}]_{min} = 0$ i.e., the vector product of two non–zero vectors vanishes, if the vectors are either parallel or anti-parallel.

v) The self–cross product, i.e., product of a vector with itself is the null vector $\vec{A} \times \vec{A} = AA \sin\theta\, \hat{n} = \vec{0}$ In physics the null vector $\vec{0}$ is simply denoted as zero.

vi) The self–vector products of unit vectors are thus zero. $\hat{\imath} \times \hat{\imath} = \hat{\jmath} \times \hat{\jmath} = \hat{k} \times \hat{k} = \vec{0}$

**18. Derive the kinematic equations of motion for constant acceleration.**

Consider an object moving in a straight line with uniform or constant acceleration 'a'. Let u be the velocity of the object at time t = 0, and v be velocity of the body at a later time t.

**Velocity - time relation :**

1) The acceleration of the body at any instant is given by the first derivative of the velocity with respect to time, $a = \frac{dv}{dt}$ or dv = a .dt

Integrating both sides with the condition that as time changes from 0 to t, the Velocity changes from u to v. For the constant acceleration,

$$\int_u^v dv = \int_0^t a dt$$

$$= a \int_u^v dt \Rightarrow [v]_u^v = a\,[t]_0^t \quad \text{--------(1)}$$

v – u = at (or) v = u + at

**Displacement – time relation :**

2) The velocity of the body is given by the first derivative of the displacement with respect to time. $v = \frac{ds}{dt}$ or ds = v dt and since v = u + at We get ds = (u + at )dt

Assume that initially at time t = 0, the particle started from the origin. At a later time t, the particle displacement is s. Further assuming that acceleration is time independent, we have $\int_0^s ds$

$$= \int_0^t u dt + \int_0^t a t dt \text{ or } s = ut + \tfrac{1}{2} at^2 \quad \text{--------------(2)}$$

**Velocity – displacement relation :**

3) The acceleration is given by the first derivative of velocity with respect to time.

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

[since ds / dt = v where s is distance traversed]

This is rewritten as $a = \frac{1}{2}\frac{dv^2}{ds}$ or $ds = \frac{1}{2a} d(v^2)$

4) Integrating the above equation, using the fact when the velocity changes from $u^2$ to $v^2$, displacement changes from 0 to s, we get

$$\int_0^s ds$$

$$= \int_u^v \frac{1}{2a} d(v^2) \;;\; s = \frac{1}{2a}(v^2 - u^2) \;;\; v^2 = u^2 + 2as \quad \text{------------(3)}$$

5) We can also derive the displacement s in terms of initial velocity u and final velocity v. From the equation (1) we can write, at = v – u

Substitute this in equation (2), we get

s = ut + ½ (v – u )t

$$s = \frac{(u+v)t}{2} \quad \text{-----------------(4)}$$

The equations (1), (2), (3) and (4) are called kinematic equations of motion, and have a wide variety of practical applications.

**Kinematic equations**

$v = u + at$ ; $s = ut + \frac{1}{2}at^2$ ; $v^2 = u^2 + 2as$ ; $s = \frac{(u+v)t}{2}$

**19. Define the term motion and explain the different types of motion.**

An object is said to be in motion if it changes its position with respect to its surroundings with the passage of time.

**a) Linear motion**

An object is said to be in linear motion if it moves in a straight line.

**Examples**

1) An athlete running on a straight track
2) A particle falling vertically downwards to the Earth.

**b) Circular motion**

Circular motion is defined as a motion described by an object traversing a circular path.

**Examples**

1) The whirling motion of a stone attached to a string
2) The motion of a satellite around the Earth

**c) Rotational motion**

If any object moves in a rotational motion about an axis, the motion is called 'rotation'.

**Examples**

i) Rotation of a disc about an axis through its center
ii) Spinning of the Earth about its own axis.

**d) Vibratory motion**

If an object or particle executes a to–and– fro motion about a fixed point, it is said to be in vibratory motion.

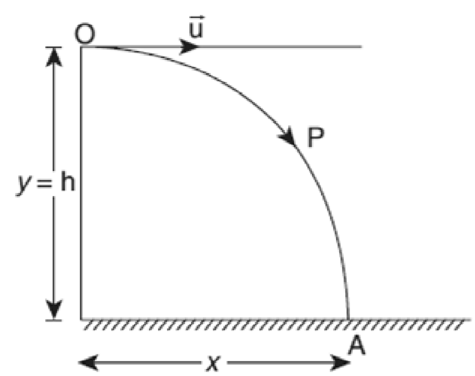
**Examples**

i) Vibration of a string on a guitar ii) Movement of a swing

**20. Find horizontal range and time of flight projectile in horizontal projection.**

Consider a projectile, say a ball, thrown horizontally with an initial velocity $\vec{u}$ from the top of a tower of height $h$ (Figure)

1) As the ball moves, it covers a horizontal distance due to its uniform horizontal velocity $u$, and a vertical downward distance because of constant acceleration due to gravity $g$.
2) Thus, under the combined effect the ball moves along the path OPA. The motion is in a 2-dimensional plane. Let the ball take time $t$ to reach the ground at point A, Then the horizontal distance travelled by the ball is $x(t) = x$, and the vertical distance travelled is $y(t) = y$



**Motion along horizontal direction**

3) The particle has zero acceleration along *x* direction. So, the initial velocity $u_x$ remains constant throughout the motion. The distance traveled by the projectile at a time *t* is given by the equation $x = u_x t + ½ at^2$ Since a = 0 along *x* direction, we have

$x = u_x t$ --------------------(1)

**Motion along downward direction**

4) Here $u_y = 0$ (initial velocity has no downward component), a = g (we choose the +ve y-axis in downward direction), and distance y at time t

From equation, $y = u_y t + ½ at^2$ , we get $y = ½ gt^2$ ----------(2)

Substituting the value of t from equation (1) in equation (2) we have

$$y = \frac{1}{2} g \frac{x^2}{u_x^2} = \left(\frac{g}{2u_x^2}\right)x^2$$

$\mathbf{y = Kx^2}$ --------------- (3), where $K = \frac{g}{2u_x^2}$

5) Equation is the equation of a parabola. Thus, the path followed by the projectile is a parabola (curve OPA in the Figure)

**Time of Flight:**

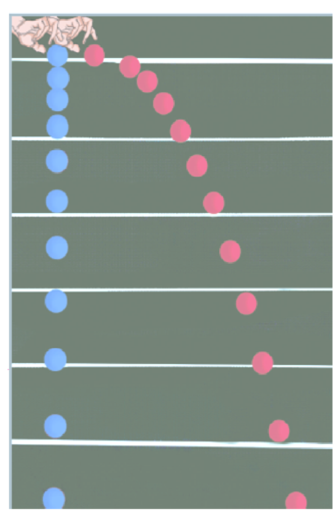
h be the height of a tower. Let T be the time taken by the projectile to hit the ground, after being thrown horizontally from the tower.

$s_y = u_y t + ½ at^2$ $s_y$=h, t=T, $u_y$=0 (i.e no initial vertical velocity)

$$T = \sqrt{\frac{2h}{g}}$$

6) Thus, the time of flight for projectile motion depends on the height of the tower, but is independent of the horizontal velocity of projection.

**Horizontal range:**



The horizontal distance covered by the projectile from the foot of the tower to the point where the projectile hits the ground is called horizontal range. For horizontal motion, we have $s_x = u_x t + ½ at^2$

Here, $s_x$ = R (range), $u_x = u$, a = 0 (no horizontal acceleration) *T* is time of flight.

Then horizontal range **=** *uT*.

7) Since the time of flight $T = \sqrt{\frac{2h}{g}}$, we substitute this and

we get the horizontal range of the particle as $R = u\sqrt{\frac{2h}{g}}$.

8) The above equation implies that the range R is directly proportional to the initial velocity *u* and inversely proportional to acceleration due to gravity *g*.

## UNIT – 03 LAWS OF MOTION

## TWO MARKS AND THREE MARKS:

**01. Explain the concept of inertia. Write two examples each for inertia of motion, inertia of rest and inertia of direction.**

This inability of objects to move on its own or change its state of motion is called inertia. Inertia means resistance to change its state.

Examples:

**Inertia of Rest** :

i) Passengers experience a backward push in a sudden start of bus.

ii) Tightening of seat belts in a car when it stops quickly.

**Inertia of Motion:**

i) Passengers experience a forward push during a sudden brake in bus.

ii) Ripe fruits fall from the trees in the direction of wind.

**Inertia of Direction:**

i) A stone moves tangential to Circle.

ii) When a car moves towards left, we turn to the right.



**02. What is the meaning by 'pseudo force'?**

Centrifugal force is called as a 'pseudo force'. A pseudo force has no origin. A pseudo force is an apparent force that acts on all masses whose motion is described using non inertial frame of reference such as a rotating reference frame.

**03. Define impulse.**

If a very large force acts on an object for a very short duration, then the force is called impulsive force or impulse.

**04. Define Inertia of rest, motion and direction.**

The inability of an object to change its state of rest is called **inertia of rest.**

The inability of an object to change its direction of motion on its own is called **inertia of direction.**

The inability of an object to change its state of uniform speed on its own is called **inertia of motion.**

**05. State the law of conservation of total linear momentum.**

If there are no external forces acting on the system, then the total linear momentum Of the system ($\vec{p}_{\text{tot}}$) is always a constant vector.

In other words, the total linear momentum of the system is conserved in time.

**06. What is the role of air bag in a car?**

Cars are designed with air bags in such a way that when the car meets with an accident, the momentum of the passengers will reduce slowly so that the average force acting on them will be smaller.

**07. Define Angle of Friction.**

The angle of friction is defined as the angle between the normal force (N) and the resultant force (R) of normal force and maximum friction force ( $f_s^{max}$ )

**08. What are the applications of angle of repose?**

01. The angle of inclination of sand trap is made to be equal to angle of repose.
02. Children are fond of playing on sliding board. Sliding will be easier when the angle of inclination of the board is greater than the angle of repose.

**09. How does the rolling wheel's work in suitcase?**

01. In rolling motion when a wheel moves on a surface, the point of contact with surface is always at rest.
02. Since the point of contact is at rest, there is no relative motion between the wheel and surface. Hence the frictional force is very less.

**10. How did the ball bearing reduce kinetic friction?**

If ball bearings are fixed between two surfaces, during the relative motion only the rolling friction comes to effect and not kinetic friction.

**11. Why is it dangerous to stand near the open door of moving bus?**

It is dangerous to stand near the open door (or) steps while travelling in the bus. When the bus takes a sudden turn in a curved road, due to centrifugal force the person is pushed away from the bus. Even though centrifugal force is a pseudo force, its effects are real.



**12. When a cricket player catches the ball, he/she pulls his /her hands gradually in The direction of the ball's motion. Why?**

01. If he stops his hands soon after catching the ball, the ball comes to rest very quickly.
02. It means that the momentum of the ball is brought to rest very quickly.
03. So the average force acting on the body will be very large.
04. Due to this large average force, the hands will get hurt.
05. To avoid getting hurt, the player brings the ball to rest slowly

**13. A man jumping on concrete floor is more dangerous than in sand floor, why?**

01. Jumping on a concrete cemented floor is more dangerous than jumping on the sand.
02. Sand brings the body to rest slowly than the concrete floor, so that the average force experienced by the body will be lesser.

## FIVE MARKS QUESTIONS:

**14. What are concurrent forces? State Lami's theorem.**

A collection of forces is said to be concurrent, if the lines of forces act at a common point. If they are in the same plane, they are concurrent as well as coplanar forces.

If a system of three concurrent and coplanar forces is in equilibrium, then Lami's Theorem states that the magnitude of each force of the system is proportional to sine of the angle between the other two forces. The constant of proportionality is same for all three forces. $\frac{|\vec{F}_1|}{\text{Sin}\alpha} = \frac{|\vec{F}_2|}{\text{Sin}\beta} = \frac{|\vec{F}_2|}{\text{Sin}\gamma}$

**Example:**

A baby is playing in a swing which is hanging with the help of two identical chains is At rest. Identify the forces acting on the baby. Apply Lami's theorem and find out the tension acting on the chain.

**15. State Newton's three laws and discuss their significance.**

**Newton's First Law :**

i) Every object continues to be in the state of rest or of uniform motion (constant velocity) unless there is external force acting on it.

ii) This inability of objects to move on its own or change its state of motion is called inertia. Inertia means resistance to change its state.

**Newton's Second Law :**

i) The force acting on an object is equal to the rate of change of its momentum $\vec{F} = \frac{d\vec{p}}{dt}$

ii) In simple words, whenever the momentum of the body changes, there must be a force acting on it. The momentum of the object is defined as $\vec{p} = m\vec{v}$. In most cases, the mass of the object remains constant during the motion. In such cases, the above equation gets modified into a simpler form $\vec{F} = \frac{d(m\vec{v})}{dt}$ $= m\frac{d\vec{v}}{dt} = m\vec{a}$ . $\boldsymbol{\vec{F} = m\vec{a}}$

**Newton's third law :**

i) Newton's third law assures that the forces occur as equal and opposite pairs. An isolated force or a single force cannot exist in nature.

ii) Newton's third law states that for every action there is an equal and opposite reaction.

iii) Here, action and reaction pair of forces do not act on the same body but on two different bodies.

iv) Any one of the forces can be called as an action force and the other the reaction force. Newton's third law is valid in both inertial and non-inertial frames.

v) These action-reaction forces are not cause and effect forces. It means that when the object 1 exerts force on the object 2, the object 2 exerts equal and opposite force on the body 1 at the same instant.

**16. Explain the similarities and differences of centripetal and centrifugal forces.**

| Centripetal force | Centrifugal force |
|---|---|
| It is a real force which is exerted on the body by the external agencies like gravitational force, tension in the string, normal force etc. | It is a pseudo force or fictitious force which cannot arise from gravitational force, tension force, normal force etc. |
| Acts in both inertial and non-inertial frames | Acts only in rotating frames (non-inertial frame) |
| It acts towards the axis of rotation or center of the circle in circular motion | It acts outwards from the axis of rotation or radially outwards from the center of the circular motion |
| $\lvert F_{cp}\rvert = m\omega^2 r = \frac{mv^2}{r}$ | $\lvert F_{cf}\rvert = m\omega^2 r = \frac{mv^2}{r}$ |
| Real force and has real effects. | Pseudo force but has real effects |
| Origin of centripetal force is interaction between two objects | Origin of centrifugal force is inertia. It does not arise from interaction. |

**17. Briefly explain 'centrifugal force' with suitable examples.**

i) Consider the case of a whirling motion of a stone tied to a string. Assume that the stone has angular velocity $\omega$ in the inertial frame (at rest).

ii) If the motion of the stone is observed from a frame which is also rotating along with the stone with same angular velocity $\omega$ then, the stone appears to be at rest.

iii) This implies that in addition to the inward centripetal force $-m\omega^2 r$ there must be an equal and opposite force that acts on the stone outward with value $+m\omega^2 r$.

iv) So the total force acting on the stone in a rotating frame is equal to zero $(-m\omega^2 r + m\omega^2 r = 0)$.

v) This outward force $+m\omega^2 r$ is called the centrifugal force.

**18. Briefly explain 'Rolling Friction'.**

i) One of the important applications is suitcases with rolling on coasters. Rolling wheels makes it easier than carrying luggage.

ii) When an object moves on a surface, essentially it is sliding on it. But wheels move on the surface through rolling motion.

iii) **In rolling motion** when a wheel moves on a surface, **the point of contact with surface is always at rest.**

iv) **Since the point of contact is at rest**, there is no relative motion between the wheel and surface. Hence the **frictional force is very less**. At the same time if an object moves **without a wheel**, there is a relative motion between the object and the surface.

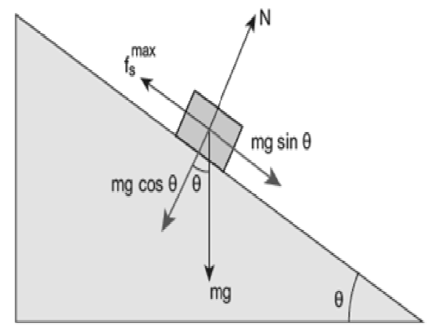
v) As a result **frictional force is larger**. This makes it **difficult to move the object**.

vi) Ideally in pure rolling, motion of the point of contact with the surface should be at rest, but in practice it is not so.

vii) Due to the elastic nature of the surface at the point of contact there will be some deformation on the object at this point on the wheel or surface.

**19. Describe the method of measuring Angle of Repose.**

i) Consider an inclined plane on which an object is placed. Let the angle which this plane makes with the horizontal be θ . For small angles of θ , the object may not slide down.




ii) As θ is increased, for a particular value of θ , the object begins to slide down. This value is called angle of repose. Hence, the angle of repose is the angle of inclined plane with the horizontal such that an object placed on it begins to slide.

iii) Consider the various forces in action here. The gravitational force mg is resolved into components parallel (*mg* sin θ ) and perpendicular (*mg* cos θ ) to the inclined plane.

iv) The component of force parallel to the inclined plane (mg sin θ) tries to move the object down. The component of force perpendicular to the inclined plane (mg cos θ) is balanced by the Normal force (N).

$$N = mg \cos\theta \quad \text{--------------(1)}$$

When the object just begins to move, the static friction attains its maximum value, $f_s = f_s^{max} = \mu_s$ N. This friction also satisfies the relation

$$f_s^{max} = \mu_s \, mg \sin\theta \quad \text{------------- (2)}$$

Equating the right hand side of equations (1) and (2), we get

$$(f_s^{max}) / N = \sin\theta / \cos\theta$$

From the definition of angle of friction, we also know that **$\tan\theta = \mu_s$** in which **θ** is the angle of friction. Thus the angle of repose is the same as angle of friction.



**20. Explain the need for banking of tracks.**

i) In a leveled circular road, skidding mainly depends on the coefficient of static friction $\mu_s$ The coefficient of static friction depends on the nature of the surface which has a maximum limiting value.

ii) To avoid this problem, usually the **outer edge of the road is slightly raised compared to inner edge**

iii) This is **called banking of roads or tracks**. This introduces an inclination, and the angle is called banking angle.

iv) Let the surface of the road make angle θ with horizontal surface. Then the normal force makes the same angle θ with the vertical.

v) When the car takes a turn, there are two forces acting on the car:

a) Gravitational force mg (downwards)

b) Normal force N (perpendicular to surface)

vi) We can resolve the normal force into two components. *N* cos θ and *N* sin θ

vii) The component *N* cos θ balances the downward gravitational force 'mg' and component *N* sin θ will provide the necessary centripetal acceleration.

By using Newton second law

N cos θ = mg ; N sin θ = $\frac{mv^2}{r}$

By dividing the equations we get, tan θ = $\frac{v^2}{rg}$

**v =** $\sqrt{\mathbf{rg\tan\theta}}$

**Need Banking of tracks:**

1) The banking angle θ and radius of curvature of the road or track determines the Safe speed of the car at the turning. If the speed of car exceeds this safe speed, then it starts to skid outward but frictional force comes into effect and provides an additional centripetal force to prevent the outward skidding.
2) At the same time, if the speed of the car is little lesser than safe speed, it starts to skid inward and frictional force comes into effect, which reduces centripetal force to prevent inward skidding.
3) However if the speed of the vehicle is sufficiently greater than the correct speed, then frictional force cannot stop the car from skidding.

**21. Write the salient features of Static and Kinetic friction.**

| Static friction | Kinetic friction |
|---|---|
| It opposes the starting of motion | It opposes the relative motion of the object with respect to the surface |
| Independent of surface of contact | Independent of surface of contact |
| $\mu_s$ depends on the nature of materials in mutual contact | $\mu_k$ depends on nature of materials and temperature of the surface |
| Depends on the magnitude of applied force | Independent of magnitude of applied force |
| It can take values from zero to $\mu_s N$ | It can never be zero and always equals to $\mu_k N$ whatever be the speed (true <10 $ms^{-1}$) |
| $f_s^{max} > f_k$ | It is less than maximal value of static friction |
| $\mu_s > \mu_k$ | Coefficient of kinetic friction is less than coefficient of static friction |

## UNIT – 04 WORK , ENERGY AND POWER

## TWO MARKS AND THREE MARKS:

**01. Write the differences between conservative and Non-conservative forces. Give two examples each.**

| Conservative forces | Non-conservative forces |
|---|---|
| Work done is independent of the path | Work done depends upon the path |
| Work done in a round trip is zero | Work done in a round trip is not zero |
| Total energy remains constant | Energy is dissipated as heat energy |
| Work done is completely recoverable | Work done is not completely recoverable |
| Force is the negative gradient of potential energy | No such relation exists. |

**02. Explain the characteristics of elastic and inelastic collision.**

| Elastic Collision | Inelastic Collision |
|---|---|
| Total momentum is conserved | Total momentum is conserved |
| Total kinetic energy is conserved | Total kinetic energy is not conserved |
| Forces involved are conservative forces | Forces involved are non-conservative forces |
| Mechanical energy is not dissipated | Mechanical energy is dissipated into heat, light, sound etc. |



**03. Define the following**

**a) Coefficient of restitution b) Power c) Law of conservation of energy**

**a) Coefficient of restitution**

It is defined as the ratio of velocity of separation (relative velocity) after collision to the velocity of approach (relative velocity) before collision, i.e.,

$$e = \frac{\text{Velocity of separation (after collision)}}{\text{Velocity of approach (before collision)}} ; \frac{(v_2 - v_1)}{(u_1 - u_2)}$$

**b) Power**

The rate of work done or energy delivered.

$$\text{Power (P)} = \frac{\text{Workdone (W)}}{\text{Time taken (t)}}$$

**c) Law of conservation of energy**

Energy can neither be created nor destroyed. It may be transformed from one form to another but the total energy of an isolated system remains constant.

**04. Define unit of power:**

One watt is defined as the power when one joule of work is done in one second.

$1W = 1Js^{-1}$

**05. Explain Work done.**

i) Work is said to be done by the force when the force applied on a body displaces it.

ii) work done is a scalar quantity. It has only magnitude and no direction.

iii) In SI system, unit of work done is N m (or) joule (J). Its dimensional formula is $ML^2T^{-2}$

**06. Define Energy, Kinetic energy and Potential Energy**

**Energy:** The capacity to do work , Dimension : $ML^2T^{-2}$ , SI Unit : Nm or joule .

**Kinetic energy :** The energy possessed by a body due to its motion.
Dimension : $ML^2T^{-2}$ , SI Unit : Nm or joule .

**Potential Energy:** The energy possessed by the body by virtue of its position
Dimension : $ML^2T^{-2}$ , SI Unit : Nm or joule .

**07. Write the significance of kinetic energy in the work – kinetic energy theorem.**

1. If the work done by the force on the body is **positive** then its **kinetic energy increases.**
2. If the work done by the force on the body is **negative** then its **kinetic energy decreases**.
3. If there is **no work done** by the force on the body then there is **no change** in its kinetic energy



**08. Define Work – kinetic energy theorem.**

The work done by the force on the body changes the kinetic energy of the body. This is called work-kinetic energy theorem.

**09. Define elastic potential energy**

The potential energy possessed by a spring due to a deforming force which stretches or compresses the spring is termed as elastic potential energy.

**10. Define A*verage power***

The average power ($P_{av}$) is defined as the ratio of the total work done to the total time taken. $P_{av} = \frac{\text{Total work done}}{\text{Total time taken}}$

**11. Define Instantaneous power**

The instantaneous power ($P_{inst}$) is defined as the power delivered at an instant (as Time interval approaches zero), $P_{inst}= \frac{dw}{dt}$

**12. What is meant by collision?**

Collision is a common phenomenon that happens around us every now and then. For example, carom, billiards, marbles, etc.,. Collisions can happen between two bodies with or without physical contacts.

**13. What is Elastic Collision?**

In a collision, the total initial kinetic energy of the bodies (before collision) is equal To the total final kinetic energy of the bodies (after collision) then, it is called as elastic collision. i.e., Total kinetic energy before collision = Total kinetic energy after collision

**14. What is Inelastic Collision?**

In a collision, the total initial kinetic energy of the bodies (before collision) is not equal to the total final kinetic energy of the bodies (after collision) then, it is called as inelastic collision. i.e., Total kinetic energy before collision ≠ Total kinetic energy after collision

## FIVE MARKS QUESTIONS

**15. State and explain work energy principle. Mention any three examples for it.**

1) It states that work done by the force acting on a body is equal to the change produced in the kinetic energy of the body.
2) Consider a body of mass m at rest on a frictionless horizontal surface.
3) The work (W) done by the constant force (F) for a displacement (s) in the same direction is, W = Fs ------------- (1)

The constant force is given by the equation, F = ma ---------- (2)

The third equation of motion can be written as, $v^2 = u^2 + 2as$

$a = \frac{v^2-u^2}{2s}$ ------------------- (3)

Substituting for a in equation (2), $F = m\left(\frac{v^2-u^2}{2s}\right)$ ------------- (4)

Substituting equation (4) in (1), $W = m\left(\frac{v^2}{2s}s\right) - m\left(\frac{u^2}{2s}s\right)$

$W = \frac{1}{2} mv^2 - \frac{1}{2} mu^2$ --------------------- (5)

**The expression for kinetic energy**:

i) The term ½ ($mv^2$ ) in the above equation is the kinetic energy of the body of mass (m) moving with velocity (v). KE = ½ $mv^2$ ------------------ (6)

ii) Kinetic energy of the body is always positive. From equations (5) and (6) $\Delta KE = \frac{1}{2} mv^2 - \frac{1}{2} mu^2$ -----------------(7) thus, W = ΔKE

iii) The expression on the right hand side (RHS) of equation (7) is the change in kinetic energy (ΔKE) of the body.

iv) This implies that the work done by the force on the body changes the kinetic energy of the body. This is called work-kinetic energy theorem.

**16. Deduce the relation between momentum and kinetic energy.**

i) Consider an object of mass m moving with a velocity $\vec{v}$. Then its linear momentum is $\vec{p} = m\vec{v}$ and its kinetic energy, KE = ½ $mv^2$

KE = ½ $mv^2$ ; = ½ $m(\vec{v}.\vec{v})$ --------(1)

ii) Multiplying both the numerator and denominator of equation (1) by mass, m

$$KE = \frac{1}{2}\frac{m^2(\vec{v}.\vec{v})}{m} \;;\; = \frac{1}{2}\frac{(m\vec{v}).(m\vec{v})}{m} \;[\vec{p} = m\vec{v}] \;;\; = \frac{1}{2}\frac{(\vec{p}).(\vec{p})}{m}$$

$$= \frac{\vec{p}^2}{2m} \;;\; KE = \frac{p^2}{2m}$$

iii) Where $|\vec{p}|$is the magnitude of the momentum. The magnitude of the linear momentum can be obtained by $|\vec{p}| = p = \sqrt{2m(KE)}$

iv) Note that if kinetic energy and mass are given, only the magnitude of the momentum can be calculated but not the direction of momentum. It is because the kinetic energy and mass are scalars.

## UNIT – 05 MOTION OF SYSTEM OF PARTICLES AND RIGID BODIES

## TWO MARKS AND THREE MARKS:

**01. Define center of mass.**

A point where the entire mass of the body appears to be concentrated.

**02. What is equilibrium?**

i) A rigid body is said to be in mechanical equilibrium when both its linear momentum and angular momentum remain constant.

ii) When all the forces act upon the object are balanced, then the object is said to be an equilibrium.

**03. Give any two examples of torque in day-to-day life.**

i) Opening and closing of a door about the hinges

ii) Turning of a nut using a wrench

iii) Opening a bottle cap (or) water top

**04. How do you distinguish between stable and unstable equilibrium?**

| **Stable equilibrium** | **Unstable equilibrium** |
|---|---|
| Linear momentum and angular momentum are zero. | Linear momentum and angular momentum are zero. |
| The body tries to come back to equilibrium if slightly disturbed and released. | The body cannot come back to equilibrium if slightly disturbed and released. |
| The center of mass of the body shifts slightly higher if disturbed from equilibrium. | The center of mass of the body shifts slightly lower if disturbed from equilibrium. |
| Potential energy of the body is minimum and it increases if disturbed. | Potential energy of the body is not minimum and it decreases if disturbed |

**05. Define couple.**

Pair of forces which are equal in magnitude but **opposite in direction** and separated by a **perpendicular distance** so that **their lines of action do not coincide** that causes a turning effect is called a couple

**06. Define center of gravity.**

The point at which the entire weight of the body acts irrespective of the position and orientation of the body.

**07. Mention any two physical significance of moment of inertia.**

i) For rotational motion, moment of inertia is a measure of rotational inertia.

ii) The moment of inertia of a body is not an invariable quantity. It depends not only on the mass of the body, but also on the way the mass is distributed around the axis of rotation.

**08. What is the difference between sliding and slipping?**

**Sliding** is the case when $v_{CM} > R\omega$ (or $v_{TRANS} > v_{ROT}$). The translation is more than the rotation.

**Slipping** is the case when $v_{CM} < R\omega$ (or $v_{TRANS} < v_{ROT}$). The rotation is more than the translation.

**09. Write the principles used in beam balance and define Mechanical Advantage.**

i) This forms the principle for beam balance used for weighing goods with the condition $d_1 = d_2$; $F_1 = F_2$. $\frac{F_1}{F_2} = \frac{d_2}{d_1}$

ii) If $F_1$ is the load and $F_2$ is our effort, we get advantage when, $d_1 < d_2$. This implies that $F_1 > F_2$. Hence, we could lift a large load with small effort. The ratio $\left(\frac{d_2}{d_1}\right)$ is called mechanical advantage of the simple lever. The pivoted point is called fulcrum. Mechanical Advantage (MA) = $\frac{d_2}{d_1}$

## CONCEPTUAL QUESTIONS:



**10. Two identical water bottles one empty and the other filled with water are allowed to roll down an inclined plane. Which one of them reaches the bottom first? Explain your answer.**

1) Bottle filled with water rolls, faster than the empty bottle. Due to M.I. $I = mr^2$
2) When it rolls, down it possesses translational KE and rotational KE
3) For the empty bottle 100% of the mass of the bottle spins as the bottle rolls.
4) But for full bottle, much of the water in the bottle is efficiency sliding down without spinning.
5) Thus 100% of the mass of the sliding water goes into translational KE and full bottle have a greater speed.

**11. Three identical solid spheres move down through three inclined planes A, B and C all same dimensions. A is without friction, B is undergoing pure rolling and C is rolling with slipping. Compare the kinetic energies $E_A$, $E_B$ and $E_C$ at the bottom.**

The KE of A without friction $E_A$ = ½ m (2gh)

The KE of B undergoes pure rolling $E_B$ = ½ m$\left(\frac{2gh}{1+\frac{K^2}{R^2}}\right)$

The KE of C rolling with slipping EC = ½ $m^2gh$

## FIVE MARKS QUESTIONS

**12. Explain the types of equilibrium with suitable examples**

**Translational equilibrium**

1) Linear momentum is constant
2) Net force is zero

**Rotational equilibrium**

1) Angular momentum is constant
2) Net torque is zero

**Static equilibrium**

1) Linear momentum and angular momentum are zero
2) Net force and net torque are zero

**Dynamic equilibrium**

1) Linear momentum and angular momentum are constant
2) Net force and net torque are zero

**Stable equilibrium**

1) Linear momentum and angular momentum are zero
2) The body tries to come back to equilibrium if slightly disturbed and released
3) The center of mass of the body shifts slightly higher if disturbed from equilibrium
4) Potential energy of the body is minimum and it increases if disturbed

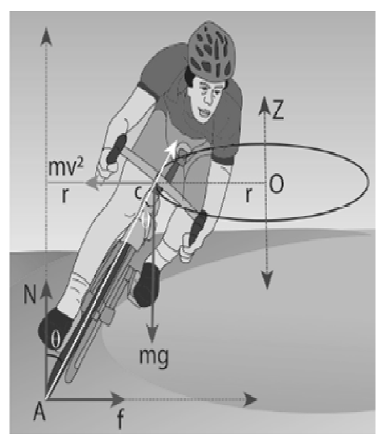
**Unstable equilibrium**

1) Linear momentum and angular momentum are zero
2) The body cannot come back to equilibrium if slightly disturbed and released
3) The center of mass of the body shifts slightly lower if disturbed from equilibrium
4) Potential energy of the body is not minimum and it decreases if disturbed

**Neutral equilibrium**

1) Linear momentum and angular momentum are zero
2) The body remains at the same equilibrium if slightly disturbed and released
3) The center of mass of the body does not shift higher or lower if disturbed from equilibrium
4) Potential energy remains same even if disturbed

**13. Explain why a cyclist bends while negotiating a curve road? Arrive at the expression for angle of bending for a given velocity.**




i) Let us consider a cyclist negotiating a circular level road (not banked) of radius r with a speed v.

ii) The cycle and the cyclist are considered as one system with mass m. The center gravity of the system is C and it goes in a circle of radius r with center at O.

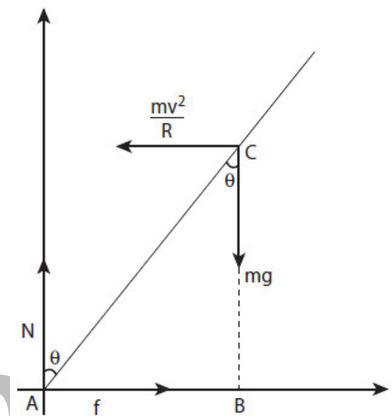
iii) Let us choose the line OC as X-axis and the vertical line through O as Z-axis as shown in Figure

iv) The system as a frame is rotating about Z-axis. The system is at rest in this rotating frame. To solve problems in rotating frame of reference, we have to apply a centrifugal force (pseudo force) on the system which will be $\frac{mv^2}{r}$.This force will act through the center of gravity.

v) The forces acting on the system are, (i) gravitational force (mg), (ii) normal force (N), (iii) frictional force (f) and (iv) centrifugal force $\left(\frac{mv^2}{r}\right)$

vi) As the system is in equilibrium in the rotational frame of reference, the net external force and net external torque must be zero. Let us consider all torques about the point A in Figure

vii) For rotational equilibrium, $\vec{\tau}$net = 0. The torque due to the gravitational force about point A is (mgAB) which causes a clockwise turn that is taken as negative. The torque due to the centripetal force is $\left(\frac{mv^2}{r}BC\right)$which causes an anticlockwise turn that is taken as positive.




$-$ mgAB + $\frac{mv^2}{r}$ BC = 0 ; mg AB = $\frac{mv^2}{r}$ BC

From ΔABC,

AB = ACsinθ and BC = ACcosθ

mg ACsinθ = $\frac{mv^2}{r}$ ACcosθ; tan θ = $\frac{v^2}{rg}$

**θ = tan$^{-1}$ $\left(\frac{v^2}{rg}\right)$**

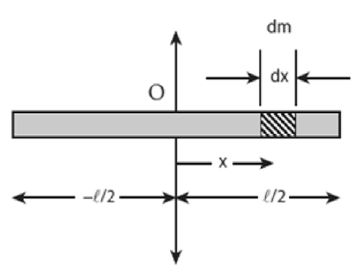
viii) While negotiating a circular level road of radius r at velocity v, a cyclist has to bend by an angle θ from vertical given by the above expression to stay in equilibrium (i.e. to avoid a fall).



**14. Derive the expression for moment of inertia of a rod about its center and perpendicular to the rod.**

1) Let us consider a uniform rod of mass (M) and length ($l$) as shown in Figure . Let us find an expression for moment of inertia of this rod about an axis that passes through the center of mass and perpendicular to the rod.

2) First an origin is to be fixed for the coordinate system so that it coincides with the center of mass, which is also the geometric center of the rod. The rod is now along the x axis.




3) We take an infinitesimally small mass (dm) at a distance (x) from the origin. The moment of inertia (dI) of this mass (dm) about the axis is,

dI = (dm)$x^2$

As the mass is uniformly distributed, the mass per unit length ($\lambda$) of the rod is,

$\lambda = \frac{M}{l}$

The (dm) mass of the infinitesimally small length as, dm = λ, dx = $\frac{M}{l}$dx.

The moment of inertia (I) of the entire rod can be found by integrating dI, I = $\int dI = \int (dm)x^2$ ; $\int \left(\frac{M}{l}dx\right)x^2$ ;

I = $\frac{M}{l}\int x^2 dx$

4) As the mass is distributed on either side of the origin, the limits for integration are taken from $-\frac{l}{2}$ to $\frac{l}{2}$

I = $\frac{M}{l}\int_{\frac{-l}{2}}^{\frac{l}{2}} x^2 dx$ ; = $\frac{M}{l}\left[\frac{x^3}{3}\right]_{\frac{-l}{2}}^{\frac{l}{2}}$

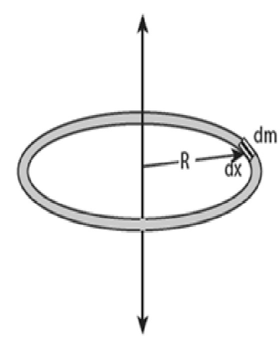
I = $\frac{M}{l}\left[\frac{l^3}{24} - \left(-\frac{l^3}{24}\right)\right]$ ; = $\frac{M}{l}\left[\frac{l^3}{24} + \frac{l^3}{24}\right]$

I = $\frac{M}{l}\left[2\left(\frac{l^3}{24}\right)\right]$ ;

**I = $\frac{1}{12}$m$l^2$**

**15. Derive the expression for moment of inertia of a uniform ring about an axis passing through the center and perpendicular to the plane.**

1) Consider a uniform ring of mass M and radius R. To find the moment of inertia of the ring about an axis passing through its center and perpendicular to the plane, let us take an infinitesimally small mass (dm) of length (dx) of the ring.




2) This (dm) is located at a distance R, which is the radius of the ring from the axis as shown in Figure

The moment of inertia (dI) of this small mass (dm) is,

dI = (dm)$R^2$

The length of the ring is its circumference (2πR). As the mass is uniformly distributed, the mass per unit length ($\lambda$ ) is,

$\lambda = \frac{M}{2\pi R}$

The (dm) mass of the infinitesimally small length as, dm = λ, dx = $\frac{M}{2\pi R}$dx.

Now, the moment of inertia (I) of the entire ring is,

I = $\int dI = \int (dm)R^2$ ;

$\int \left(\frac{M}{2\pi R}dx\right)R^2$

I = $\frac{MR}{2\pi}\int dx$

To cover the entire length of the ring, the limits of integration are taken from 0 to 2πR

I = $\frac{MR}{2\pi}\int_0^{2\pi R} dx$ ; = $\frac{MR}{2\pi}[x]_0^{2\pi R}$ ;

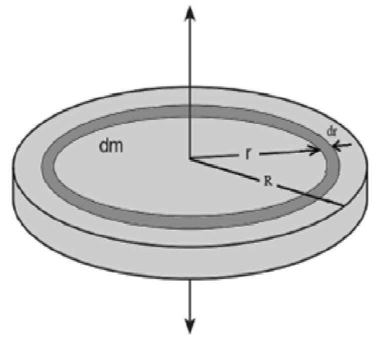
= $\frac{MR}{2\pi}[2\pi R - 0]$

**I = M$R^2$**

**16. Derive the expression for moment of inertia of a uniform disc about an axis passing through the center and perpendicular to the plane.**

i) Consider a disc of mass M and radius R. This disc is made up of many infinitesimally small rings as shown in Figure. Consider one such ring of mass (dm) and thickness (dr) and radius (r). The moment of inertia (dI) of this small ring is, $dI = (dm)r^2$

ii) As the mass is uniformly distributed, the mass per unit area (σ) is, $\sigma = \frac{M}{\pi R^2}$




The mass of the infinitesimally small ring is,

$dm = \sigma 2\pi r dr = \frac{M}{\pi R^2} 2\pi r dr$

where, the term (2πr dr) is the area of this elemental ring (2πr is the length and dr is the thickness) $dm = \frac{2M}{R^2} r dr$. ; $dI = \frac{2M}{R^2} r^3 dr$

The moment of inertia (I) of the entire disc is, $I = \int dI$

$$I = \int_0^R \frac{2M}{R^2} r^3 dr; \quad = \frac{2M}{R^2} \int_0^R r^3 dr$$

$$I = \frac{2M}{R^2} \left[\frac{r^4}{4}\right]_0^R ; \quad = \frac{2M}{R^2} \left[\frac{R^4}{4} - 0\right]$$

$$\mathbf{I = \tfrac{1}{2} MR^2}$$



**17. State and prove parallel axis theorem.**

i) Parallel axis theorem states that the moment of inertia of a body about any axis is equal to the sum of its moment of inertia about a parallel axis through its center of mass and the product of the mass of the body and the square of the perpendicular distance between the two axes.

ii)If IC is the moment of inertia of the body of mass M about an axis passing through the center of mass, then the moment of inertia I about a parallel axis at a distance d from it is given by the relation, $I = I_C + Md^2$

iii) let us consider a rigid body as shown in Figure. Its moment of inertia about an axis AB passing through the center of mass is $I_C$. DE is another axis parallel to AB at a perpendicular distance d from AB. The moment of inertia of the body about DE is I.

We attempt to get an expression for I in terms of $I_C$. For this, let us consider a point mass m on the body at position x from its center of mass.

iv) The moment of inertia of the point mass about the axis DE is, $m(x + d)^2$. The moment of inertia I of the whole body about DE is the summation of the above expression.

$I = \Sigma m(x + d)^2$

This equation could further be written as,

$I = \Sigma m(x^2 + d^2 + 2xd)$

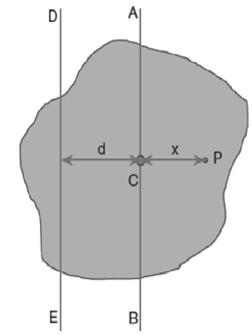
$I = \Sigma(mx^2 + md^2 + 2dmx)$

$I = \Sigma mx^2 + \Sigma md^2 + 2d\Sigma mx$

v) Here, $\Sigma mx^2$ is the moment of inertia of the body about the center of mass. Hence, $I_C = \Sigma mx^2$

The term, $\Sigma mx = 0$ because, x can take positive and negative values with respect to the axis AB. The summation $(\Sigma mx)$ will be zero

Thus, $I = I_C + \Sigma md^2$ ; $I_C + (\Sigma m)d^2$




vi) Here, $\Sigma m$ is the entire mass M of the object $(\Sigma m = M)$

$I = I_C + Md^2$

Hence, the parallel axis theorem is proved.

**18. State and prove perpendicular axis theorem.**

i) The theorem states that the moment of inertia of a plane laminar body about an axis perpendicular to its plane is equal to the sum of moments of inertia about two perpendicular axes lying in the plane of the body such that all the three axes are mutually perpendicular and have a common point.

ii) Let the X and Y-axes lie in the plane and Z-axis perpendicular to the plane of the laminar object. If the moments of inertia of the body about X and Y-axes are $I_X$ and $I_Y$ respectively and $I_Z$ is the moment of inertia about Z-axis, then the perpendicular axis theorem could be expressed as,

$I_Z = I_X + I_Y$

iii) To prove this theorem, let us consider a plane laminar object of negligible thickness on which lies the origin (O). The X and Y-axes lie on the plane and Z-axis is perpendicular to it as shown in Figure. The lamina is considered to be made up of a large number of particles of mass m. Let us choose one such particle at a point P which has coordinates (x, y) at a distance r from O.

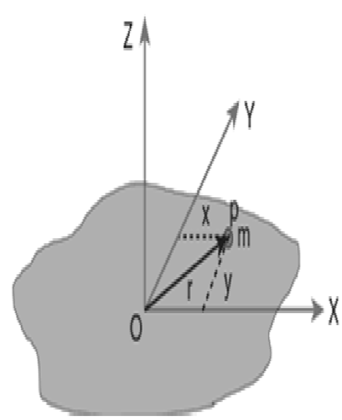
iv) The moment of inertia of the particle about Z-axis is, $mr^2$ The summation of the above expression gives the moment of inertia of the entire lamina about Z-axis as,

$I_Z = \Sigma mr^2$

Here, $r^2 = x^2 + y^2$

Then, $I_Z = \Sigma m ( x^2 + y^2 )$

$I_Z = \Sigma mx^2 + \Sigma my^2$




In the above expression, the term $\Sigma mx^2$ is the moment of inertia of the body about the Y-axis and similarly the term $\Sigma my^2$ is the moment of inertia about X-axis. Thus,

$I_X = \Sigma my^2$ and $I_Y = \Sigma mx^2$

Substituting in the equation for $I_z$ gives, $\mathbf{I_Z = I_X + I_Y}$

Thus, the perpendicular axis theorem is proved.

## UNIT – 06 GRAVITATION

## TWO MARKS AND THREE MARKS:

**01. State Kepler's three laws.**

1. **Law of orbits:** Each planet moves around the Sun in an elliptical orbit with the Sun at one of the foci.
2. **Law of area:** The radial vector (line joining the Sun to a planet) sweeps equal areas in equal intervals of time
3. **Law of period:** The square of the time period of revolution of a planet around the Sun in its Elliptical orbit is directly proportional to the cube of the semi-major axis of The ellipse.

**02. State Newton's Universal law of gravitation.**

Newton's law of gravitation states that a particle of mass $M_1$ attracts any other particle of mass $M_2$ in the universe with an attractive force. The strength of this force of attraction was found to be directly proportional to the product of their masses and is inversely proportional to the square of the distance between them.

**03. Why is there no lunar eclipse and solar eclipse every month?**

Moon's orbit is tilted $5^0$ with respect to Earth's orbit, only during certain periods of the year; the Sun, Earth and Moon align in straight line leading to either lunar eclipse or solar eclipse depending on the alignment.

**04. Why do we have seasons on Earth?**

The seasons in the Earth arise due to the rotation of Earth around the Sun with 23.5° tilt. Due to this 23.5° tilt, when the northern part of Earth is farther to the Sun, the southern part is nearer to the Sun. So when it is summer in the northern hemisphere, the southern hemisphere experience winter.

**05. Water falls from the top of a hill to the ground. Why?**

This is because the top of the hill is a point of higher gravitational potential than the surface of the Earth. i.e. $V_{hill} > V_{ground}$.

## FIVE MARKS QUESTIONS:

**06. Prove that at points near the surface of the Earth, the gravitational potential energy of the object is U = mgh.**

1) Consider the Earth and mass system, with *r*, the distance between the mass m and the Earth's centre. Then the gravitational potential energy,

$$U = -\frac{GM_e m}{r} \text{ ----------------- } 1$$

2) Here r = Re+h, where Re is the radius of the Earth. h is the height above the Earth's surface, $U = -G\frac{M_e m}{(R_e+h)}$ ------------- 2

If h << Re, equation (2) can be modified as

$$U = -G\frac{M_e m}{R_e\left(1+\frac{h}{R_e}\right)} \;;\quad U = -G\frac{M_e m}{R_e}\left(1+\frac{h}{R_e}\right)^{-1} \text{ ---------- } 3$$

3) By using Binomial expansion and neglecting the higher order terms, we get

$$U = -G\frac{M_e m}{R_e}\left(1-\frac{h}{R_e}\right) \text{ ---------- } 4$$

We know that, for a mass m on the Earth's surface,

$$G\frac{M_e m}{R_e} = mgR_e \text{ ---------------- } 5$$

Substituting equation (5) in (4) we get, $U = -mgR_e + mgh$

It is clear that the first term in the above expression is independent of the height h. For example, if the object is taken from h and it can be omitted.

**U = mgh**



**07. Derive an expression for escape speed.**

1) Consider an object of mass M on the surface of the Earth. When it is thrown up with an initial speed $v_i$ , the initial total energy of the object is

$$E_i = ½ MV_i^2 - \frac{GMM_E}{R_E} \text{ ---------------- } 1$$

Where $M_E$, is the mass of the Earth and $R_E$ - the radius of the Earth.

The term $-\frac{GMM_E}{R_E}$ is the potential energy of the mass M.

2) When the object reaches a height far away from Earth and hence treated as approaching infinity, the gravitational potential energy becomes zero [ U (∞) = 0] and the kinetic energy becomes zero as well. Therefore the final total energy of the object becomes zero. This is for minimum energy and for minimum speed to escape. Otherwise Kinetic energy can be non-zero.

$E_f = 0$ , According to the law of energy conservation, $E_i = E_f$ -------- 2

Substituting (1) in (2) we get,

$$½ MV_i^2 - \frac{GMM_E}{R_E} = 0$$

$$½ MV_i^2 = \frac{GMM_E}{R_E} \text{ ----------------- } 3$$

3) The escape speed, the minimum speed required by an object to escape Earth's gravitational field, hence replace, $V_i$ with $V_e$. i.e,

$$½ MV_e^2 = \frac{GMM_E}{R_E}$$

$V_e^2 = \frac{GMM_E}{R_E} \cdot \frac{2}{M}$ ; $V_e^2 = \frac{2GM_E}{R_E}$ ------------- 4

Using $g = \frac{GM_E}{R_e}$ – – – – – – – – – – – – – – – – – – – 5

$V_e^2 = 2gR_E$ ; $V_e = \sqrt{2gRE}$ -------------- 6

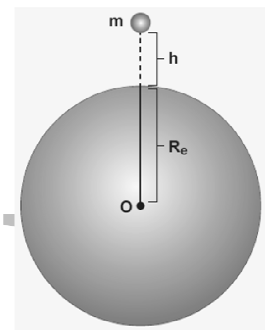
From equation (6) the escape speed depends on two factors: acceleration due to gravity and radius of the Earth. It is completely independent of the mass of the object.

**08. Explain the variation of g with altitude.**

**Variation of g with altitude:**

Consider an object of mass m at a height h from the surface of the Earth. Acceleration experienced by the object due to Earth is $g' = \frac{GM}{(R_e+h)^2}$

$$g' = \frac{GM}{R_e^2\left(1+\frac{h}{R_e}\right)^2} \quad ; \quad g' = \frac{GM}{R_e^2}\left(1+\frac{h}{R_e}\right)^{-2}$$




If h << $R_e$ . We can use Binomial expansion.

Taking the terms upto first order

$$g' = \frac{GM}{R_e^2}\left(1 - 2\frac{h}{R_e}\right) ;$$

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

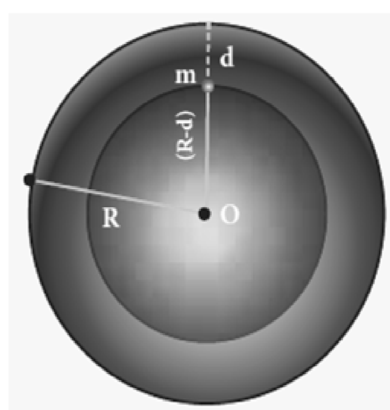
We find that $g' < g$ . This means that as altitude h increases the acceleration due to gravity g decreases.

**09. Explain the variation of g with depth from the Earth's surface.**

**Variation of g with depth:**

Consider a particle of mass m which is in a deep mine on the earth. Ex. Coal mines – in Neyveli). Assume the depth of the mine as d. To Calculate g at a depth d, consider the following points. The part of the Earth which is above the radius ($R_e$ – d) do not contribute to the acceleration. The result is proved earlier and is given as $g' = \frac{GM'}{(R_e-d)^2}$ Here M is the mass of the Earth of radius ($R_e$ – d). Assuming the density of earth ρ to be constant,

$$\rho = \frac{M'}{V'} \; ; \; \frac{M'}{V'} = \frac{M}{V} \text{ and } M' = \frac{M}{V}V'$$




$$M' = \left(\frac{M}{\frac{4}{3}\pi R_e^3}\right)\left(\frac{4}{3}\pi(R_e-d)^3\right) \; ;$$

$$M' = \frac{M}{R_e^3}(R_e-d)^3$$

$$g' = G\frac{M}{R_e^3}(R_e-d)^3 \cdot \frac{1}{(R_e-d)^2} \; ;$$

$$g' = GM\frac{R_e\left(1-\frac{d}{R_e}\right)}{R_e^3}$$

$$g' = GM\frac{\left(1-\frac{d}{R_e}\right)}{R_e^2} \text{ thus } g' = g\left(1-\frac{d}{R_e}\right).$$

Here also $g'<g$ . As depth increases, $g'$ decreases.

**10. Derive the time period of satellite orbiting the Earth.**

**Time period of the satellite:**

The distance covered by the satellite during one rotation in its orbit is equal to $2\pi$ ($R_E$ +h) and time taken for it is the time period, T. Then

$$\frac{\text{Distance travelled}}{\text{Time taken}} = \frac{2\pi\,(\mathrm{RE}+\mathrm{h})}{T}$$

From equation, $\sqrt{\frac{GM_E}{(R_E+h)}} = \frac{2\pi\,(\mathrm{RE}+\mathrm{h})}{T}$ ---------------- 1

$T = \frac{2\pi}{\sqrt{GM_E}}(R_E+h)^{\frac{3}{2}}$ -------------------- 2

Squaring both sides of the equation (2), we get $T^2 = \frac{4\pi^2}{GM_E}(R_E + h)^3$

$\frac{4\pi^2}{GM_E}$ = Constant say c, $T^2 = c\,(R_E + h)^3$ ---------------- 3

Equation (3) implies that a satellite orbiting the Earth has the same relation between time and distance as that of Kepler's law of planetary motion. For a satellite orbiting near the surface of the Earth, h is negligible compared to the radius of the Earth $R_E$ . Then, $T^2 = \frac{4\pi^2}{GM_E}R_E^3$ ; $T^2 = \frac{4\pi^2}{\frac{GM_E}{R_E^2}}$

$T^2 = \frac{4\pi^2}{g}R_E$ Since $\frac{GM_E}{R_E^2} = g$ ; $T = 2\pi\sqrt{\frac{R_E}{g}}$

## UNIT – 07 PROPERTIES OF MATTER

## TWO MARKS AND THREE MARKS:

**01. Define stress and strain.**

The force per unit area is called as stress. Stress, $\sigma = \frac{Force}{Area} = \frac{F}{A}$

The SI unit of stress is N $m^{-2}$ or Pascal (Pa) and its dimension is $[ML^{-1}T^{-2}]$.

The fractional change in the size of the object, in other words, strain measures the degree of deformation. Strain, $e = \frac{Change\ in\ Size}{Original\ size} = \frac{\Delta l}{l}$

**02. State Hooke's law of elasticity.**

Hooke's law is for a small deformation, when the stress and strain are proportional to each other.

**03. Define Poisson's ratio.**

The ratio of relative contraction (lateral strain) to relative expansion (longitudinal strain). It is denoted by the symbol μ.

Poisson s ratio, μ = Lateral strain / Longitudinal strain

**04. Which one of these is more elastic, steel or rubber? Why?**

Steel is more elastic than rubber because the steel has higher young's modulus than rubber. That's why, if equal stress is applied on both steel and rubber, the steel produces less strain.

**05. A spring balance shows wrong readings after using for a long time. Why?**

When the spring balances have been used for a long time they develop elastic fatigue in them and therefore the reading shown by such balances will be wrong.

**06. State Pascal's law in fluids.**

If the pressure in a liquid is changed at a particular point, the change is transmitted to the entire liquid without being diminished in magnitude.

**07. State Archimedes principle.**

It states that when a body is partially or wholly immersed in a fluid, it experiences an upward thrust equal to the weight of the fluid displaced by it and its up-thrust acts through the centre of gravity of the liquid displaced.

**08. What do you mean by up-thrust or buoyancy?**

The upward force exerted by a fluid that opposes the weight of an immersed object in a fluid is called up-thrust or buoyant force and the phenomenon is called buoyancy.

**09. State the law of floatation.**

The law of floatation states that a body will float in a liquid if the weight of the liquid displaced by the immersed part of the body equals the weight of the body.

**10. Distinguish between streamlined flow and turbulent flow.**

**Streamlined flow:** When a liquid flows such that each particle of the liquid passing through a point moves along the same path with the same velocity as its predecessor then the flow of liquid is said to be a streamlined flow.

The velocity of the particle at any point is constant. It is also referred to as steady or laminar flow.

The actual path taken by the particle of the moving fluid is called a streamline, which is a curve, the tangent to which at any point gives the direction of the flow of the fluid at that point.

**Turbulent flow:** When the speed of the moving fluid exceeds the critical speed, $v_c$ the motion becomes turbulent.

The velocity changes both in magnitude and direction from particle to particle.

The path taken by the particles in turbulent flow becomes erratic and whirlpool-like circles called eddy current or eddies.



**11. What is Reynold's number? Give its significance.**

Reynold's number($R_C$) is a dimensionless number, which is used to find out the nature of flow of the liquid. $R_C = \frac{\rho v D}{\eta}$

Where, $\rho$- density of the liquid, v –The velocity of flow of liquid.

D- Diameter of the pipe, $\eta$ - The coefficient of viscosity of the fluid.

**12. Define terminal velocity.**

The maximum constant velocity acquired by a body while falling freely through a viscous medium is called the terminal velocity.

**13. Write down the expression for the Stoke's force and explain the symbols involved in it.**

Viscous force F acting on a spherical body of radius r depends directly on

i) radius (*r*) of the sphere

ii) velocity (*v*) of the sphere and

iii) coefficient of viscosity η of the liquid F = $6\pi\eta r v$

**14. Distinguish between cohesive and adhesive forces.**

The force between the like molecules which holds the liquid together is called '*cohesive force*'. When the liquid is in contact with a solid, the molecules of the these solid and liquid will experience an attractive force which is called '*adhesive force*'.

**15. A drop of oil placed on the surface of water spreads out. But a drop of water place on oil contracts to a spherical shape. Why?**

A drop of oil placed on the surface of water spreads because the force of adhesion between water and oil molecules dominates the cohesive force of oil molecules.

On the other hand, cohesive force of water molecules dominates the adhesive force between water and oil molecules. So drop of water on oil contracts to a spherical shape.

**16. State the principle and usage of Venturimeter.**

Bernoulli's theorem is the principle of Venturimeter.

Venturimeter is used to measure the rate of flow or flow speed of the incompressible fluid flowing through a pipe.

**17. What are the applications of surface tension?**

1) Oil pouring on the water reduces surface tension. So that the floating mosquitoes eggs drown and killed.
2) Finely adjusted surface tension of the liquid makes droplets of desired size, which helps in desktop printing, automobile painting and decorative items.
3) Specks of dirt are removed from the cloth when it is washed in detergents added hot water, which has low surface tension.
4) A fabric can be made waterproof, by adding suitable waterproof material (wax) to the fabric. This increases the angle of contact due to surface tension.



**18. What physical quantity actually do we check by pressing the tyre after pumping?**

After pumping the tyre, we actually check the compressibility of air by pressing the tyre. For smooth riding, rear tyre should have less compressibility than the front.

**19. Give some examples for surface tension.**

Clinging of painting brush hairs, when taken out of water.
Needle float on the water, Camphor boat.

**20. What are the applications of viscosity?**

1) Viscosity of liquids helps in choosing the lubricants for various machinery parts. Low viscous lubricants are used in light machinery parts and high viscous lubricants are used in heavy machinery parts.
2) As high viscous liquids damp the motion, they are used in hydraulic brakes as brake oil.
3) Blood circulation through arteries and veins depends upon the viscosity of fluids.
4) Viscosity is used in Millikan's oil-drop method to find the charge of an electron.

**21. Explain the Stoke's law application in raindrop falling.**

According to Stoke's law, terminal velocity is directly proportional to square of radius of the spherical body. So that smaller raindrops having less terminal velocity float as cloud in air. When they gather as bigger drops get higher terminal velocity and start falling.

**22. Define Young's modulus. Give its unit.**

Young's modulus is defined as the ratio of tensile or compressive stress to the tensile or compressive strain. Its unit is N $m^{-2}$ or pascal.

**23. What are the applications of elasticity?**

Elasticity is used in structural engineering in which bridges and buildings are designed such a way that it can withstand load of flowing traffic, the force of winds and even its own weight.

The material of high Young's modulus is used in constructing beams.

## CONCEPTUAL QUESTIONS

**24. Why coffee runs up into a sugar lump (a small cube of sugar) when one corner of the sugar lump is held in the liquid?**

The coffee runs up into the pores of sugar lump due to capillary action of the liquid.

**25. Why two holes are made to empty an oil tin?**

When oil comes out from a hole of an oil tin, pressure inside it decreased than the atmosphere. Therefore, the surrounding air rush up into the same hole prevents the oil to come out. Hence two holes are made to empty the oil tin.

**26. We can cut vegetables easily with a sharp knife as compared to a blunt knife. Why?**

Since the stress produced on the vegetables by the sharp knife is higher than the blunt knife, vegetables can be cut easily with the sharp knife.

**27. Why the passengers are advised to remove the ink from their pens while going up in an aero-plane?**

When an aero-plane ascends, the atmospheric pressure is decreased. Hence, the ink from the pen will leak out. So that, the passengers are advised to remove the ink from their pens while going up in the aero-plane.

**28. We use straw to suck soft drinks, why?**

When we suck the soft drinks through the straw, the pressure inside the straw becomes less than the atmospheric pressure. Due to the difference in pressure, the soft drink rises in the straw and we are able to enjoy it conveniently.

## FIVE MARKS QUESTIONS:

**29. Explain the different types of modulus of elasticity.**

There are three types of elastic modulus.

(a) Young's modulus, (b) Rigidity modulus (or Shear modulus)

(c) Bulk modulus

**Young's modulus:**

When a wire is stretched or compressed, then the ratio between tensile stress (or compressive stress) and tensile strain (or compressive strain) is defined as Young's modulus.

$$= \frac{\text{Tensile stress or compressive stress}}{\text{Tensile starin or compressive strain}} \quad Y = \frac{\sigma_t}{\varepsilon_t} \text{ or } Y = \frac{\sigma_c}{\varepsilon_c}$$

The unit for Young modulus has the same unit of stress because, strain has no unit. So, S.I. unit of Young modulus is N $m^{-2}$ or pascal.

**Bulk modulus:**

Bulk modulus is defined as the ratio of volume stress to the volume strain.

Bulk modulus, K = $\frac{\text{Normal (Perpendicular)stress or pressure}}{\text{Volume strain}}$

The normal stress or pressure is $\sigma_n = \frac{F_n}{\Delta A} = \Delta p$

The volume strain is $\varepsilon_v = \frac{\Delta V}{V}$

Therefore, Bulk modulus is K = $-\frac{\sigma_n}{\varepsilon_v} = -\frac{\Delta p}{\frac{\Delta V}{V}}$

The negative sign in the equation means that when pressure is applied on the body, its volume decreases. Further, the equation implies that a material can be easily compressed if it has a small value of bulk modulus.

**The rigidity modulus or shear modulus:**

The rigidity modulus is defined as Rigidity modulus or Shear modulus,

$$\eta_R = \frac{\text{Shearing stress}}{\text{Angle of shear or shearing strain}}$$

The shearing stress is $\sigma_s = \frac{\text{Trangential force}}{\text{Area over which it is applied}} = \frac{F_t}{\Delta A}$

The angle of shear or shearing strain $\varepsilon_s = \frac{x}{h} = \theta$

Therefore, Rigidity modulus is $\eta = \frac{\sigma_s}{\varepsilon_s} = \frac{\frac{F_t}{\Delta A}}{\frac{x}{h}} = \frac{\frac{F_t}{\Delta A}}{\theta}$

Further, the equation (7.9) implies, that a material can be easily twisted if it has small value of rigidity modulus. For example, consider a wire, when it is twisted through an angle θ, a restoring torque is developed, that is

$$\tau \propto \theta$$

This means that for a larger torque, wire will twist by a larger amount (angle of shear θ is large). Since, rigidity modulus is inversely proportional to angle of shear, the modulus of rigidity is small.

**30. Derive Poiseuille's formula for the volume of a liquid flowing per second through a pipe under streamlined flow.**

Consider a liquid flowing steadily through a horizontal capillary tube. Let $v = \left(\frac{V}{t}\right)$ be the volume of the liquid flowing out per second through a capillary tube. It depends on (1) coefficient of viscosity (η) of the liquid, (2) radius of the tube (r), and (3) the pressure gradient$\left(\frac{P}{l}\right)$. Then, $v \,\alpha\, \eta^a r^b \left(\frac{P}{l}\right)^c$;

$v = k\, \eta^a r^b \left(\frac{P}{l}\right)^c$ where, k is a dimensionless constant. Therefore,

$[v] = \frac{\text{Volume}}{\text{time}} = [L^3T^{-1}]$, $\left[\frac{dP}{dx}\right] = \frac{\text{Pressure}}{\text{distance}} = [ML^{-2}T^{-2}]$,

$[\eta] = [ML^{-1}T^{-1}]$ and $[r] = [L]$

Substituting in equation, So, equating the powers of M, L, and T on both sides, we get a + c = 0, –a + b –2c =3, and –a –2c = –1

We have three unknowns *a*, *b*, and *c.* We have three equations, on solving, we get a = –1, b = 4, and c = 1

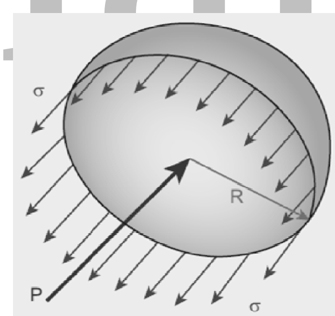
Therefore, equation becomes, $v = k\eta^{-1}r^4\left(\frac{P}{l}\right)^1$

Experimentally, the value of *k* is shown to be $\frac{\pi}{8}$, we have $v = \frac{\pi r^4 P}{8\eta l}$



**31. Obtain an expression for the excess of pressure inside a i) liquid drop ii) liquid bubble iii) air bubble.**

**i) Excess of pressure inside air bubble in a liquid.**

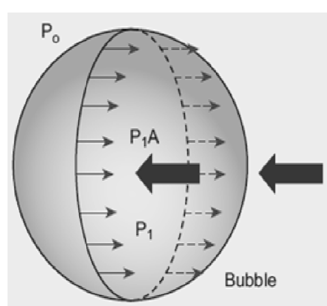



Consider an air bubble of radius R inside a liquid having surface tension T as shown in Figure (a). Let $P_1$ and $P_2$ be the pressures outside and inside the air bubble, respectively. Now, the excess pressure inside the air bubble is

$\Delta P = P_1 - P_2$. To find the excess pressure inside the air bubble, let us consider the forces acting on the air bubble.

**ii) Excess pressure inside a soap bubble.**

Consider a soap bubble of radius *R* and the surface tension of the soap bubble be *T* as shown in Figure (b). A soap bubble has two liquid surfaces in contact with air, one inside the bubble and other outside the bubble. Therefore, the force on the soap bubble due to surface tension is 2×2π*RT*. The various forces acting on the soap bubble are,




i) Force due to surface tension $F_T = 4\pi RT$ towards right

ii) Force due to outside pressure $F_{P1} = P_1\pi R^2$ towards right

iii) Force due to inside pressure $F_{P2} = P_2\pi R^2$ towards left

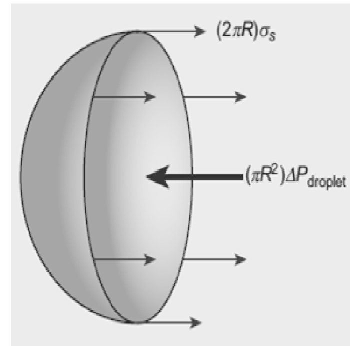
As the bubble is in equilibrium, $F_{P2} = F_T + F_{P1}$

$P_2\pi R^2 = 4\pi RT + P_1\pi R^2 \Rightarrow (P_2 - P_1)\pi R^2 = 4\pi RT$

Excess pressure is $\Delta P = P_2 - P_1 = \frac{4T}{R}$

**iii) Excess pressure inside the liquid drop**

Consider a liquid drop of radius R and the surface tension of the liquid is T as shown in Figure. The various forces acting on the liquid drop are,




i) Force due to surface tension $F_T = 2\pi RT$ towards right

ii) Force due to outside pressure $F_{P1} = P_1\pi R^2$ towards right

iii) Force due to inside pressure $F_{P2} = P_2\pi R^2$ towards left

As the liquid drop is in equilibrium, $F_{P2} = F_T + F_{P1}$

$P_2\pi R^2 = 2\pi RT + P_1\pi R^2 \Rightarrow (P_2 - P_1)\pi R^2 = 2\pi RT$

Excess pressure is $\Delta P = P_2 - P_1 = \frac{2T}{R}$

**32. State and prove Bernoulli's theorem for a flow of incompressible, non-viscous, and streamlined flow of fluid.**

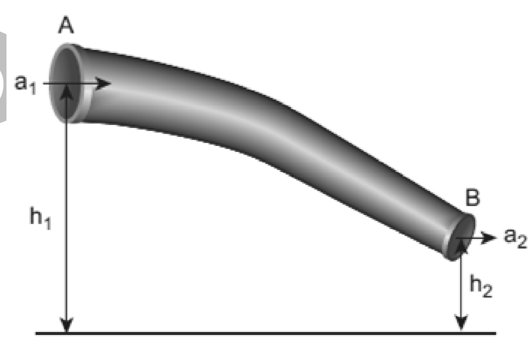
**Bernoulli's theorem:**

According to Bernoulli's theorem, the sum of pressure energy, kinetic energy, and potential energy per unit mass of an incompressible, non-viscous fluid in a streamlined flow remains a constant.

$\frac{P}{\rho} + \frac{1}{2}v^2 + gh =$ Constant, this is known as Bernoulli's equation.

**Proof:**

Let us consider a flow of liquid through a pipe AB as shown in Figure. Let V be the volume of the liquid when it enters *A* in a time *t* which is equal to the volume of the liquid leaving *B* in the same time. Let $a_A$, $v_A$ and $P_A$ be the area of cross section of the tube, velocity of the liquid and pressure exerted by the liquid at *A* respectively.




Let the force exerted by the liquid at *A* is $F_A = P_A a_A$

Distance travelled by the liquid in time t is $d = v_A t$

Therefore, the work done is $W = F_A d = P_A a_A v_A t$

But $a_A v_A t = a_A d = V$, volume of the liquid entering at A.

Thus, the work done is the pressure energy (at A), $W = F_A d = P_A V$

Pressure energy per unit volume at A $= \frac{\text{Pressure energy}}{\text{Volume}} = \frac{P_A V}{V} = P_A$

Pressure energy per unit mass at A $= \frac{\text{Pressure energy}}{\text{Mass}} = \frac{P_A V}{m} = \frac{P_A}{\frac{m}{V}} = \frac{P_A}{\rho}$

Since m is the mass of the liquid entering at A in a given time, therefore, pressure energy of the liquid at A is $E_{PA} = P_A V = P_A V \times \left(\frac{m}{m}\right) = m\frac{P_A}{\rho}$

Potential energy of the liquid at A, $P_{EA} = mgh_A$,

Due to the flow of liquid, the kinetic energy of the liquid at A,

$KE_A = \frac{1}{2} m V_A^2$

Therefore, the total energy due to the flow of liquid at A,

$$E_A = EP_A + KE_A + PE_A \quad E_A = m\frac{P_A}{\rho} + \frac{1}{2} mV_A^2 + mgh_A$$

Similarly, let $a_B$, $v_B$, and $P_B$ be the area of cross section of the tube, velocity of the liquid, and pressure exerted by the liquid at B. Calculating the total energy at $E_B$, we get $E_B = m\frac{P_B}{\rho} + \frac{1}{2} mV_B^2 + mgh_B$

From the law of conservation of energy, $E_A = E_B$

$$E_A = m\frac{P_A}{\rho} + \frac{1}{2} mV_A^2 + mgh_A = E_B = m\frac{P_B}{\rho} + \frac{1}{2} mV_B^2 + mgh_B$$

$$\frac{P_A}{\rho} + \frac{1}{2} V_A^2 + gh_A = \frac{P_B}{\rho} + \frac{1}{2} V_B^2 + gh_B = \text{constant}$$

Thus, the above equation can be written as $\frac{P}{\rho g} + \frac{1}{2}\frac{v^2}{g} + h = \text{constant}$

**33. Write any two applications of Bernoulli's theorem.**

**(a) Blowing off roofs during wind storm**

1) In olden days, the roofs of the huts or houses were designed with a slope. One important scientific reason is that as per the Bernoulli's principle, it will be safeguarded except roof during storm or cyclone.

2) During cyclonic condition, the roof is blown off without damaging the other parts of the house.

3) In accordance with the Bernoulli's principle, the high wind blowing over the roof creates a low-pressure $P_1$.

4) The pressure under the roof $P_2$ is greater. Therefore, this pressure difference $(P_2 – P_1)$ creates an up thrust and the roof is blown off.



**(b) Aerofoil lift**

1) The wings of an airplane (aerofoil) are so designed that its upper surface is more curved than the lower surface and the front edge is broader than the real edge.

2) As the aircraft moves, the air moves faster above the aerofoil than at the bottom.

3) According to Bernoulli's Principle, the pressure of air below is greater than above, which creates an up-thrust called the dynamic lift to the aircraft.

## UNIT – 08 HEAT AND THERMODYNAMICS

## TWO MARKS AND THREE MARKS:

**01. Define specific heat capacity and give its unit.**

Specific heat capacity of a substance is defined as the amount of heat energy required to raise the temperature of 1kg of a substance by 1 Kelvin or 1°C

$\Delta Q$ = ms $\Delta T$

Therefore, s = $\frac{1}{m}\frac{\Delta Q}{\Delta T}$

Where s – Specific heat capacity of a substance and its value depends only on the nature of the substance not amount of substance.

$\Delta Q$ - Amount of heat energy ; $\Delta T$ - Change in temperature ;

m – Mass of the substance ; The SI unit for specific heat capacity is $Jkg^{-1}K^{-1}$

**02. Define molar specific heat capacity.**

Molar specific heat capacity is defined as heat energy required to increase the temperature of one mole of substance by 1K or 1°C. C = $\frac{1}{\mu}\frac{\Delta Q}{\Delta T}$

Here C is known as molar specific heat capacity of a substance and μ is number of moles in the substance.

The SI unit for molar specific heat capacity is J $mol^{-1}$ $K^{-1}$ .

**03. What is a thermal expansion?**

Thermal expansion is the tendency of matter to change in shape, area, and volume due to a change in temperature.

All three states of matter (solid, liquid and gas) expand when heated. When a solid is heated, its atoms vibrate with higher amplitude about their fixed points. The relative change in the size of solids is small.

**04. Define latent heat capacity. Give its unit.**

Latent heat capacity of a substance is defined as the amount of heat energy required to change the state of a unit mass of the material.

Q = m x L ; L = $\frac{Q}{m}$

Where L = Latent heat capacity of the substance; Q = Amount of heat; m = mass of the substance. The SI unit for Latent heat capacity is J $kg^{-1}$ .

**05. State Stefan-Boltzmann law.**

Stefan Boltzmann law states that, the total amount of heat radiated per second per unit area of a black body is directly proportional to the fourth power of its absolute temperature.

E $\alpha$ $T^4$ or E = $\sigma T^4$ ; Where, σ is known as Stefan's constant. Its value is 5.67 × $10^{-8}$ W $m^{-2}$ $k^{-4}$

**06. What is Wien's law?**

Wien's law states that, the wavelength of maximum intensity of emission of a black body radiation is inversely proportional to the absolute temperature of the black body. $\lambda_m \,\alpha\, \frac{1}{T}$ or $\lambda_m = \frac{b}{T}$. Where, b is known as Wien's constant.

Its value is $2.898 \times 10^{-3}$ m K

**07. Define thermal conductivity. Give its unit.**

The quantity of heat transferred through a unit length of a material in a direction normal to unit surface area due to a unit temperature difference under steady state conditions is known as thermal conductivity of a material.

$\frac{Q}{L} = \frac{KA\Delta T}{L}$ ; Where, K is known as the coefficient of thermal conductivity. SI unit of thermal conductivity is J $s^{-1}$ $m^{-1}$ $K^{-1}$ or W $m^{-1}$ $K^{-1}$.

**08. What is a black body?**

A black body is an object that absorbs all electromagnetic radiations. It is a perfect absorber and radiator of energy with no reflecting power.

**09. What are the different types of thermodynamic systems?**

Open system can exchange both matter and energy with the environment.
Closed system exchange energy, but not matter with the environment.
Isolated system can exchange neither energy nor matter with the environment.



**10. Define one calorie.**

The amount of heat required at a pressure of standard atmosphere to raise the temperature of 1g of water $1^0$C.

**11. State the first law of thermodynamics.**

Change in internal energy (ΔU) of the system is equal to heat supplied to the system (Q) minus the work done by the system (W) on the surroundings.

**12. Define the quasi-static process.**

A quasi-static process is an infinitely slow process in which the system changes its variables (P,V,T) so slowly such that it remains in thermal, mechanical and chemical equilibrium with its surroundings throughout. By this infinite slow variation, the system is always almost close to equilibrium state.

**13. What is PV diagram?**

PV diagram is a graph between pressure P and volume V of the system. The P-V diagram is used to calculate the amount of work done by the gas during expansion or on the gas during compression.

**14. What is meant by reversible and irreversible processes?**

**Reversible process:** A thermodynamic process can be considered reversible only if it possible to retrace the path in the opposite direction in such a way that the system and surroundings pass through the same states as in the initial, direct process. Example: A quasi–static isothermal expansion of gas, slow compression and expansion of a spring.

**Irreversible process:** All natural processes are irreversible. Irreversible process cannot be plotted in a PV diagram, because these processes cannot have unique values of pressure, temperature at every stage of the process.

**15. Define heat engine.**

Heat engine is a device which takes heat as input and converts this heat in to work by undergoing a cyclic process.

**16. Define the coefficient of performance.**

COP is a measure of the efficiency of a refrigerator. It is defined as the ratio of heat extracted from the cold body (sink) to the external work done by the compressor W. COP = $\beta = \frac{Q_L}{W}$

**17. Can water be boiled without heating?**

Yes, at low pressure, the water boils fast at low temperature below the room temperature, when the pressure is made low, the water starts boiling without supplying any heat.

**18. Define Triple point.**

Triple point the triple point of a substance is the temperature and pressure at which the three phases (gas, liquid and solid) of that substance coexist in thermodynamic equilibrium. The triple point of water is at 273.1 K

**19. Write the applications of thermal conversion.**

1) Boiling water in a cooking pot is an example of convection. Water at the bottom of the pot receives more heat. Due to heating, the water expands and the density of water decreases at the bottom.

2) Due to this decrease in density, molecules rise to the top. At the same time the molecules at the top receive less heat and become denser and come to the bottom of the pot.

3) This process goes on continuously. The back and forth movement of molecules is called convection current.

4) To keep the room warm, we use room heater. The air molecules near the heater will heat up and expand.

5) As they expand, the density of air molecules will decrease and rise up while the higher density cold air will come down. This circulation of air molecules is called convection current.

## FIVE MARKS QUESTIONS:

**20. Explain in detail the thermal expansion.**

1) Thermal expansion is the tendency of matter to change in shape, area, and volume due to a change in temperature.

2) All three states of matter (solid, liquid and gas) expand when heated. When a solid is heated, its atoms vibrate with higher amplitude about their fixed points. The relative change in the size of solids is small. Railway tracks are given small gaps so that in the summer, the tracks expand and do not buckle. Railroad tracks and bridges have expansion joints to allow them to expand and contract freely with temperature changes.

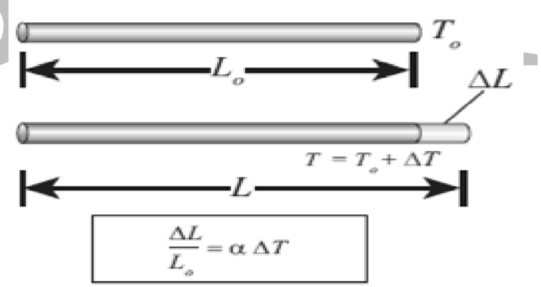
**3) Liquids**, have less intermolecular forces than solids and hence they expand more than solids. This is the principle behind the mercury thermometers.

4) In the case of **gas** molecules, the intermolecular forces are almost negligible and hence they expand much more than solids. For example in hot air balloons when gas particles get heated, they expand and take up more space.

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

6) The expansion in length is called **linear expansion**. Similarly the expansion in area is termed as **area expansion** and the expansion in volume is termed as **volume expansion**.

**Linear Expansion:**




In solids, for a small change in temperature $\Delta T$, the fractional change in length $\left(\frac{\Delta L}{L}\right)$ is directly proportional to $\Delta T$. $\frac{\Delta L}{L} = a_L \Delta T$

Therefore, $\alpha_L = \frac{\Delta L}{L \Delta T}$ ; Where,

$\alpha L$ = coefficient of linear expansion.

$\Delta L$ = Change in length; L = Original length ;

$\Delta T$ = Change in temperature.

**Area Expansion:**

For a small change in temperature $\Delta T$ the fractional change in area $\left(\frac{\Delta A}{A}\right)$ of a substance is directly proportional to $\Delta T$ and it can be written as

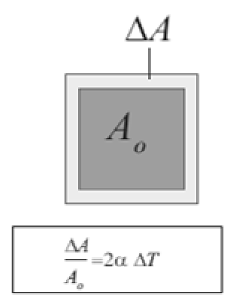
$\frac{\Delta A}{A} = \alpha_A \Delta T$

Therefore,

$\alpha_A = \frac{\Delta A}{A \Delta T}$ ; Where, $\alpha A$ = coefficient of area expansion.

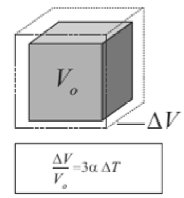
$\Delta A$ = Change in area; A = Original area;

$\Delta T$ = Change in temperature



**Volume Expansion:**

For a small change in temperature ΔT the fractional change in volume$\left(\frac{\Delta V}{V}\right)$ of a substance is directly proportional to ΔT.




$\frac{\Delta V}{V} = \alpha_V\, \Delta T$ , Therefore, $\alpha_V = \frac{\Delta V}{V \Delta T}$

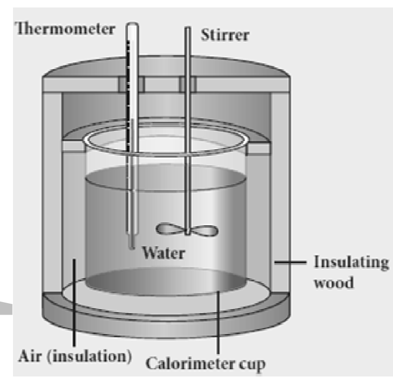
Where, αV = coefficient of volume expansion;

ΔV = Change in volume; V = Original volume ; ΔT = Change in temperature. Unit of coefficient of linear, area and volumetric expansion of solids is $^{\circ}C^{-1}$ or $K^{-1}$

**21. Explain Calorimetry and derive an expression for final temperature when two thermodynamic systems are mixed.**

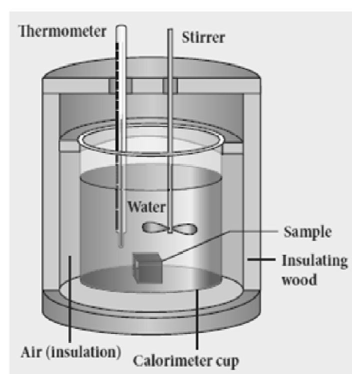
**Calorimetry :**

1) Calorimetry means the measurement of the amount of heat released or absorbed by thermodynamic system during the heating process. When a body at higher temperature is brought in contact with another body at lower temperature, the heat lost by the hot body is equal to the heat gained by the cold body. No heat is allowed to escape to the surroundings. It can be mathematically expressed as $Q_{gain} = -Q_{lost}$ ; $Q_{gain} + Q_{lost} = 0$




2) Heat gained or lost is measured with a calorimeter. Usually the calorimeter is an insulated container of water as shown in Figure.

3) A sample is heated at high temperature ($T_1$) and immersed into water at room temperature ($T_2$) in the calorimeter. After some time both sample and water reach a final equilibrium temperature $T_f$ . Since the calorimeter is insulated, heat given by the hot sample is equal to heat gained by the water. It is shown in the Figure.




$Q_{gain} = -Q_{lost}$

Note the sign convention. The heat lost is denoted by negative sign and heat gained is denoted as positive.

From the definition of specific heat capacity

$Q_{gain} = m_2 s_2 (T_f - T_2)$

$Q_{lost} = m_1 s_1 (T_f - T_1)$

Here $s_1$ and $s_2$ specific heat capacity of hot sample and water respectively. So we can write

$m_2 s_2 (T_f - T_2) = - m_1 s_1 (T_f - T_1)$

$m_2 s_2 T_f - m_2 s_2 T_2 = - m_1 s_1 T_f + m_1 s_1 T_1$

$m_2 s_2 T_f + m_1 s_1 T_f = m_2 s_2 T_2 + m_1 s_1 T_1$

The final temperature $T_f = \frac{m_1 S_1 T_1 + m_2 S_2 T_2}{m_1 S_1 + m_2 S_2}$

**22. Discuss various modes of heat transfer.**

**Conduction:**

Conduction is the process of direct transfer of heat through matter due to temperature difference. When two objects are in direct contact with one another, heat will be transferred from the hotter object to the colder one. Thermal conductivity depends on the nature of the material.

**Convection:**

Convection is the process in which heat transfer is by actual movement of molecules in fluids such as liquids and gases. In convection, molecules move freely from one place to another.

**Radiation:**

Radiation is a form of energy transfer from one body to another by electromagnetic waves. Radiation which requires no medium to transfer energy from one object to another.

**Example:** 1. Solar energy from the Sun. 2. Radiation from room heater.

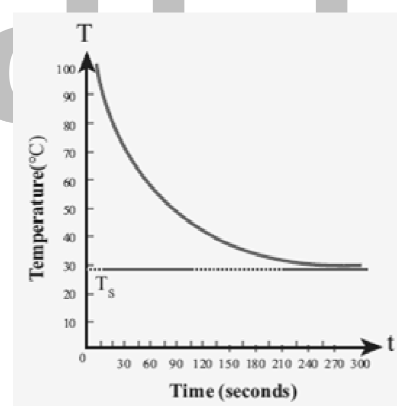
**23. Explain in detail Newton's law of cooling.**

**Newton's law of cooling:**



1) Newton's law of cooling states that the rate of loss of heat of a body is directly proportional to the difference in the temperature between that body and its surroundings .

$\frac{dQ}{dt}\ \alpha\ -(T - T)$ ------------- 1




2) The negative sign indicates that the quantity of heat lost by liquid goes on decreasing with time. Where, T = Temperature of the object

$T_s$ = Temperature of the surrounding.

From the graph in Figure , it is clear that the rate of cooling is high initially and decreases with falling temperature.

3) Let us consider an object of mass m and specific heat capacity s at temperature T. Let Ts be the temperature of the surroundings. If the temperature falls by a small amount dT in time dt, then the amount of heat lost is, dQ = msdT ---------------- 2

4) Dividing both sides of equation (2) by $\frac{dQ}{dt} = \frac{msdT}{dt}$ -------------3

From Newton's law of cooling $\frac{dQ}{dt}\ \alpha\ -(T - T_S)$

$\frac{dQ}{dt} = -a\,(T - T_S)$ ---------- 4

Where a is some positive constant. From equation (2) and (4)

$-a\,(T - T_S) = ms\frac{dT}{dt}$

$\frac{dT}{(T - TS)} = -\frac{a}{ms}dt$ -------------------- 5

Integrating equation (5) on both sides,

$$\int_0^\infty \frac{dT}{(T-TS)} = -\int_0^t \frac{a}{ms}\,dt$$

$$\text{In}\,(T - T_S) = \frac{a}{ms}t + b_1$$

Where $b_1$ is the constant of integration. taking exponential both sides, we get, $T = T_S + b_2\, e^{\frac{a}{ms}t}$ . Here $b_2 = eb_1$ = Constant

**24. Derive Mayer's relation for an ideal gas.**

**Meyer's relation**

1) Consider μ mole of an ideal gas in a container with volume V, pressure P and temperature T.

2) When the gas is heated at constant volume the temperature increases by dT. As no work is done by the gas, the heat that flows into the system will increase only the internal energy. Let the change in internal energy be dU.

If Cv is the molar specific heat capacity at constant volume,

$dU = \mu C_v dT$ -------------- 1

3) Suppose the gas is heated at constant pressure so that the temperature increases by dT. If 'Q' is the heat supplied in this process and 'dV' the change in volume of the gas. $Q = \mu C_p dT$ ------------ 2

4) If W is the work done by the gas in this process, then

$W = PdV$ -------------3

But from the first law of thermodynamics, $Q = dU + W$ ---------4

Substituting equations (1), (2) and (3) in (4), we get,

$\mu C_p dT = \mu C_v\, dT + PdV$ ------------5

5) For mole of ideal gas, the equation of state is given by

$PV = \mu RT \Rightarrow PdV + VdP = \mu RdT$ ----------- 6

Since the pressure is constant, $dP=0$

$\therefore C_p dT = C_v dT + RdT$

$\therefore C_P = C_v + R$ (or) $C_p - C_v = R$ ------------ 7

This relation is called Meyer's relation

**25. Explain the heat engine and obtain its efficiency.**

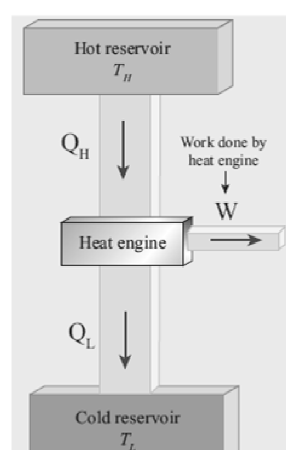
Heat engine is a device which takes heat as input and converts this heat in to work by undergoing a cyclic process.

**A heat engine has three parts:**

(a) Hot reservoir (b) Working substance

(c) Cold reservoir

A Schematic diagram for heat engine is given below in the figure




1) Hot reservoir (or) Source: It supplies heat to the engine. It is always maintained at a high temperature $T_H$

2) Working substance: It is a substance like gas or water, which converts the heat supplied into work.

i) A simple example of a heat engine is a steam engine. In olden days steam engines were used to drive trains. The working substance in these is water which absorbs heat from the burning of coal.

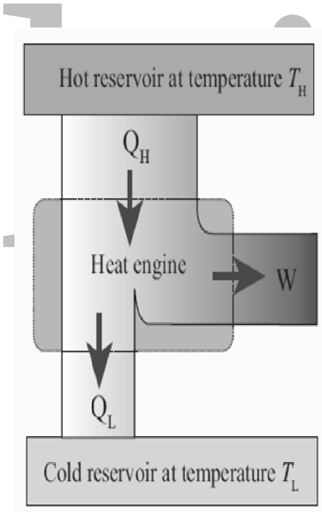
ii) The heat converts the water into steam. This steam is does work by rotating the wheels of the train, thus making the train move.

3) Cold reservoir (or) Sink: The heat engine ejects some amount of heat ($Q_L$) in to cold reservoir after it doing work. It is always maintained at a low temperature $T_L$.

**For example,** in the automobile engine, the cold reservoir is the surroundings at room temperature. The automobile ejects heat to these surroundings through a silencer.

4) The heat engine works in a cyclic process. After a cyclic process it returns to the same state. Since the heat engine returns to the same state after it ejects heat, the change in the internal energy of the heat engine is zero.

5) The efficiency of the heat engine is defined as the ratio of the work done (output) to the heat absorbed (input) in one cyclic process. Let the working substance absorb heat $Q_H$ units from the source and reject $Q_L$ units to the sink after doing work W units




We can write Input heat = Work done + ejected heat

$Q_H = W + Q_L$

$W = Q_H - Q_L$

Then the efficiency of heat engine

$$\eta = \frac{Output}{Input} = \frac{W}{Q_H} = \frac{Q_H - Q_L}{Q_H}$$

$$\eta = \frac{Output}{Input} = \frac{W}{Q_H} = 1 - \frac{Q_L}{Q_H}$$

6) Note here that $Q_H$, $Q_L$ and W all are taken as positive, a sign convention followed in this expression. Since $Q_L < Q_H$, the efficiency (η) always less than 1. This implies that heat absorbed is not completely converted into work. The second law of thermodynamics placed fundamental restrictions on converting heat completely into work.

**26. Derive the expression for Carnot engine efficiency.**

**Efficiency of a Carnot engine**

1) Efficiency is defined as the ratio of work done by the working substance in one cycle to the amount of heat extracted from the source.

$$\eta = \frac{Work\ done}{Heat\ extracted} = \frac{W}{Q_H} \text{ ---------- } 1$$

From the first law of thermodynamics, $W = Q_H - Q_L$

$$\eta = \frac{QH - QL}{Q_H} = 1 - \frac{Q_L}{Q_H} \text{ -------------- } 2$$

Applying isothermal conditions, we get,

$$Q_H = \mu RT_H \ln\frac{V_2}{V_4} \quad ; Q_L = \mu RT_L \ln\frac{V_3}{V_4} \text{ ------------ } 3$$

Here we omit the negative sign. Since we are interested in only the amount of heat ($Q_L$) ejected into the sink, we have, $\frac{Q_L}{Q_H} = \frac{T_L \, In \frac{V_3}{V_4}}{T_H \, In \frac{V_2}{V_1}}$ ---------4

By applying adiabatic conditions, we get, $T_H V_2^{\gamma-1} = T_L V_3^{\gamma-1}$

By dividing the above two equations, we get, $T_H V_1^{\gamma-1} = T_L V_4^{\gamma-1}$

By dividing the above two equations, we get, $\left(\frac{V_2}{V_1}\right)^{\gamma-1} = \left(\frac{V_3}{V_4}\right)^{\gamma-1}$

Which implies that, $\frac{V_2}{V_1} = \frac{V_3}{V_4}$ ---------------5

Substituting equation (5) in (4), we get, $\frac{Q_L}{Q_H} = \frac{T_L}{T_H}$

The efficiency $\eta$ - 1 $- \frac{T_L}{T_H}$

Note : $T_L$ and $T_H$ should be expressed in Kelvin scale.

**27. Explain in detail the working of a refrigerator.**

**REFRIGERATOR**

A refrigerator is a Carnot's engine working in the reverse order.

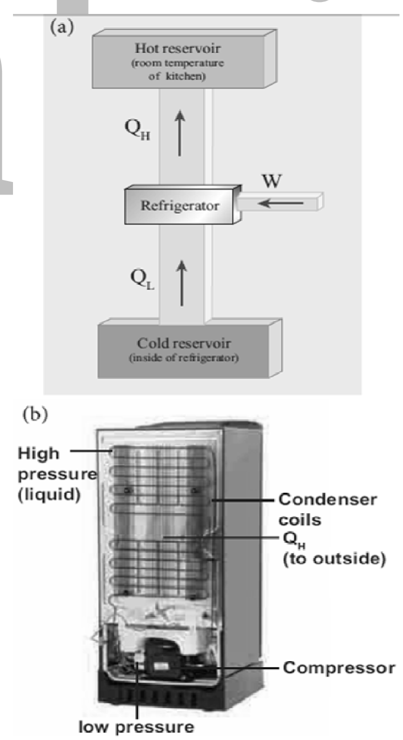
**Working Principle:**

The working substance (gas) absorbs a quantity of heat $Q_L$ from the cold body (sink) at a lower temperature $T_L$. A certain amount of work W is done on the working substance by the compressor and a quantity of heat $Q_H$ is rejected to the hot body (source) ie, the atmosphere at $T_H$. When you stand beneath of refrigerator, you can feel warmth air.

From the first law of thermodynamics ,

we have $Q_L + W = Q_H$

As a result the cold reservoir (refrigerator) further cools down and the surroundings (kitchen or atmosphere) gets hotter.



## UNIT – 09 KINETIC THEORY OF GASES

## TWO MARKS AND THREE MARKS:

**01. Why moon has no atmosphere?**

The escape speed of gases on the surface of Moon is much less than the root mean square speeds of gases due to low gravity. Due to this all the gases escape from the surface of the Moon.

**02. Write the expression for rms speed, average speed and most probable speed of a gas molecule.**

$$V_{rms} = \sqrt{\frac{3RT}{M}}\ ;\ V_{ave}\ \overline{V} = \sqrt{\frac{8RT}{\pi M}}\ ;\ V_{mp} = \sqrt{\frac{2RT}{M}}$$

**03. Define the term degrees of freedom.**

The minimum number of independent coordinates needed to specify the position and configuration of a thermo-dynamical system in space is called the degree of freedom of the system.

**04. List the factors affecting the mean free path.**

1) Mean free path increases with increasing temperature. As the temperature increases, the average speed of each molecule will increase. It is the reason why the smell of hot sizzling food reaches several meter away than smell of cold food.
2) Mean free path increases with decreasing pressure of the gas and diameter of the gas molecules.



**05. What is the reason for Brownian motion?**

According to kinetic theory, any particle suspended in a liquid or gas is continuously bombarded from all the directions so that the mean free path is almost negligible. This leads to the motion of the particles in a random and zig–zag manner.

**06. What are the factors which affect Brownian motion?**

1) Brownian motion increases with increasing temperature.
2) Brownian motion decreases with bigger particle size, high viscosity and density of the liquid (or) gas.

**07. What is meant by rms speed of the molecules of a gas? Is rms speed same as the average speed?**

The rms speed of the molecule of a gas is defined as the square root of the mean of the square of speeds of all molecules.

No, rms speed is different from the average speed. $V_{rms} = \sqrt{\frac{V_1^2+V_2^2+V_3^2}{3}}$

$\overline{\mathrm{V}}$ = Average speed = $\frac{V_1+V_2+V_3}{3}$

**08. Why No hydrogen in Earth's atmosphere?**

As the root mean square speed of hydrogen is much less than that of nitrogen, it easily escapes from the earth's atmosphere. In fact, the presence of nonreactive nitrogen instead of highly combustible hydrogen deters many disastrous consequences.

## FIVE MARKS QUESTIONS:

**09. Write down the postulates of kinetic theory of gases.**

1) All the molecules of a gas are identical, elastic spheres.
2) The molecules of different gases are different.
3) The number of molecules in a gas is very large and the average separation between them is larger than size of the gas molecules.
4) The molecules of a gas are in a state of continuous random motion.
5) The molecules collide with one another and also with the walls of the container.
6) These collisions are perfectly elastic so that there is no loss of kinetic energy during collisions.

**10. Describe the total degrees of freedom for mono-atomic molecule, diatomic molecule and tri-atomic molecule.**

**Mono-atomic molecule:** A mono-atomic molecule by virtue of its nature has only three translational degrees of freedom. Therefore f = 3

**Example:** Helium, Neon, Argon

**Diatomic molecule:** There are two cases.

**1) At Normal temperature** A molecule of a diatomic gas consists of two atoms bound to each other by a force of attraction. Physically the molecule can be regarded as a system of two point masses fixed at the ends of a mass less elastic spring. The center of mass lies in the center of the diatomic molecule. So, the motion of the center of mass requires three translational degrees of freedom (figure a). In addition, the diatomic molecule can rotate about three mutually perpendicular axes (figure b). But the moment of inertia about its own axis of rotation is negligible (about y axis in the figure). Therefore, it has only two rotational degrees of freedom (one rotation is about Z axis and another rotation is about Y axis). Therefore totally there are five degrees of freedom. f = 5

**2) At High Temperature** At a very high temperature such as 5000 K, the diatomic molecules possess additional two degrees of freedom due to vibrational motion[one due to kinetic energy of vibration and the other is due to potential energy] (Figure c). So totally there are seven degrees of freedom.f = 7.

**Examples:** Hydrogen, Nitrogen, Oxygen.

**3) Tri-atomic molecules** There are two cases.

**Linear tri-atomic molecule** In this type, two atoms lie on either side of the central atom as shown in the Figure. Linear tri-atomic molecule has three translational degrees of freedom. It has two rotational degrees of freedom because it is similar to diatomic molecule except there is an additional atom at the center. At normal temperature, linear tri-atomic molecule will have five degrees of freedom. At high temperature it has two additional vibrational degrees of freedom. So a linear tri-atomic molecule has seven degrees of freedom. **Example:** Carbon dioxide

**Non-linear tri-atomic molecule** In this case, the three atoms lie at the vertices of a triangle as shown in the Figure. It has three translational degrees of freedom and three rotational degrees of freedom about three mutually orthogonal axes. The total degrees of freedom, f = 6

**Example:** Water, Sulphurdioxide.

**11. Derive the ratio of two specific heat capacities of mono-atomic, diatomic and Tri-atomic molecules.**

**Application of law of equipartition energy in specific heat of a gas**

Meyer's relation $C_P - C_V = R$ connects the two specific heats for one mole of an ideal gas.

Equipartition law of energy is used to calculate the value of $C_P - C_V$ and the ratio between them $\gamma = \frac{C_P}{C_V}$. Here $\gamma$ is called adiabatic exponent.

**i) Monatomic molecule:**

Average kinetic energy of a molecule = $\left[\frac{3}{2}kT\right]$

Total energy of a mole of gas $\frac{3}{2}kT \times N_A$ ; = $\frac{3}{2}RT$

For one mole, the molar specific heat at constant volume $C_V = \frac{dU}{dT} = \frac{d}{dT}\left[\frac{3}{2}RT\right]$

$$C_V = \left[\frac{3}{2}R\right] ; C_P = C_V + R$$

$$= \frac{3}{2}R + R = \frac{5}{2}R$$

The ratio of specific heats, $\gamma = \frac{C_P}{C_V}$ ;

$$= \frac{\frac{5}{2}R}{\frac{3}{2}R} = \frac{5}{3} \quad \gamma = 1.67$$

**ii) Diatomic molecule:**

Average kinetic energy of a diatomic molecule at low temperature = $\frac{5}{2}kT$

Total energy of one mole of gas = $\frac{5}{2}kT \times N_A$ ; = $\frac{5}{2}RT$

(Here, the total energy is purely kinetic) For one mole Specific heat at constant volume. $C_V = \frac{dU}{dT}$ ; =$\left[\frac{5}{2}RT\right]$ ; $C_V = \frac{5}{2}R$

But, $C_P = C_V + R$

$$= \frac{5}{2}R + R = \frac{7}{2}R$$

The ratio of specific heats, $\gamma = \frac{C_P}{C_V}$ ;

$$= \frac{\frac{7}{2}R}{\frac{5}{2}R} = \frac{7}{5} \quad \gamma = 1.40$$

Energy of a diatomic molecule at high temperature is equal to $\frac{7}{2}$ RT

$C_V = \frac{dU}{dT}$ ; $= \left[\frac{7}{2}RT\right]$ ; $C_V = \frac{7}{2}R$

But, $C_P = C_V + R$

$= \frac{7}{2}R + R = \frac{9}{2}R$

Note that the $C_V$ and $C_P$ are higher for diatomic molecules than the mono atomic molecules. It implies that to increase the temperature of diatomic gas molecules by 1°C it require more heat energy than mono-atomic molecules.

The ratio of specific heats, $\gamma = \frac{C_P}{C_V}$ ; $= \frac{\frac{9}{2}R}{\frac{7}{2}R} = \frac{9}{7} \quad \gamma = 1.28$

**ii) Tri-atomic molecule:**

**a) Linear molecule:**

Energy of one mole $= \frac{7}{2}kT \times N_A$ ; $= \frac{7}{2}RT$

$C_V = \frac{dU}{dT}$ ; $= \frac{d}{dT}\left[\frac{7}{2}RT\right]$ ; $C_V = \frac{7}{2}R$

But, $C_P = C_V + R$

$= \frac{7}{2}R + R = \frac{9}{2}R$

The ratio of specific heats, $\gamma = \frac{C_P}{C_V}$ ;

$$= \frac{\frac{9}{2}R}{\frac{7}{2}R} = \frac{9}{7} \quad \gamma = 1.28$$

**b) Non-linear molecule:**

Energy of a mole $= \frac{6}{2}kT \times N_A$; $= \frac{6}{2}RT = 3RT$

$C_V = \frac{dU}{dT}$ ; $= 3R$ ;

But, $C_P = C_V + R$ ;

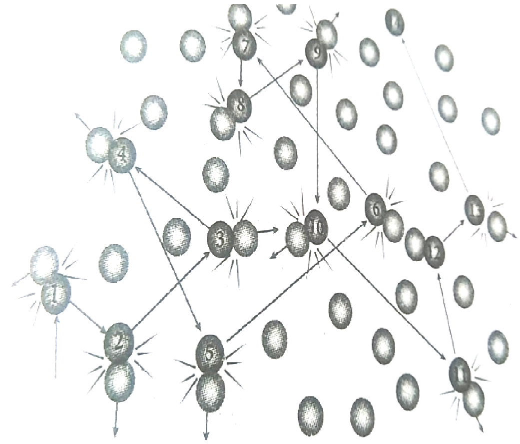
$= 3R + R = 4R$

The ratio of specific heats, $\gamma = \frac{C_P}{C_V}$

$$= \frac{4R}{3R} = \frac{4}{3} \quad \gamma = 1.33$$

Note that according to kinetic theory model of gases the specific heat capacity at constant volume and constant pressure are independent of temperature. But in reality it is not sure. The specific heat capacity varies with the temperature.

**12. Describe the Brownian motion.**



1) Brownian motion is due to the bombardment of suspended particles by molecules of the surrounding fluid.

2) According to kinetic theory, any particle suspended in a liquid or gas is continuously bombarded from all the directions so that the mean free path is almost negligible. This leads to the motion of the particles in a random and zig–zag manner

**Factors affecting Brownian motion**

1) Brownian motion increases with increasing temperature.
2) Brownian motion decreases with bigger particle size, high viscosity and density of the liquid (or) gas.

## UNIT – 10 OSCILLATIONS

## TWO MARKS AND THREE MARKS:

**01. What is an epoch?**

The displacement time t = 0 s (initial time), the phase $\varphi = \varphi_0$ is called epoch. (initial phase) where $\varphi_0$ is called the angle of epoch.

**02. Write down the time period of simple pendulum.**

The angular frequency of this oscillator (natural frequency of this system) is $\omega^2 = \frac{g}{l} \Rightarrow \omega = \sqrt{\frac{g}{l}}$ in rads$^{-1}$

The frequency of oscillations is $f = \frac{1}{2\pi}\sqrt{\frac{g}{l}}$ in Hz, and time period of oscillations is $T = 2\pi\sqrt{\frac{l}{g}}$

**03. State the laws of simple pendulum?**

**Law of length:** For a given value of acceleration due to gravity, the time period of a simple pendulum is directly proportional to the square root of length of the pendulum. $T \,\alpha\, \sqrt{l}$

**Law of acceleration:** For a fixed length, the time period of a simple pendulum is inversely proportional to square root of acceleration due to gravity. $T \,\alpha\, \frac{1}{\sqrt{g}}$

**04. Write down the equation of time period for linear harmonic oscillator.**

From Newton's second law, we can write the equation for the particle executing simple harmonic motion $m\frac{d^2x}{dt^2} = k\,x$ ; $\frac{d^2x}{dt^2} = -\frac{k}{m}x$

Comparing the equation with simple harmonic motion equation,

we get, $\omega = \sqrt{\frac{k}{m}}$ rad s$^{-1}$

Natural frequency of the oscillator is $f = \frac{\omega}{2\pi} = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$ Hertz.

and the time period of the oscillation is $T = \frac{1}{f} = 2\pi\sqrt{\frac{m}{k}}$ second.

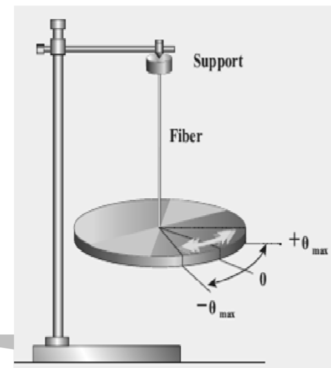
**05. State five characteristics of SHM.**

**Displacement:** The distance travelled by the vibrating particle at any instant of time t from its mean position is known as displacement.
**Velocity:** The rate of change of displacement of the particle is velocity.
**Acceleration:** The rate of change of velocity of the particle is acceleration.
**Amplitude:** The maximum displacement on either side of mean position.
**Time Period:** The time taken by the particle executing SHM to complete one vibration.

**FIVE MARKS QUESTIONS:**

**06. What is meant by angular harmonic oscillation? Compute the time period of angular harmonic oscillation.**

1) When a body is allowed to rotate freely about a given axis then the oscillation is known as the angular oscillation. The point at which the resultant torque acting on the body is taken to be zero is called mean position.
2) If the body is displaced from the mean position, then the resultant torque acts such that it is proportional to the angular displacement and this torque has a tendency to bring the body towards the mean position. Let $\vec{\theta}$ be the angular displacement of the body and the resultant torque $\vec{\tau}$ acting on the body is $\vec{\tau} \,\alpha\, \vec{\theta}$ ------------- 1




$\vec{\tau} = -k\vec{\theta}$ ------------- 2

k is the restoring torsion constant, which is torque per unit angular displacement. If $I$ is the moment of inertia of the body and $\vec{\alpha}$ is the angular acceleration then $\vec{\tau} = I\vec{\alpha} = -k\vec{\theta}$ . But $\vec{\alpha} = \frac{d^2\vec{\theta}}{dt^2}$ and therefore,

$\vec{\alpha} = \frac{d^2\vec{\theta}}{dt^2} = -\frac{k}{I}\vec{\theta}$ ------------- 3

3) This differential equation resembles simple harmonic differential equation.
So, comparing equation with simple harmonic motion given in equation,

we have $\omega = \sqrt{\frac{k}{I}}$ rad $s^{-1}$ ----------- 4

The frequency of the angular harmonic motion is $f = \frac{\omega}{2\pi} = \frac{1}{2\pi}\sqrt{\frac{k}{I}}$ Hz……5

and the time period of the oscillation is $T = \frac{1}{f} = 2\pi\sqrt{\frac{I}{k}}$ second.

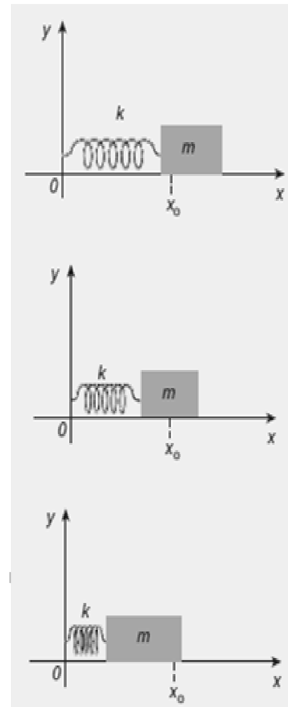


**07. Write down the difference between simple harmonic motion and angular simple harmonic motion.**

| S. No. | Simple Harmonic Motion | Angular Harmonic Motion |
|---|---|---|
| 1 | The displacement of the particle is measured in terms of linear displacement $\vec{r}$ | The displacement of the particle is measured in terms of angular displacement $\vec{\theta}$ |
| 2 | Acceleration of the particle is $\vec{a} = -\omega^2\vec{r}$ | Angular Acceleration of the particle is $\vec{\alpha} = -\omega^2\vec{\theta}$ |
| **3** | Force , $\vec{F} = m\vec{a}$ where m is called mass of the particle. | Torque, $\vec{\tau} = I\vec{\alpha}$ where I is called moment of inertia of a body. |
| 4 | The restoring force $\vec{F} = -k\,\vec{r}$ where k is restoring force constant | The restoring torque $\vec{\tau} = -k\,\vec{\theta}$ where k is restoring torsion constant. Note: k pronounced “kappa” |
| 5 | Angular frequency $\omega = \sqrt{\frac{k}{m}}$ rad$^{-1}$ | Angular frequency $\omega = \sqrt{\frac{k}{I}}$ rad$^{-1}$ |

**08. Explain the horizontal oscillations of a spring.**

1) Consider a system containing a block of mass m attached to a mass less spring with stiffness constant or force constant or spring constant k placed on a smooth horizontal surface (frictionless surface) as shown in Figure.




2) Let $x_0$ be the equilibrium position or mean position of mass m when it is left undisturbed. Suppose the mass is displaced through a small displacement x towards right from its equilibrium position and then released, it will oscillate back and forth about its mean position $x_0$.

3) Let F be the restoring force (due to stretching of the spring) which is proportional to the amount of displacement of block. For one dimensional motion, mathematically, we have $F \alpha x$ ; $F = -kx$

4) Where negative sign implies that the restoring force will always act opposite to the direction of the displacement. Notice that, the restoring force is linear with the displacement.

5) This is not always true; in case if we apply a very large stretching force, then the amplitude of oscillations becomes very large (which means, force is proportional to displacement containing higher powers of x) and therefore, the oscillation of the system is not linear and hence, it is called non-linear oscillation.

6) We restrict ourselves only to linear oscillations throughout our discussions, which means Hooke's law is valid (force and displacement have a linear relationship).

From Newton's second law, we can write the equation for the particle executing simple harmonic motion m $\frac{d^2x}{dt^2} = -kx$ ;

$$\frac{d^2x}{dt^2} = -\frac{k}{m}x \text{ ----------------1}$$

Comparing the equation (1) with simple harmonic motion equation, we get

$$\omega^2 = \frac{k}{m}$$

Which means the angular frequency or natural frequency of the oscillator is

$\omega = \sqrt{\frac{k}{m}}$ rsd $s^{-1}$ -------------- 2

Natural frequency of the oscillator is $f = \frac{\omega}{2\pi} = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$ Hertz --------- 3

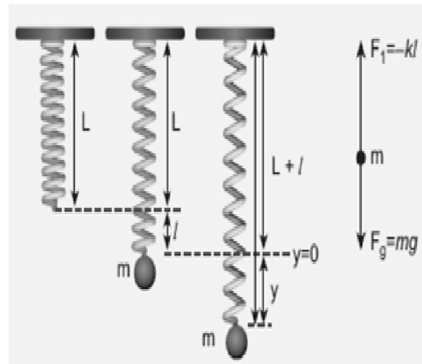
and the time period of the oscillation is $T = \frac{1}{f} = 2\pi\sqrt{\frac{m}{k}}$ second --------- 4

Notice that **in simple harmonic motion, the time period of oscillation is independent of amplitude**. This is valid only if the amplitude of oscillation is small.

**09. Describe the vertical oscillations of a spring.**

1) Consider a mass less spring with stiffness constant or force constant k attached to a ceiling as shown in Figure. Let the length of the spring before loading mass m be L. If the block of mass m is attached to the other end of spring, then the spring elongates by a length l.

2) Let F1 be the restoring force due to stretching of spring. Due to mass m, the gravitational force acts vertically downward. We can draw free-body diagram for this system as shown in Figure. When the system is under equilibrium,




$F_1$ + mg = 0---------------- 1

3) But the spring elongates by small displacement $l$,

therefore, $F_1 \propto l \Rightarrow F_1 = -k\,l$ ------------ 2

Substituting equation (2) in equation (1),

we get $-k\,l + mg = 0$

$mg = kl$ or $\frac{m}{k} = \frac{l}{g}$ ----------- 3

4) Suppose we apply a very small external force on the mass such that the mass further displaces downward by a displacement y, then it will oscillate up and down. Now, the restoring force due to this stretching of spring (total extension of spring is $y + l$ ) is $F_2 \propto (y + l)$ $F_2 = -k(y + l) = -ky - kl$ ------ 4

Since, the mass moves up and down with acceleration $\frac{d^2y}{dt^2}$, by drawing the free body diagram for this case, we get $-ky - kl + mg = m\frac{d^2y}{dt^2}$--------- 5

The net force acting on the mass due to this stretching is $F = F_2 + mg$

$F = -ky - kl + mg$ ------------- 6

5) The gravitational force opposes the restoring force. Substituting equation (3) in equation (6), we get $F = -ky - kl + kl = -ky$

Applying Newton's law, we get $m\frac{d^2y}{dt^2} = -ky$

$m\frac{d^2y}{dt^2} = -\frac{k}{m}y$ ------------- 7

6) The above equation is in the form of simple harmonic differential equation.

Therefore, we get the time period as $T = \frac{1}{f} = 2\pi\sqrt{\frac{m}{k}}$ second

The time period can be rewritten using equation (3)

$T = 2\pi\sqrt{\frac{m}{k}} = 2\pi\sqrt{\frac{l}{g}}$ second

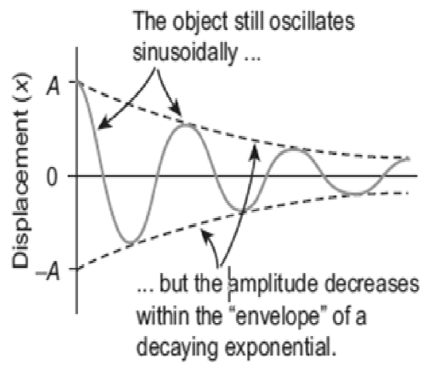
The acceleration due to gravity g can be computed from the formula

$g = 4\pi^2\left(\frac{l}{T^2}\right) ms^{-1}$

**10. Explain in detail the four different types of oscillations.**

**Damped oscillations:**

1) During the oscillation of a simple pendulum, we have assumed that the amplitude of the oscillation is constant and also the total energy of the oscillator is constant. But in reality, in a medium, due to the presence of friction and air drag, the amplitude of oscillation decreases as time progresses.
2) It implies that the oscillation is not sustained and the energy of the SHM decreases gradually indicating the loss of energy. The energy lost is absorbed by the surrounding medium. This type of oscillatory motion is known as damped oscillation.




3) In other words, if an oscillator moves in a resistive medium, its amplitude goes on decreasing and the energy of the oscillator is used to do work against the resistive medium.
4) The motion of the oscillator is said to be damped and in this case, the resistive force (or damping force) is proportional to the velocity of the oscillator.

**Examples** (i) The oscillations of a pendulum (including air friction) or pendulum oscillating inside an oil filled container. (ii) Electromagnetic oscillations in a tank circuit. (iii) Oscillations in a dead beat and ballistic galvanometers.

**Maintained oscillations:**

1) While playing in swing, the oscillations will stop after a few cycles, this is due to damping. To avoid damping we have to supply a push to sustain oscillations.
2) By supplying energy from an external source, the amplitude of the oscillation can be made constant. Such vibrations are known as maintained vibrations.

**Example:** The vibration of a tuning fork getting energy from a battery or from external power supply.

**Forced oscillations:**

1) Any oscillator driven by an external periodic agency to overcome the damping is known as forced oscillator or driven oscillator.
2) In this type of vibration, the body executing vibration initially vibrates with its natural frequency and due to the presence of external periodic force, the body later vibrates with the frequency of the applied periodic force. Such vibrations are known as forced vibrations.

   **Example:** Sound boards of stringed instruments.

**Resonance:**

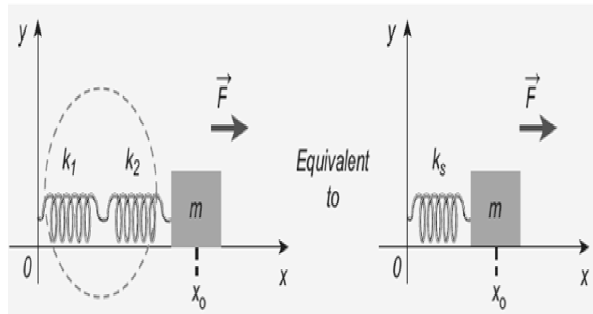
1) It is a special case of forced vibrations where the frequency of external periodic force (or driving force) matches with the natural frequency of the vibrating body (driven).
2) As a result the oscillating body begins to vibrate such that its amplitude increases at each step and ultimately it has a large amplitude. Such a phenomenon is known as resonance and the corresponding vibrations are known as resonance vibrations. **Example** The breaking of glass due to sound.

**11. Explain the effective spring constant in series connection and parallel connection**

**a) Springs connected in series**

1) When two or more springs are connected in series, all the springs in series with an equivalent spring (effective spring) whose net effect is the same as if all the springs are in series connection.

2) Given the value of individual spring constants $k_1$, $k_2$, $k_3$,... (known quantity), we can establish a mathematical relationship to find out an effective (or equivalent) spring constant $k_s$ (unknown quantity). For simplicity, let us consider only two springs whose spring constant are $k_1$ and $k_2$ and which can be attached to a mass m as shown in Figure.




3) The results thus obtained can be generalized for any number of springs in series. Let F be the applied force towards right as shown in Figure.

4) Since the spring constants for different spring are different and the connection points between them is not rigidly fixed, the strings can stretch in different lengths.

5) Let $x_1$ and $x_2$ be the elongation of springs from their equilibrium position (un-stretched position) due to the applied force F. Then, the net displacement of the mass point is $x = x_1 + x_2$ ------------1

From Hooke's law, the net force

$F = -k_s (x_1+x_2) \Rightarrow x_1 + x_2 = -\frac{F}{k_s}$ ------------2

For springs in series connection

$-k_1x_1 = -k_2x_2 = F$

$x_1 = -\frac{F}{k_1}$ and $x_2 = -\frac{F}{k_2}$ -----------3

Therefore, substituting equation (3) in equation (2), the effective spring constant can be calculated as $-\frac{F}{k_1} - \frac{F}{k_2} = \frac{F}{k_s}$

$\frac{1}{k_s} = \frac{1}{k_1} + \frac{1}{k_2}$ or $k_s = \frac{k_1k_2}{k_1+k_2}$ $Nm^{-1}$ ------------- 4

6) Suppose we have n springs connected in series, the effective spring constant in series is $\frac{1}{k_s} = \frac{1}{k_1} + \frac{1}{k_2} + \frac{1}{k_3} + \dots + \frac{1}{k_n} = \sum_{i=1}^{n} \frac{1}{k_i}$ ----------5

If all spring constants are identical i.e., $k_1 = k_2 = \dots = k_n = k$

then $\frac{1}{k_s} = \frac{n}{k} \Rightarrow k_s = \frac{k}{n}$ ----------- 6

7) This means that the effective spring constant. reduces by the factor n. Hence, for springs in series connection, the effective spring constant is lesser than the individual spring constants.

8) From equation (3), we have, $k_1x_1 = k_2x_2$ Then the ratio of compressed distance or elongated distance $x_1$ and $x_2$ is $\frac{x_2}{x_1} = \frac{k_1}{k_2}$ ------------7

The elastic potential energy stored in first and second springs are

$v_1 = \frac{1}{2}k_1x_1^2$ and $v_2 = \frac{1}{2}k_2x_2^2$ respectively.

Then, their ratio is $\frac{v_1}{v_2} = \frac{\frac{1}{2}k_1x_1^2}{\frac{1}{2}k_2x_2^2}$ ------------ 8

**b) Springs connected in parallel**

1) When two or more springs are connected in parallel, we can replace, all these springs with an equivalent spring (effective spring) whose net effect is same as if all the springs are in parallel connection.

2) Given the values of individual spring constants to be $k_1, k_2, k_3, \ldots$ (known quantities), we can establish a mathematical relationship to find out an effective (or equivalent) spring constant $k_p$ (unknown quantity).

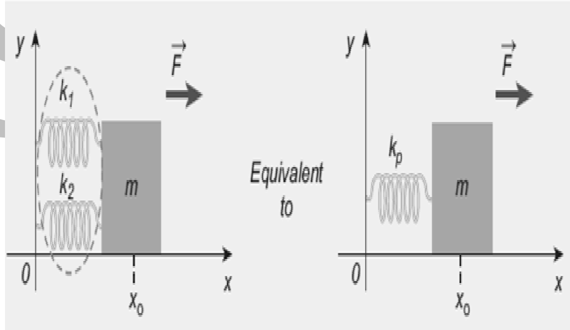
3) For simplicity, let us consider only two springs of spring constants $k_1$ and $k_2$ attached to a mass m as shown in Figure. The results can be generalized to any number of springs in parallel.

4) Let the force F be applied towards right as shown in Figure. In this case, both the springs elongate or compress by the same amount of displacement. Therefore, net force for the displacement of mass m is

$F = -k_px$ -------------- 1

where $k_p$ is called **effective spring constant**.

5) Let the first spring be elongated by a displacement x due to force $F_1$ and second spring be elongated by the same displacement x due to force $F_2$, then the net force $F = -k_1x - k_2x$ ------------- 2




Equating equations (2) and (1), we get

$k_p = k_1 + k_2$ --------------------- 3

Generalizing, for n springs connected in parallel, $k_p = \sum_{i=1}^{n} k_i$ ---------- 4

If all spring constants are identical i.e., $k_1 = k_2 = \ldots = k_n = k$

then $k_p = nk$ -------------- 5.

6) This implies that the effective spring constant increases by a factor n. Hence, for the springs in parallel connection, the effective spring constant is greater than individual spring constant.

## UNIT – 11 WAVES

## TWO MARKS AND THREE MARKS:

**01. What are transverse waves? Give one example.**

In transverse wave motion, the constituents of the medium oscillate or vibrate about their mean positions in a direction perpendicular to the direction of propagation (direction of energy transfer) of waves.

**Example:** light (electromagnetic waves)

**02. What are longitudinal waves? Give one example.**

In longitudinal wave motion, the constituent of the medium oscillate or vibrate about their mean positions in a direction parallel to the direction of propagation (direction of energy transfer) of waves.

**Example:** Sound waves travelling in air.

**03. Define wavelength.**

For **transverse waves,** the distance between two neighbouring crests or troughs is known as the wavelength.

For **longitudinal waves**, the distance between two neighbouring compressions or rarefactions is known as the wavelength.

The SI unit of wavelength is meter.

**04. Define intensity of sound and loudness of sound.**

The **intensity of sound** is defined as "the sound power transmitted per unit area taken normal to the propagation of the sound wave".

The **loudness of sound** is defined as "the degree of sensation of sound produced in the ear or the perception of sound by the listener".

**05. Explain Doppler Effect.**

When the source and the observer are in relative motion with respect to each other and to the medium in which sound propagates, the frequency of the sound wave observed is different from the frequency of the source. This phenomenon is called Doppler Effect.

**06. Explain red shift and blue shift in Doppler Effect.**

The spectral lines of the star are found to shift towards red end of the spectrum (**called as red shift**) then the star is receding away from the Earth. Similarly, if the spectral lines of the star are found to shift towards the blue end of the spectrum (**called as blue shift**) then the star is approaching Earth.

**07. What is meant by an echo? Explain.**

1) An echo is a repetition of sound produced by the reflection of sound waves from a wall, mountain or other obstructing surfaces. The speed of sound in air at 20°C is 344 m $s^{-1}$. If we shout at a wall which is at 344 m away, then the sound will take 1 second to reach the wall.

2) After reflection, the sound will take one more second to reach us. Therefore, we hear the echo after two seconds. Scientists have estimated that we can hear two sounds properly if the time gap or time interval between each sound is $\left(\frac{1}{10}\right)^{\mathrm{th}}$ of a second (persistence of hearing) i.e., 0.1 s. Then,

Velocity = $\frac{\text{Distance travelled}}{\text{Time taken}}$ ; = $\frac{2d}{t}$

2d = 344 x 0.1=34.1m; d = 17.2 m

The minimum distance from a sound reflecting wall to hear an echo at 20°C is 17.2 meter.

**08. What is reverberation?**

In a closed room the sound is repeatedly reflected from the walls and it is even heard long after the sound source ceases to function. The residual sound remaining in an enclosure and the phenomenon of multiple reflections of sound is called reverberation.



## CONCEPTUAL QUESTIONS:

**09. Why is the roar of our national animal different from the sound of a mosquito?**

Roaring of a national animal and tiger produces a sound of law pitch and high intensity or loudness, whereas the buzzing of mosquito produces a sound of high pitch and low intensity or loudness.

**10. In an empty room why is it that a tone sounds louder than in the room having things like furniture etc.**

Sound is a form of energy. The furniture which act as obstacles absorbs most of energy. So the intensity of sound becomes low but in empty room, due to the absence of obstacles the intensity of sound remains mostly same but we feel it louder.

**11. How do animals sense impending danger of hurricane?**

Some animals are believed to be sensitive to be low frequency sound waves emitted by hurricanes. They can also defect the slight drops in air and water pressure that signal a storm's approach.

## FIVE MARKS QUESTIONS:

**12. Briefly explain the difference between travelling waves and standing waves.**

| S. No. | Progressive waves | Stationary waves |
|---|---|---|
| 1 | Crests and troughs are formed in transverse progressive waves, and compression and rarefaction are formed in longitudinal progressive waves. These waves move forward or backward in a medium i.e., they will advance in a medium with a definite velocity. | Crests and troughs are formed in transverse stationary waves, and compression and rarefaction are formed in longitudinal stationary waves. These waves neither move forward nor backward in a medium i.e., they will not advance in a medium. |
| 2 | All the particles in the medium vibrate such that the amplitude of the vibration for all particles is same. | Except at nodes, all other particles of the medium vibrate such that amplitude of vibration is different for different particles. The amplitude is minimum or zero at nodes and maximum at anti-nodes. |
| 3 | These wave carry energy while propagating. | These waves do not transport energy. |



**13. Describe Newton's formula for velocity of sound waves in air and also discuss the Laplace's correction.**

1) Newton assumed that when sound propagates in air, the formation of compression and rarefaction takes place in a very slow manner so that the process is isothermal in nature.

2) That is, the heat produced during compression (pressure increases, volume decreases), and heat lost during rarefaction (pressure decreases, volume increases) occur over a period of time such that the temperature of the medium remains constant. Therefore, by treating the air molecules to form an ideal gas, the changes in pressure and volume obey Boyle's law,

$PV = \text{Constant}$ ------------ 1

3) Differentiating equation (1), we get $PdV + VdP = 0$ or

$P = -V\frac{dP}{dV} = B_T$ -------- 2

where, BT is an isothermal bulk modulus of air. Substituting equation (2) in equation $V = \sqrt{\frac{B}{\rho}}$ the speed of sound in air is

$V_T = \sqrt{\frac{B_T}{\rho}} = \sqrt{\frac{P}{\rho}}$ --------------3

Since P is the pressure of air whose value at NTP (Normal Temperature and Pressure) is 76 cm of mercury, we have

$P = (0.76 \times 13.6 \times 10^3 \times 9.8)\ N\ m^{-2}$

ρ = 1.293 kg m-3. here ρ is density of air

Then the speed of sound in air at Normal Temperature and Pressure (NTP) is

$V_T = \sqrt{\frac{0.76 \text{ x} 13.6 \text{ x } 10^3 \text{x } 9.8}{1.293}}$ =279.80 $ms^{-1}$ ≈ 280 ms-1 (theoretical value)

But the speed of sound in air at 0°C is experimentally observed as 332$ms^{-1}$ which is close upto 16% more than theoretical value

(Percentage error is $\frac{(332-280)}{332}$ x 100% = 15.6%) This error is not small.

**Laplace's correction:**

1) Laplace assumed that when the sound propagates through a medium, the particles oscillate very rapidly such that the compression and rarefaction occur very fast. Hence the exchange of heat produced due to compression and cooling effect due to rarefaction do not take place, because, air (medium) is a bad conductor of heat.

2) Since, temperature is no longer considered as a constant here, sound propagation is an adiabatic process. By adiabatic considerations, the gas obeys Poisson's law (not Boyle's law as Newton assumed), which is

$Pv^{\gamma}$ = Constant -----------4

Where, $\gamma = \frac{C_P}{C_V}$, which is the ratio between specific heat at constant pressure and specific heat at constant volume. Differentiating equation (4) on both the sides, we get

$v^{\gamma}$ dP + P($\gamma V \gamma^{-1} dV$) = 0 or $\gamma^{P} = -V\frac{dP}{dV}$ $B_A$ -------------5

where, BA is the adiabatic bulk modulus of air. Now, substituting equation (5) in equation V = $\sqrt{\frac{B}{\rho}}$ the speed of sound in air is

$V_A = \sqrt{\frac{B_T}{\rho}} = \sqrt{\frac{\gamma P}{\rho}} = \sqrt{\gamma} V_T$ -------------6

$V_A$ = 331$ms^{-1}$

**14. Discuss the law of transverse vibrations in stretched strings.**

**i) The law of length:**

For a given wire with tension T (which is fixed) and mass per unit length μ (fixed) the frequency varies inversely with the vibrating length.

Therefore, $f \, \alpha \, \frac{1}{l} \Rightarrow f = \frac{c}{l} \Rightarrow l \times f$ = C, where C is a constant.

**ii) The law of tension:**

For a given vibrating length $l$ (fixed) and mass per unit length μ (fixed) the frequency varies directly with the square root of the tension T, $f \, \alpha \, \sqrt{T}$

$\Rightarrow f = A\sqrt{T}$ where A is a constant

**iii) The law of mass:**

For a given vibrating length $l$ (fixed) and tension T (fixed) the frequency varies inversely with the square root of the mass per unit length $\mu$, $f \, \alpha \, \frac{1}{\sqrt{\mu}}$

$\Rightarrow f = \frac{B}{\sqrt{\mu}}$, where B is a constant.

**15. What is a sonometer? Give its construction and working. Explain how to determine the frequency of tuning fork using sonometer.**

1) **Sono** means *sound* related, and sonometer implies sound-related measurements. It is a device for demonstrating the relationship between the frequency of the sound produced in the transverse standing wave in a string, and the tension, length and mass per unit length of the string.

2) Therefore, using this device, we can determine the following quantities:

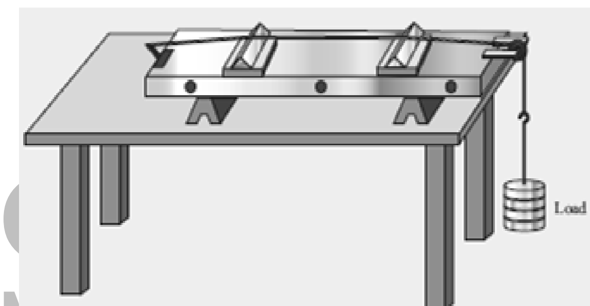
a) the frequency of the tuning fork or frequency of alternating current

b) the tension in the string

c) the unknown hanging mass

**Construction:**

3) The sonometer is made up of a hollow box which is one meter long with a uniform metallic thin string attached to it. One end of the string is connected to a hook and the other end is connected to a weight hanger through a pulley as shown in Figure.




4) Since only one string is used, it is also known as monochord. The weights are added to the free end of the wire to increase the tension of the wire.

5) Two adjustable wooden knives are put over the board, and their positions are adjusted to change the vibrating length of the stretched wire.

**Working :**

6) A transverse stationary or standing wave is produced and hence, at the knife edges P and Q, nodes are formed. In between the knife edges, anti-nodes are formed.

If the length of the vibrating element is $l$ then $l = \frac{\lambda}{2} \Rightarrow \lambda = 2l$

7) Let $f$ be the frequency of the vibrating element, T the tension of in the string and μ the mass per unit length of the string. Then using equation $v = \sqrt{\frac{T}{\mu}}$ , we get $f = \frac{v}{\lambda}$

$= \frac{1}{2l}\sqrt{\frac{T}{\mu}}$ in Hz ------------1

8) Let ρ be the density of the material of the string and d be the diameter of the string. Then the mass per unit length μ,

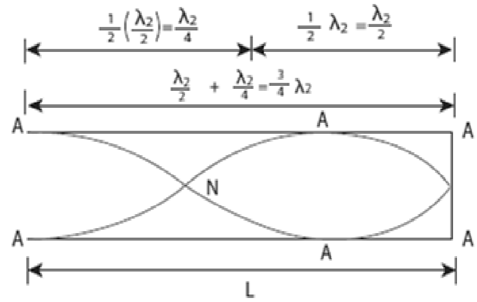
$\mu$ = Area × density = $\pi r^2\rho = \frac{\pi\rho d^2}{4}$ ; $f = \frac{v}{\lambda} = \frac{1}{2l}\sqrt{\frac{T}{\frac{\pi\rho d^2}{4}}}$  $f = \frac{1}{ld}\sqrt{\frac{T}{\pi\rho}}$

**16. Explain how overtones are produced in a**

**(a) Closed organ pipe (b) Open organ pipe**

**a) Closed organ pipes:**

1) It is a pipe with one end closed and the other end open. If one end of a pipe is closed, the wave reflected at this closed end is 180° out of phase with the incoming wave.




2) Thus there is no displacement of the particles at the closed end. Therefore, nodes are formed at the closed end and anti-nodes are formed at open end.

3) Consider the simplest mode of vibration of the air column called the fundamental mode. Anti-node is formed at the open end and node at closed end. From the Figure , let L be the length of the tube and the wavelength of the wave produced. For the fundamental mode of vibration, we have,

$L = \frac{\lambda_1}{4}$ or $\lambda_1 = 4L$ ; The frequency of the note emitted is

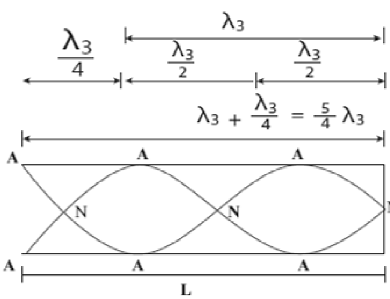
$f_1 = \frac{v}{\lambda_1} = \frac{v}{4L}$ which is called the fundamental note.

4) The frequencies higher than fundamental frequency can be produced by blowing air strongly at open end. Such frequencies are called overtones.

The Figure 2 shows the second mode of vibration having two nodes and two anti-nodes. $4L = 3\lambda_2$ $L = \frac{3\lambda_2}{4}$ or $\lambda_2 = \frac{4L}{3}$

The frequency of this $f_2 = \frac{v}{\lambda_2} = \frac{3v}{4L} = 3f_1$ is called first over tone, since here, the frequency is three times the fundamental frequency it is called third harmonic.

5) The Figure 3 shows third mode of vibration having three nodes and three anti-nodes. $4L = 5\lambda_3$



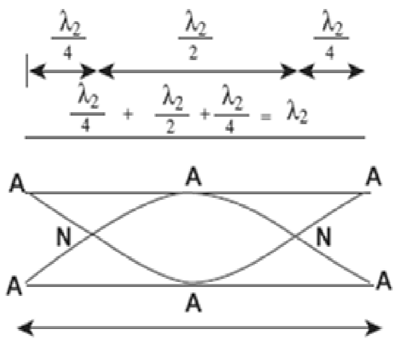

$L = \frac{5\lambda_3}{4}$ or $\lambda_3 = \frac{4L}{5}$

The frequency of this $f_3 = \frac{v}{\lambda_3} = \frac{5v}{4L} = 5f_1$ is called second over tone, and since n = 5 here, this is called fifth harmonic.

6) Hence, the closed organ pipe has only odd harmonics and frequency of the nth harmonic is $f_n = (2n+1)f_1$. Therefore, the frequencies of harmonics are in the ratio $f_1 : f_2 : f_3 : f_4 : \ldots = 1 : 3 : 5 : 7 : \ldots$

**b) Open organ pipe :**

1) It is a pipe with both the ends open. At both open ends, anti-nodes are formed. Let us consider the simplest mode of vibration of the air column called fundamental mode. Since anti-nodes are formed at the open end, a node is formed at the mid-point of the pipe.




2) From Figure, if L be the length of the tube, the wavelength of the wave produced is given by

$L = \frac{\lambda_1}{2}$ or $\lambda_1 = 2L$

The frequency of the note emitted is

$f_1 = \frac{v}{\lambda_1} = \frac{v}{2L}$

which is called the fundamental note.

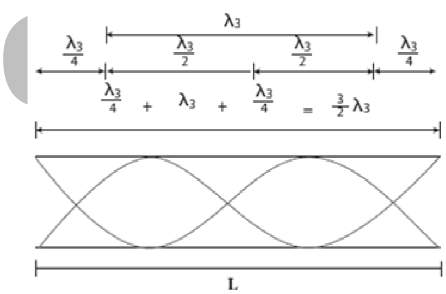
3) The frequencies higher than fundamental frequency can be produced by blowing air strongly at one of the open ends. Such frequencies are called overtones.

4) The Figure shows the second mode of vibration in open pipes. It has two nodes and three anti-nodes, and therefore, $L = \lambda_2$ or $\lambda_2 = L$ . The frequency $f_2 = \frac{v}{\lambda_2} = \frac{v}{L}$

$= 2 \times \frac{v}{2L} = 2f_1$ is called **first over tone**. Since n = 2 here, it is called the **second harmonic**.

5) The Figure shows the third mode of vibration having three nodes and four anti-nodes $L = \frac{3}{2}\lambda_3$ or $\lambda_3 = \frac{2L}{3}$ ;

$f_3 = \frac{v}{\lambda_3} = \frac{3v}{2L} = 3 \times \frac{v}{2L} = 3f_1$




is called second over tone. Since n = 3 here, it is called the third harmonic.

6) Hence, the open organ pipe has all the harmonics and frequency of $n^{th}$ harmonic is $f_n = nf_1$. Therefore, the frequencies of harmonics are in the ratio $f_1 : f_2 : f_3 : f_4 : \ldots = 1 : 2 : 3 : 4 : \ldots$

**17. Discuss the effect of pressure, temperature, density , humidity and wind.**

**a) Effect of pressure:**

1) For a fixed temperature, when the pressure varies, correspondingly density also varies such that the ratio $\left(\frac{P}{\rho}\right)$ becomes constant. This means that the speed of sound is independent of pressure for a fixed temperature.

2) If the temperature remains same at the top and the bottom of a mountain then the speed of sound will remain same at these two points. But, in practice, the temperatures are not same at top and bottom of a mountain; hence, the speed of sound is different at different points.

**b) Effect of temperature:**

Since v ∝ T ,

1) The speed of sound varies directly to the square root of temperature in kelvin. Let $v_0$ be the speed of sound at temperature at 0° C or 273 K and v be the speed of sound at any arbitrary temperature T (in kelvin),

then $\frac{v}{v_0} = \sqrt{\frac{T}{273}} = \sqrt{\frac{273+t}{273}}$

$v = v_0\sqrt{1+\frac{t}{273}} \cong v_0 \left(1+\frac{t}{546}\right)$ (using binomial expansion)

Since $v_0$ = 331m $s^{-1}$ at $0^0C$, v at any temperature in $t^0C$ is

v = (331 + 0.60t) $ms^{-1}$

2) Thus the speed of sound in air increases by 0.61 $ms^{-1}$ per degree celcius rise in temperature. Note that when the temperature is increased, the molecules will vibrate faster due to gain in thermal energy and hence, speed of sound increases.

**c) Effect of density:**

1) Let us consider two gases with different densities having same temperature and pressure. Then the speed of sound in the two gases are

$v_1 = \sqrt{\frac{\gamma_1 P}{\rho_1}}$ ----------1 and $v_2 = \sqrt{\frac{\gamma_2 P}{\rho_2}}$ ----------2

Taking ratio of equation (1) and equation (2), we get $\frac{v_1}{v_2} = \frac{\sqrt{\frac{\gamma_1 P}{\rho_1}}}{\sqrt{\frac{\gamma_2 P}{\rho_2}}} = \sqrt{\frac{\gamma_1\rho_2}{\gamma_2\rho_1}}$

For gases having same value of $\gamma$, $\frac{v_1}{v_2} = \sqrt{\frac{\rho_2}{\rho_1}}$ ----------- 3

Thus the velocity of sound in a gas is inversely proportional to the square root of the density of the gas.

**d) Effect of moisture (Humidity):**

1) We know that density of moist air is 0.625 of that of dry air, which means the presence of moisture in air (increase in humidity) decreases its density. Therefore, speed of sound increases with rise in humidity.

From equation $v = \sqrt{\frac{\gamma P}{\rho}} = \sqrt{\gamma^c T}$

v = $\sqrt{\frac{\gamma P}{\rho}}$ Let $\rho_1$, $v_1$ and $\rho_2$, $v_2$ be the density and speeds of sound in dry air and moist air, respectively. Then $\frac{v_1}{v_2} = \frac{\sqrt{\frac{\gamma_1 P}{\rho_1}}}{\sqrt{\frac{\gamma_2 P}{\rho_2}}} = \sqrt{\frac{\rho_2}{\rho_1}}$ if $\gamma_1 = \gamma_2$

Since P is the total atmospheric pressure, it can be shown that $\frac{\rho_2}{\rho_1} = \frac{P}{P_1 + 0.625 P_2}$

**e) Effect of wind:**

The speed of sound is also affected by blowing of wind. In the direction along the wind blowing, the speed of sound increases whereas in the direction opposite to wind blowing, the speed of sound decreases.

**18. Write the applications of reflection of sound waves:**

**a) Stethoscope:** It works on the principle of multiple reflections.

It consists of three main parts:

i) Chest piece (ii) Ear piece (iii) Rubber tube

**i) Chest piece:** It consists of a small disc-shaped resonator (diaphragm) which is very sensitive to sound and amplifies the sound it detects.

**ii) Ear piece:** It is made up of metal tubes which are used to hear sounds detected by the chest piece.

**iii) Rubber tube:** This tube connects both chest piece and ear piece. It is used to transmit the sound signal detected by the diaphragm, to the ear piece. The sound of heart beats (or lungs) or any sound produced by internal organs can be detected, and it reaches the ear piece through this tube by multiple reflections.

**b) Echo:**

1) An echo is a repetition of sound produced by the reflection of sound waves from a wall, mountain or other obstructing surfaces. The speed of sound in air at 20°C is 344 m $s^{-1}$. If we shout at a wall which is at 344 m away, then the sound will take 1 second to reach the wall.

2) After reflection, the sound will take one more second to reach us. Therefore, we hear the echo after two seconds. Scientists have estimated that we can hear two sounds properly if the time gap or time interval between each sound is $\left(\frac{1}{10}\right)^{\text{th}}$ of a second (persistence of hearing) i.e., 0.1 s. Then,

Velocity = $\frac{\text{Distance travelled}}{\text{Time taken}}$ ; = $\frac{2d}{t}$

2d = 344 x 0.1=34.1m; d = 17.2 m

The minimum distance from a sound reflecting wall to hear an echo at 20°C is 17.2 meter.

**c) SONAR: SO***und* **NA***vigation* and **R***anging*. Sonar systems make use of reflections of sound waves in water to locate the position or motion of an object. Similarly, dolphins and bats use the sonar principle to find their way in the darkness.

**d) Reverberation:** In a closed room the sound is repeatedly reflected from the walls and it is even heard long after the sound source ceases to function.

The residual sound remaining in an enclosure and the phenomenon of multiple reflections of sound is called reverberation.

The duration for which the sound persists is called reverberation time. It should be noted that the reverberation time greatly affects the quality of sound heard in a hall. Therefore, halls are constructed with some optimum reverberation time.

**19. Write characteristics of progressive waves:**

1) Particles in the medium vibrate about their mean positions with the same amplitude.
2) The phase of every particle ranges from 0 to 2π.
3) No particle remains at rest permanently. During wave propagation, particles come to the rest position only twice at the extreme points.
4) Transverse progressive waves are characterized by crests and troughs whereas longitudinal progressive waves are characterized by compressions and rarefactions.
5) When the particles pass through the mean position they always move with the same maximum velocity.
6) The displacement, velocity and acceleration of particles separated from each other by nλ are the same, where n is an integer, and λ is the wavelength.

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| | Term 1 | Term 2 | Term 3 | Periodical Test | SLAS | |

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