APPLIED PHYSICS-1

FIRST SEMESTER

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UNIT 1

UNITS AND DIMENSIONS

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1.1 DEFINITION OF PHYSICS AND PHYSICAL QUANTITIES

Physics: *Physics is the branch of science, which deals with the study of nature and properties of matter and energy. The subject matter of physics includes heat, light, sound, electricity, magnetism and the structure of atoms.*

Physical Quantities: *All quantities in terms of which laws of physics can be expressed and which can be measured are called physical quantities.*

For example : Distance, Speed, Mass, Force etc.

1.2 UNITS: FUNDAMENTAL AND DERIVED UNITS

Measurement: *In our daily life, we need to express and compare the magnitude of different quantities; this can be done only by measuring them.*

Measurement is the comparison of an unknown physical quantity with a known fixed physical quantity.

Unit: *The known fixed physical quantity is called unit.*

OR

The quantity used as standard for measurement is called unit.

For example, when we say that length of the class room is 8 metre, we compare the length of class room with standard quantity of length called metre.

$$\text{Length of class room} = 8 \text{ metre}$$

$$\boxed{Q = nu}$$

$\text{Physical Quantity} = \text{Numerical value} \times \text{unit}$

$$Q = \text{Physical Quantity}$$
$$n = \text{Numerical value}$$
$$u = \text{Standard unit}$$

e.g. $\text{Mass of stool} = 15\ kg$

$$\text{Mass} = \text{Physical quantity}$$
$$15 = \text{Numerical value}$$
$$Kg = \text{Standard unit}$$

Means mass of stool is 15 times of known quantity i.e. Kg.

Classification of Units: *Units can be classified into two categories.*

- **Fundamental**
- **Derived**

Fundamental Quantity: *The quantity which is independent of other physical quantities. In mechanics, mass, length and time are called fundamental quantities. Units of these fundamental physical quantities are called* **Fundamental units.**

e.g. Fundamental Physical Quantity	*Fundamental unit*
Mass	*Kg, Gram, Pound*
Length	*Metre, Centimetre, Foot*
Time	*Second*

Derived Quantity: *The quantity which is derived from the fundamental quantities is a derived quantity. For example area, speed etc.*

$$\begin{aligned} Area &= Length \times Breadth \\ &= Length \times Length \\ &= (Length)^2 \\ Speed &= Distance / Time \\ &= Length / Time \end{aligned}$$

The units for derived quantities are called **Derived Units.**

1.3 SYSTEMS OF UNITS: CGS, FPS, MKS, SI

For measurement of physical quantities, the following systems are commonly used:-

(i) **C.G.S system**: *In this system, the unit of length is centimetre, the unit of mass is gram and the unit of time is second.*

(ii) **F.P.S system**: *In this system, the unit of length is foot, the unit of mass is pound and the unit of time is second.*

(iii) **M.K.S**: *In this system, the unit of length is metre, unit of mass is kg and the unit of time is second.*

(iv) **S.I System**: *This system is an improved and extended version of M.K.S system of units. It is called international system of unit.*

Table of Fundamental Units

Sr. No.	**Name of Physical Quantity**	**Unit**	**Symbol**
1	*Length*	*Metre*	*m*
2	*Mass*	*Kilogram*	*Kg*
3	*Time*	*Second*	*s*
4	*Temperature*	*Kelvin*	*K*

5	*Electric Current*	*Ampere*	*A*
6	*Luminous Intensity*	*Candela*	*Cd*
7	*Quantity of Matter*	*Mole*	*mol*

Table of Supplementary unit

Sr. No	**Name of Physical Quantity**	**Unit**	**Symbol**
1	*Plane angle*	*Radian*	*rad*
2	*Solid angle*	*Steradian*	*sr*

1.4 DEFINITION OF DIMENSIONS

Dimensions: *The powers, to which the fundamental units of mass, length and time written as M, L and T are raised, which include their nature and not their magnitude are called dimensions of a physical quantity.*

For example *Area = Length x Breadth*

$= [L^1] \times [L^1] = [L^2] = [M^0L^2T^0]$

Power (0, 2, 0) of fundamental units are called dimensions of area in mass, length and time respectively.

e.g. *Density = mass/volume*

$= [M]/[L^3]$

$= [M^1L^{-3}T^0]$

DIMENSIONAL FORMULAE AND SI UNITS OF PHYSICAL QUANTITIES

Dimensional Formula: *An expression along with power of mass, length & time which indicates how physical quantity depends upon fundamental physical quantity.*

e.g. *Speed = Distance/Time*

$= [L^1]/[T^1] = [M^0L^1T^{-1}]$

It tells us that speed depends upon L & T. It does not depend upon M.

1.5 Dimensional Equation: *An equation obtained by equating the physical quantity with its dimensional formula is called dimensional equation.*

The dimensional equation of area, density & velocity are given as under-

Area $= [M^0L^2T^0]$

Density $= [M^1L^{-3}T^0]$

Velocity $= [M^0L^1T^{-1}]$

Dimensional formula & SI unit of Physical Quantities

Sr. No.	Physical Quantity	Formula	Dimensions	Name of S.I unit
1	Force	Mass × acceleration	$[M^1L^1T^{-2}]$	Newton (N)
2	Work	Force × distance	$[M^1L^2T^{-2}]$	Joule (J)
3	Power	Work / time	$[M^1L^2T^{-3}]$	Watt (W)
4	Energy (all form)	Stored work	$[M^1L^2T^{-2}]$	Joule (J)
5	Pressure, Stress	Force/area	$[M^1L^{-1}T^{-2}]$	Nm^{-2}
6	Momentum	Mass × velocity	$[M^1L^1T^{-1}]$	$Kgms^{-1}$
7	Moment of force	Force × distance	$[M^1L^2T^{-2}]$	Nm
8	Impulse	Force × time	$[M^1L^1T^{-1}]$	Ns
9	Strain	Change in dimension / Original dimension	$[M^0L^0T^0]$	No unit
10	Modulus of elasticity	Stress / Strain	$[M^1L^{-1}T^{-2}]$	Nm^{-2}
11	Surface energy	Energy / Area	$[M^1L^0T^{-2}]$	$Joule/m^2$
12	Surface Tension	Force / Length	$[M^1L^0T^{-2}]$	N/m
13	Co-efficient of viscosity	Force × Distance/ Area × Velocity	$[M^1L^{-1}T^{-1}]$	N/m^2
14	Moment of inertia	Mass × (radius of gyration)^2	$[M^1L^2T^0]$	$Kg\text{-}m^2$
15	Angular Velocity	Angle / time	$[M^0L^0T^{-1}]$	rad per sec
16	Frequency	1/Time period	$[M^0L^0T^{-1}]$	Hertz
17	Area	Length × Breadth	$[M^0L^2T^0]$	$Metre^2$
18	Volume	Length × breadth × height	$[M^0L^3T^0]$	$Metre^3$
19	Density	Mass/ volume	$[M^1L^{-3}T^0]$	Kg/m^3
20	Speed or velocity	Distance/ time	$[M^0L^1T^{-1}]$	m/s
21	Acceleration	Velocity/time	$[M^0L^1T^{-2}]$	m/s^2

22	*Pressure*	*Force/area*	$[M^1L^{-1}T^{-2}]$	N/m^2

PRINCIPLE OF HOMOGENEITY OF DIMENSIONS

It states that the dimensions of all the terms on both sides of an equation must be the same. According to the principle of homogeneity, the comparison, addition & subtraction of all physical quantities is possible only if they are of the same nature i.e., they have the same dimensions.

If the power of M, L and T on two sides of the given equation are same, then the physical equation is correct otherwise not. Therefore, this principle is very helpful to check the correctness of a physical equation.

Example: A physical relation must be dimensionally homogeneous, i.e., all the terms on both sides of the equation must have the same dimensions.

In the equation, $S = ut + ½ at^2$

The length (S) has been equated to velocity (u) & time (t), which at first seems to be meaningless, But if this equation is dimensionally homogeneous, i.e., the dimensions of all the terms on both sides are the same, then it has physical meaning.

Now, dimensions of various quantities in the equation are:

Distance, $S = [L^1]$

Velocity, $u = [L^1T^{-1}]$

Time, $t = [T^1]$

Acceleration, $a = [L^1T^{-2}]$

½ is a constant and has no dimensions.

Thus, the dimensions of the term on L.H.S. is $S=[L^1]$ *and*

Dimensions of terms on R.H.S=

$$ut + ½ at^2 = [L^1T^{-1}]\,[T^1] + [L^1T^{-2}]\,[T^2] = [L^1] + [L^1]$$

Here, the dimensions of all the terms on both sides of the equation are the same. Therefore, the equation is dimensionally homogeneous.

1.6 DIMENSIONAL EQUATIONS, APPLICATIONS OF DIMENSIONAL EQUATIONS

Dimensional Analysis: *A careful examination of the dimensions of various quantities involved in a physical relation is called dimensional analysis. The analysis of the dimensions of a physical quantity is of great help to us in a number of ways as discussed under the uses of dimensional equations.*

Uses of dimensional equation*: The principle of homogeneity & dimensional analysis has put to the following uses:*

(i) Checking the correctness of physical equation.
(ii) To convert a physical quantity from one system of units into another.

1. **To check the correctness of Physical relations**: *According to principle of Homogeneity of dimensions, a physical relation or equation is correct, if the dimensions of all the terms on both sides of the equation are the same. If the dimension of even one term differs from those of others, the equation is not correct.*

Example 1 *Check the correctness of the following formulae by dimensional analysis.*

(i) $F = mv^2/r$ *(ii)* $t = 2\pi\sqrt{l}/g$

Where all the letters have their usual meanings

Sol. $\boldsymbol{F = mv^2/r}$

Dimensions of the term on L.H.S

Force, $F = [M^1L^1T^{-2}]$

Dimensions of the term on R.H.S

$\mathbf{mv^2/r} = [M^1][L^1T^{-1}]^2 / [L]$

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

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

The dimensions of the term on the L.H.S are equal to the dimensions of the term on R.H.S. Therefore, the relation is correct.

(ii) $\boldsymbol{t = 2\pi\sqrt{\frac{l}{g}}}$

Here, Dimension of term on L.H.S

$t = [T^1] = [M^0L^0T^1]$

Dimensions of terms on R.H.S

Dimension of length $= [L^1]$

Dimension of g (acc. due to gravity) $= [L^1T^{-2}]$

2π being constant have no dimensions.

Hence, the dimensions of terms $2\pi\sqrt{\frac{l}{g}}$ *on R.H.S*

$= (L^1/ L^1T^{-2}])^{1/2} = [T^1] = [M^0L^0T^1]$

Thus, the dimensions of the terms on both sides of the relation are the same i.e., $[M^0L^0T^1]$*.Therefore, the relation is correct.*

2. **To convert a physical quantity from one system of units into another.**

Physical quantity can be expressed as

$Q = nu$

Let n_1u_1 *represent the numerical value and unit of a physical quantity in one system and* n_2u_2 *in the other system.*

If for a physical quantity Q; $M_1L_1T_1$ *be the fundamental unit in one system and* $M_2L_2T_2$ *be fundamental unit of the other system and dimensions in mass, length and time in each system can be respectively a,b,c.*

$$u_1 = [M_1^a L_1^b T_1^c]$$

$$u_2 = [M_2^a L_2^b T_2^c]$$

As we know

$$n_1 u_1 = n_2 u_2$$

$$n_2 = n_1 u_1 / u_2$$

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

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

While applying the above relations the system of unit as first system in which numerical value of physical quantity is given and the other as second system

Thus knowing $[M_1L_1T_1]$, $[M_2L_2T_2]$ a, b, c and n_1, we can calculate n_2.

Example 1 *Convert a force of 1 Newton to dyne.*

Sol. *To convert the force from MKS system to CGS system, we need the equation*

$$Q = n_1 u_1 = n_2 u_2$$

Thus $n_2 = \frac{n_1 u_1}{u_2}$

Here $n_1 = 1$, $u_1 = 1N$, $u_2 = dyne$

$$n_2 = n_1 \frac{\left[M_1 L_1 T_1^{-2}\right]}{\left[M_2 L_2 T_2^{-2}\right]}$$

$$n_2 = n_1 \left(\frac{M_1}{M_2}\right)\left(\frac{L_1}{L_2}\right)\left(\frac{T_1}{T_2}\right)^{-2}$$

$$n_2 = n_1 \left(\frac{kg}{gm}\right)\left(\frac{m}{cm}\right)\left(\frac{s}{s}\right)^{-2}$$

$$n_2 = n_1 \left(\frac{1000gm}{gm}\right)\left(\frac{100cm}{cm}\right)\left(\frac{s}{s}\right)^{-2}$$

$$n_2 = 1(1000)(100)$$

$$n_2 = 10^5$$

Thus **1N=**10^5 **dynes**.

Example 2 *Convert work of 1 erg into Joule.*

Sol: *Here we need to convert work from CGS system to MKS system*

Thus in the equation

$$n_2 = \frac{n_1 u_1}{u_2}$$

$n_1 = 1$

$u_1 = erg$ *(CGS unit of work)*

$u_2 = joule$ *(SI unit of work)*

$$n_2 = \frac{n_1 u_1}{u_2}$$

$$n_2 = n_1 \frac{M_1 L_1^2 T_1^{-2}}{M_2 L_2^2 T_2^{-2}}$$

$$n_2 = n_1 \left(\frac{M_1}{M_2}\right)\left(\frac{L_1}{L_2}\right)^2 \left(\frac{T_1}{T_2}\right)^{-2}$$

$$n_2 = n_1 \left(\frac{gm}{kg}\right)\left(\frac{cm}{m}\right)^2 \left(\frac{s}{s}\right)^{-2}$$

$$n_2 = n_1 \left(\frac{gm}{1000gm}\right)\left(\frac{cm}{100cm}\right)^2 \left(\frac{s}{s}\right)^{-2}$$

$$n_2 = 1(10^{-3})(10^{-2})^2 \quad n_2 = 10^{-7}$$

Thus, **1 erg=** 10^{-7} **Joule**.

UNIT 2

FORCE AND MOTION

2.1 SCALAR AND VECTOR QUANTITIES

Scalar Quantities:

Scalar quantities are those quantities which are having only magnitude but no direction.

Examples: *Mass, length, density, volume, energy, temperature, electric charge, current, electric potential etc.*

Vector Quantities:

Vector quantities are those quantities which are having both magnitude as well as direction.

Examples: *Displacement, velocity, acceleration, force, electric intensity, magnetic intensity etc.*

Representation of Vector: *A vector is represented by a straight line with an arrow head. Here, the length of the line represents the magnitude and arrow head gives the direction of vector.*

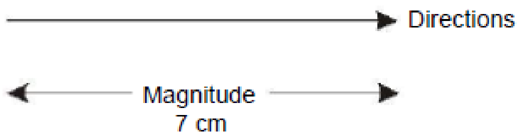


Figure:1

Types of Vectors

Unit Vector: *A vector divided by its magnitude is called a unit vector. It has a magnitude one unit and direction same as the direction of given vector. It is denoted by* $\hat{A}$.

$$\hat{A} = \frac{\vec{A}}{A}$$

Collinear Vectors: *Two or more vectors having equal or unequal magnitudes, but having same direction are called collinear vectors*

Figure: 2

Zero Vector: *A vector having zero magnitude and arbitrary direction (be not fixed) is called zero vector. It is denoted by O.*

2.2 ADDITION OF VECTORS, TRIANGLE &PARALLELOGRAM LAW

Addition of Vectors

(i) Triangle law of vector addition.

If two vectors can be represented in magnitude and direction by the two sides of a triangle taken in the same order, then the resultant is represented in magnitude and direction, by third side of the triangle taken in the opposite order (Fig. 2.5).

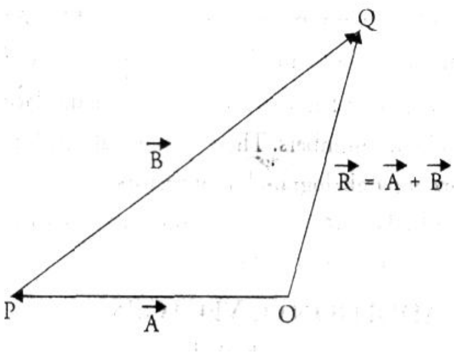


Figure: 3

Magnitude of the resultant is given by

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

And direction of the resultant is given by

$$\tan\beta = \frac{B\sin\theta}{A + B\cos\theta}$$

(ii) Parallelogram (||gm) law of vectors*:*

It states that if two vectors, acting simultaneously at a point, can have represented both in magnitude and direction by the two adjacent sides of a parallelogram, the resultant is represented by the diagonal of the parallelogram passing through that point (Fig. 2.6).

Magnitude of the resultant is given by

$$R = \sqrt{P^2 + Q^2 + 2PQ\cos\theta}$$

And direction of the resultant is given by

$$\tan\Phi = \frac{Q\sin\theta}{P + Q\cos\theta}$$

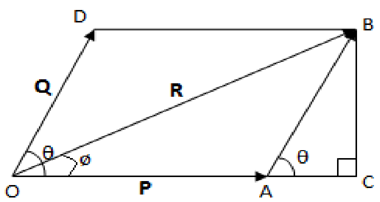


Figure: 4

2.3 SCALAR AND VECTOR PRODUCT

Multiplication of Vectors

(i) Scalar (or dot) Product: *It is defined as the product of magnitude of two vectors and the cosine of the smaller angle between them. The resultant is scalar. The dot product of vectors $\vec{A}$ and $\vec{B}$ is defined as*

$$\vec{A}.\vec{B} = A\,B\cos\theta$$

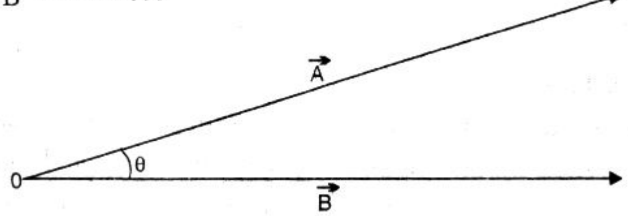


Figure: 5

(ii) Vector (or Cross) Product: *It is defined as a vector having a magnitude equal to the product of the magnitudes of the two vectors and the sine of the angle between them and is in the direction perpendicular to the plane containing the two vectors.*
Thus, the vector product of two vectors A and B is equal to

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

2.4 FORCE AND ITS UNITS, CONCEPT OF RESOLUTION OF FORCE

Force: *Force is an agent that produces acceleration in the body on which it acts.*

Or

It is a push or a pull which change or tends to change the position of the body at rest or in uniform motion.
Force is a vector quantity as it has both direction and magnitude. For example,

(i) *To move a football, we have to exert a push i.e., kick on the football*
(ii) *To stop football or a body moving with same velocity, we have to apply push in a direction opposite to the direction of the body.*

SI unit is Newton.
Dimension formula: $[MLT^{-2}]$

Resolution of a Force

The phenomenon of breaking a given force into two or more forces in different directions is known as 'resolution of force'. The forces obtained on splitting the given force are called components of the given force.

If these are at right angles to each other, then these components are called rectangular components.

Let a force F be represented by a line OP. Let OB (or F_x) is component of F along x-axis and OC (or F_y) is component along y-axis (Fig. 2.8).

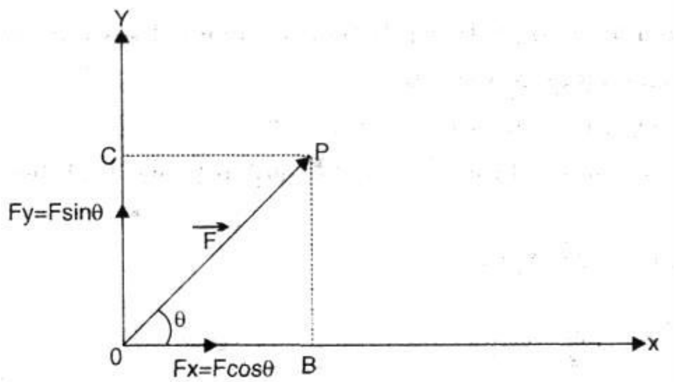


Figure: 6

Let force F makes an angle θ with x-*axis.*

In Δ OPB

$$sin\theta = \frac{PB}{OP}$$

$PB = OP\, sin\theta$

$F_y = F\, sin\theta$

$cos\theta = \frac{OB}{OP}$

$OB = OP\, cos\theta$

$F_x = F\, cos\theta$

$Vector \vec{F} = \vec{F}_x + \vec{F}_y$

Resultant: $F = \sqrt{F_x^2 + F_y^2}$

2.5 NEWTON'S LAWS OF MOTION

Sir Isaac Newton gave three fundamental laws. These laws are called Newton's laws of motion.

Newton's First Law: *It states that everybody continues in its state of rest or of uniform motion in a straight line until some external force is applied on it.*

For example, the book lying on a table will not move at its own. It does not change its position from the state of rest until no external force is applied on it.

Newton's Second law: *The rate of change of momentum of a body is directly proportional to the applied force and the change takes place in the direction of force applied.*

Or

Acceleration produced in a body is directly proportional to force applied.

Let a body of mass m moving with a velocity u. Let a force F be applied so that its velocity changes from u to v in t second.

Initial momentum = mu

Final momentum after time t second = mv

Total change in momentum = mv-mu.

Thus, the rate of change of momentum will be

$$\frac{mv - mu}{t}$$

From Newton's second law

$$F \propto \frac{mv-mu}{t} \text{ or } F \propto \frac{m(v-u)}{t}$$

$$\text{but} \frac{v - u}{t} = \frac{\text{Change in velocity}}{\text{Time}} = \text{Acceleration}(a)$$

Hence, we have

$$F \propto ma$$

or $F = k\, ma$

Where k is constant of proportionality, for convenience let k = 1.

Then $F = ma$

Newton's Third law: *To every action there is an equal and opposite reaction or action and reaction are equal and opposite.*

When a body exerts a force on another body, the other body also exerts an equal force on the first body, in opposite direction.

From Newton's third law these forces always occur in pairs.

F_{AB} (force on A by B) = -F_{BA} (force on B by A)

2.6 LINEAR MOMENTUM, CONSERVATION OF MOMENTUM, IMPULSE

Linear Momentum (p): *The quantity of motion contained in the body is linear momentum. It is given by product of mass and the velocity of the body. It is a vector and its direction is the same as the direction of the velocity.*

Let m be the mass and v is the velocity of a body at some instant, then momentum is given by $p = mv$

Example, a fast-moving cricket ball has more momentum in it than a slow moving one. But a slow-moving heavy roller has more momentum than a fast cricket ball.

Units of momentum:

The SI unit is kg m/s i.e. $kg.ms^{-1}$.

Dimension formula = $[M^1L^1T^{-1}]$.

Conservation of Momentum

If external force acting on a system of bodies is zero then the total linear momentum of a system always remains constant.

i.e. If F=0

Thus, $F = \frac{dp}{dt} = 0$

Hence, p (momentum) is constant.

Recoil of the Gun: *When a bullet is fired with a gun the bullet moves in forward direction and gun is recoiled/pushed backwards. Let*

m = mass of bullet
u = velocity of bullet
M = mass of gun
v = velocity of gun

The gun and bullet form an isolated system, so the total momentum of gun and bullet before firing = 0

Total momentum of gun and bullet after firing=m.u+M.v

Using law of conservation of momentum

$$0 = m.u + M.v$$
$$M.v = -m.u$$
$$v = \frac{-mu}{M}$$

This is the expression for recoil velocity of gun.

Here negative sign shows that motion of the gun is in opposite direction to that of the bullet. Also, velocity of gun is inversely proportional to its mass. Lesser the mass, larger will be the recoil velocity of the gun.

Impulse

Impulse is defined as the total change in momentum produced by the impulsive force.

OR

Impulse may be defined as the product of force and time and is equal to the total change in momentum of the body.

$$F.t = p_2 - p_1 = \text{total change in momentum}$$

Example *A kick given to a football or blow made with hammer.*

2.7 CIRCULAR MOTION

The motion of a body in a circle of fixed radius is called circular motion.

For example, the motion of a stone tied to a string when whirled in the air is a circular motion.

Angular Displacement: *The angle described by a body moving in a circle is called angular displacement.*

Consider a body moves in a circle, starting from A to B so that â˘ *BOA is called angular displacement*

SI unit of angular displacement is radian (rad.)

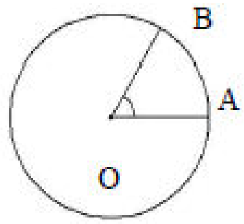


Figure: 7

Angular Velocity: *Angular velocity of a body moving in a circle is the rate of change of angular displacement with time*. It is denoted by ω (omega)

If θ is the angular displacement in time t then

$$\omega = \frac{\theta}{t}$$

SI unit of angular velocity is rad/s

Time Period: *Time taken by a body moving in a circle to complete one cycle is called time period. It is denoted by T*

Frequency (*n*): *The number of cycles completed by a body in one second is called frequency.*

It is reciprocal of time period

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

Angular Acceleration: *The time rate of change of angular velocity of a body.*

It is denoted by α. Let angular velocity of a body moving in a circle change from ω_1 to ω_2 *in time t, then*

$$\alpha = \frac{\omega_1 - \omega_2}{t}$$

SI unit of 'α' is rad/s^2

Relationship between linear and angular velocity

Consider a body moving in a circle of radius r Let it start from A and reaches to B after time t, so that â˘ BOA = θ (Fig. 2.9).

Now

$$angle = \frac{arc}{radius}$$

$$\theta = \frac{AB}{OA} = \frac{S}{r}$$

$$S = r\theta$$

Divide both sides by time (t)

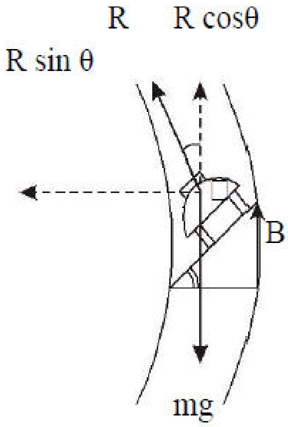
$$\frac{S}{t} = r\frac{\theta}{t}$$

Here $\frac{S}{t} = v$ *is linear velocity*

And $\frac{\theta}{t} = \omega$ *is angular velocity*

Hence $v = r\omega$

CENTRIPETAL AND CENTRIFUGAL FORCES



Centripetal Force

The force acting along the radius towards the centre of circle to keep a body moving with uniform speed in a circular path is called centripetal force. It is denoted by F_C.

$$F_c = \frac{mv^2}{r}$$

For example, a stone tied at one end of a string whose other end is held in hand, when round in the air, the centripetal force is supplied by the tension in the string.

Centrifugal Force: *A body moving in circle with uniform speed experience a force in a direction away from the centre of the circle. This force is called centrifugal force.*

For example, cream is separated from milk by using centrifugal force. When milk is rotated in cream separator, cream particles in the milk being lighter, experience less centrifugal force.

APPLICATION OF CENTRIPETAL FORCE IN BANKING BANKING OF ROADS

Banking of Roads: *While travelling on a road, you must have noticed that the outer edge of circular road is slightly raised above as compared to the inner edge of road. This is called banking of roads (Fig. 2.10).*

Angle of Banking: *The angle through which the outer edge of circular road is raised above the inner edge of circular roads is called angle of banking.*

Application of centripetal force in banking of roads

Let

m = mass of vehicle

r=radius of circular road

v=uniform speed (velocity) of vehicle

θ = *angle of banking*

At the body two forces act.

Figure : 8

(i) Weight (mg) of vehicle vertically downwards.

(ii) Normal reaction (R).

R makes an angle θ and divides the forces into two components

(i) $R\sin\theta$ towards the *centre*

(ii) $R\cos\theta$ vertically upwards and balance by weight of (mg) vehicle

Rsinθ provides the necessary centripetal force $(\frac{mv^2}{r})$

$$R\ Sin\theta = \frac{mv^2}{r} \qquad \text{- - - - - (1)}$$

and
$$R\ Cos\theta = mg \qquad \text{- - - - -(2)}$$

Divide equation 1 by 2

$$\frac{RSin\theta}{RCos\theta} = \frac{\frac{mv^2}{r}}{mg}$$

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

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

2.8 ROTATIONAL MOTION WITH EXAMPLES

The rotation of a body about fixed axis is called Rotational motion. For example,

(i) Motion of a wheel about its axis

(ii) Rotation of earth about its axis.

2.9 DEFINITION OF TORQUE AND ANGULAR MOMENTUM

Torque (τ)

It is measured by the product of magnitude of force and perpendicular distance of the line of action of force from the axis of rotation.

It is denoted by τ,

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

Where F is force and r is perpendicular distance.

Unit: Newton (N)

Dimension Formula: $[M^1L^2T^{-2}]$

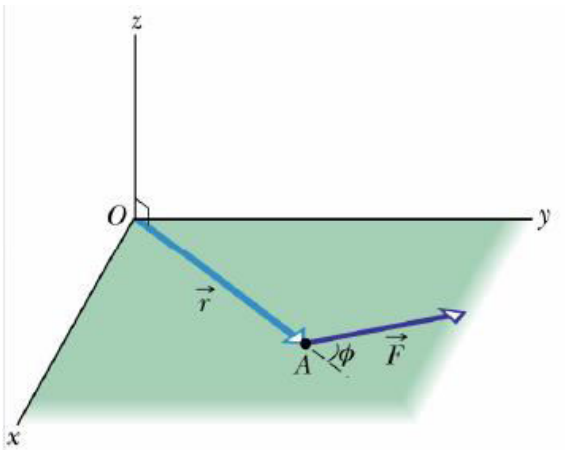


figure : 9

Angular Momentum (L)

Angular momentum of a rotating body about its axis of rotation is the algebraic sum of the linear momentum of its particles about the axis. It is denoted by L.

$$L = Momentum \times perpendicular\ distance$$

$L = p \times r$

or $L = mvr$

Unit: Kg m^2/sec

Dimensional Formula = $[ML^2T^{-1}]$

MOMENT OF INERTIA AND ITS PHYSICAL SIGNIFICANCE

Moment of Inertia

Moment of Inertia of a rotating body about an axis is defined as the sum of the product of the mass of various particles constituting the body and square of respective perpendicular distance of different particles of the body from the axis of rotation.

Expression for the Moment of Inertia:

Let us consider a rigid body of mass M having n number of particles revolving about any axis. Let $m_1, m_2, m_3 \ldots, m_n$ be the masses of particles at distance $r_1, r_2, r_3 \ldots r_n$ from the axis of rotation respectively (Fig. 4.2).

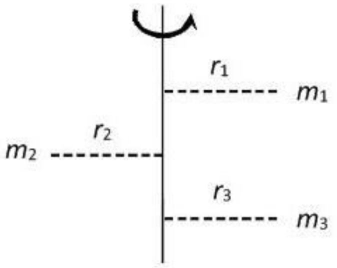


Figure: 10

Moment of Inertia of whole body

$$I = m_1r_1^2 + m_2r_2^2 + \ldots m_nr_n^2$$

or $$I = \sum_{i=1}^{n} m_i r_i^2$$

Physical Significance of Moment of Inertia

It is totally analogous to the concept of inertial mass. Moment of inertia plays the same role in rotational motion as that of mass in translational motion. In rotational motion, a body, which is free to rotate about a given axis, opposes any change in state of rotation. Moment of Inertia of a body depends on the distribution of mass in a body with respect to the axis of rotation

UNIT 3

WORK, POWER AND ENERGY

3.1 WORK (DEFINITION, SYMBOL, FORMULA AND SI UNITS)

Work

Work is said to be done when the force applied on a body displaces it through certain distance in the direction of applied force.

$$Work = Force \times Displacement$$

In vector form, it is written as $\vec{F} \times \vec{S} = FS\ Cos\theta$

It is measured as the product of the magnitude of force and the distance covered by the body in the direction of the force. It is a scalar quantity.

Unit: *SI unit of work is joule (J). In CGS system, unit of work is erg.*

$1\ J = 10^7$ *ergs Dimension of work* $= [M^1L^2T^{-2}]$

Example1. *What work is done in dragging a block 10 m horizontally when a 50 N force is applied by a rope making an angle of 30° with the ground?*

Sol. *Here,* $F = 50\ N$, $S = 10\ m$, $\theta = 30$

$$W = FS\ Cos\ \theta$$

$$W = 50 \times 10 \times Cos\ 30°$$

$$W = 50x10x\sqrt{3/2}$$

$$= 612.4\ J$$

Example2. *A man weighing 50 kg supports a body of 25 kg on head. What is the work done when he moves a distance of 20 m?*

Sol. *Total mass* $= 50 + 25 = 75\ kg$

$$\theta = 90°$$

$$Distance = 20\ m$$

$$W = FS \times 0 \qquad (Cos\ 90^o = 0)$$

$$W = 0$$

Thus, work done is zero

FRICTION: *FRICTION IS DEFINED AS THE RESISTANCE OFFERED BY THE SURFACES THAT ARE IN CONTACT WHEN THEY MOVE PAST EACH OTHER.*

APPLICATIONS IN DAILY LIFE: *1.* **Walking** *–We can walk only if we apply frictional force.Friction is what holds your shoe to the ground. The friction present on the ice is very little, this is the reason why it is hard to walk on the slippery surface of the ice.*

2.**Writing** – *A frictional force is created when the tip of the pen comes in contact with the surface of the paper. Rolling friction is what comes into play while writing with a ballpoint pen while sliding friction arises when one writes with a pencil.*

3.**Skating** – *A thin film of water under the blade is necessary to make the skate slide. The heat generated by the skate blade rubbing against the surface of ice causes some of the ice to melt right below the blade where the skater glides over the ice. This water acts as a lubricant reducing friction.*

4.**Lighting a matchstick** – *When the head of the matchstick is rubbed against a rough surface, heat is generated and this heat converts red phosphorous to white phosphorous. White phosphorous is highly inflammable and the match stick ignites. Sometimes, matchsticks fail to ignite due to the presence of water. Water lowers friction.*

5.**Driving of the vehicle on a surface-** *While driving a vehicle, the engine generates a force on the driving wheels. This force initiates the vehicle to move forwards. Friction is the force that opposes the tyre rubber from sliding on the road surface. This friction avoids skidding of vehicles.*

6.**Applications of breaks in the vehicle to stop it-** *Friction braking is the most widely used braking method in vehicles. This process involves the conversion of kinetic energy to thermal energy by applying friction to the moving parts of a vehicle. The friction force resists the motion and in turn, generates heat. This conversion of energy eventually bringing the velocity to zero.*

3.2 ENERGY (DEFINITION AND ITS SI UNITS), EXAMPLES OF TRANSFORMATION OF ENERGY

Energy

Energy of a body is defined as the capacity of the body to do the work. Like work, energy is also a scalar quantity.

Unit: SI system - Joule, CGS system - erg

Dimensional Formula: $[ML^2 T^{-2}]$.

Examples of Transformation of Energy

The energy change from one form to another is called transformation of energy. For example-

- *In a heat engine, heat energy changes into mechanical energy*
- *In an electric bulb, the electric energy changes into light energy.*
- *In an electric heater, the electric energy changes into heat energy.*
- *In a fan, the electric energy changes into mechanical energy which rotates the fan.*
- *In the sun, mass changes into radiant energy.*
- *In an electric motor, the electric energy is converted into mechanical energy.*
- *In burning of coal, oil etc., chemical energy changes into heat and light energy.*
- *In a dam, potential energy of water changes into kinetic energy, then K.E rotates the turbine which produces the electric energy.*
- *In an electric bell, electric energy changes into sound energy.*

- *In a generator, mechanical energy is converted into the electric energy.*

3.3 KINETIC ENERGY (FORMULA, EXAMPLES AND ITS DERIVATION)

Kinetic Energy (K.E.): *Energy possessed by the body by virtue of its motions is called kinetic energy. For example (i) running water (ii) Wind energy; work on the K.E. of air (iii) Moving bullet.*

Expression for Kinetic Energy

Consider F is the force acting on the body at rest (i.e., u = 0), then it moves in the direction of force to distance (s).

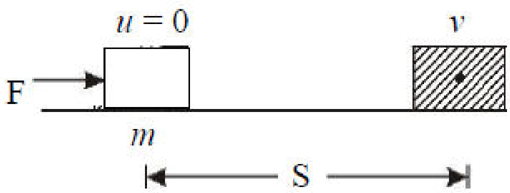


Figure: 11

Let v be the final velocity.

Using relation $v^2 - u^2 = 2aS$

$$\frac{v^2 - u^2}{2S} = a$$

$$\frac{v^2 - 0}{2S} = a$$

$$\frac{v^2}{2S} = a \qquad \text{--------------(1)}$$

Now, work done, W= F.S

or $W = maS$ *(using F =ma)* ------------- (2)

By equation (1) and (2)

$$W = m.\frac{v^2}{2S}.S$$

or $W = \frac{1}{2}mv^2$

This work done is stored in the body as kinetic energy. So kinetic energy possessed by the body is $(K.E.) = \frac{1}{2}mv^2$

3.4 POTENTIAL ENERGY (FORMULA, EXAMPLES AND ITS DERIVATION)

Potential Energy (P.E.): *Energy possessed by the body by virtue of its position is called potential energy. Example*

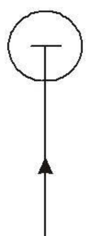
(i) Water stored in a dam

(ii) Mango hanging on the branch of a tree

Expression for Potential Energy (P.E)

It is defined as the energy possessed by the body by virtue of its position above the surface of earth.

$W = F x S$



$Work\ done \quad = Force \times height$

$\quad\quad\quad\quad\quad\quad = mg \times h = mgh$

h

This work done is stored in the form of gravitational potential energy.
Hence Potential energy =mgh.

Figure: 12

Law of Conservation of Energy

Energy can neither be created nor be destroyed but can be converted from one form to another.

3.5 CONSERVATION OF MECHANICAL ENERGY OF A FREE FALLING BODY

Let us consider K.E., P.E. and total energy of a body of mass m falling freely under gravity from a height h from the surface of ground.

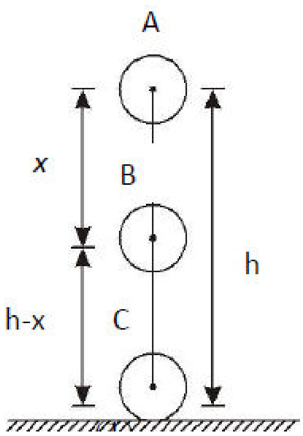


Figure: 13

According to Fig. 3.3
At position A:

$Initial\ velocity\ (u) = 0$

$K.E = \frac{1}{2}mv^2$

$P.\ E. = mgh$

$Total\ Energy = K.E + P.E$

$= 0 + mgh$

$= mgh$ ------------- (1)

At position B

$Potential\ energy = mg(h - x)$

$Velocity\ at\ point\ B = u$

$From\ equation\ of\ motion\ K.E. = \frac{1}{2}mu^2$

As $\quad V^2 - U^2 = 2aS$

Hence $\quad u^2 - 0^2 = 2gx$

or $\quad u^2 = 2gx$

Putting this value we get, $KE = \frac{1}{2}m(2gx)$

or $\quad K.E. = mgx$

$Total\ Energy = K.E + P.E$

$= mgx + mg(h - x)$

$= mgh$ --------(2)

At position C

$Potential\ energy = 0 (as\ h = 0)$

$Velocity\ at\ Point\ B = v$

$From\ equation\ of\ motion\ K.E. = \frac{1}{2}mv^2$

As $V^2 - U^2 = 2aS$

Hence $v^2 - 0^2 = 2gh$

or $v^2 = 2gh$

Putting this value we get $KE = \frac{1}{2}m(2gh)$

or $K.E. = mgh$

Total Energy $= K.E + P.E$

$= mgh + 0$

$= mgh$ ---------(3)

From equations (1), (2) and (3), it is clear that total mechanical energy of freely falling body at all the positions is same and hence remains conserved.

3.6 POWER

Power is defined as the rate at which work is done by a force. The work done per unit time is also called power.

If a body do work W in time t, then power is

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

Units of Power: *SI unit of power is watt (W)*

Power is said to be 1 W, if 1 J work is done in 1 s.

$$1W = \frac{1J}{1s}$$

Bigger units of power are:

Kilowatt (KW) $= 10^3 W$

Megawatt (MW) $= 10^6 W$

Horse power (hp) $= 746 W$

Dimension of power $= [M^1 L^2 T^{-3}]$

Example 5 *A man weighing 65 kg lifts a mass of 45 kg to the top of a building 10 meters high in 12second. Find;*

(i) Total work done by him.

(ii) The power developed by him.

Solution *Mass of the man,* $m_1 = 65\ kg$

Mass lifted $m_2 = 45\ kg$

Height through which raised $h = 10\ m$

Time taken $t = 12$ *seconds.*

(i) Total work done by the man, $W = mgh$

$= 110 \times 9.81 \times 10 = 10791.0J$

(ii) Power developed $P = \frac{W}{t} = \frac{10791J}{12s} = 899.25W$

CHAPTER - 4

PROPERTIES OF MATTER

Topics to be covered:

1. *Definition of Elasticity, Deforming force, Restoring force, example of Elastic and plastic body,*
2. *Definition of Stress and strain,* Hooke's law, Modulus of Elasticity
3. *Pressure (definition, atmospheric pressure, gauge pressure, absolute pressure*, Pascal's Law
4. *Surface tension: definition, SI unit, applications of surface tension, effect of temperature on Surface tension*
5. *Viscosity: definition, unit, examples, effect of temperature on viscosity.*

Deforming Forces: *The forces which bring the change in configuration of the body are called deforming forces.*

Restoring Force: *It is a force exerted on a body or a system that tends to move it towards an equilibrium state.*

Elasticity: *It is the property of solid materials by virtue of which a body returns to their original shape and size after the deforming forces have been removed from the body.*

Elastic Body: *It is the body that returns to its original shape after a deformation. Examples are Golf ball, Soccer ball, Rubber band etc.*
Plastic Body: *It is the body that does not return to its original shape after a deformation. Examples are Polyethylene (PE), Polypropylene (PP), Polystyrene (PS) and Polyvinyl Chloride (PVC) etc.*

Stress: *It is defined as the restoring force per unit area of a material. i.e.*

Stress = Restoring Force/ area taken.

Strain: *It is defined as the ratio of change in configuration to the original configuration, when a deforming force is applied to a body.*

The strain is of three types:

1. Longitudinal strain = *Change in length* (Δl) / original *length (l)*

2. Volumetric strain = *Change in volume* (Δv) / original volume *(v).*

3. Shearing strain = *Lateral Displacement /Distance between surfaces*

$$= \Delta\theta / l = \tan \Phi$$

Hook' s Law /Modulus of Elasticity:

Hook's law: *According to this law, "Within elastic limits, the stress applied on a body is directly proportional to the strain." i.e.*
Stress α Strain

Stress = E × Strain ;
Where E = proportionality constant which is known as modulus of elasticity.
Modulus of Elasticity: *The ratio of stress and strain is called modulus of elasticity. i.e*

$$E = \frac{stress}{strain}$$

Types of Modulus of Elasticity: *There are three types of Modulus of Elasticity given as below:*

1. Young's Modulus(Y): *The ratio of norm*al stress to the longitudinal strain is defined as Young's *modulus and is denoted by the symbol ' Y '.*

Since strain is a dimensionless quantity, the unit of Young's modulus is the same as that of stress *i.e.* $N\,m^{-2}$.

2. Bulk Modulus (B): *The ratio of normal (hydraulic) stress to the volumetric strain is called bulk modulus. It is denoted by symbol ' B '.*

B = ΔP /(ΔV/V)

Where:

B: Bulk modulus

ΔP: change of the pressure or force applied per unit area on the material

ΔV: change of the volume of the material due to the compression

V: Initial volume of the material.

SI unit of bulk modulus is the same as that of pressure i.e. Nm^{-2} *or Pa .*

Shear Modulus or Modulus of rigidity (♈): *The ratio of shearing stress to the corresponding shearing strain is called the shear modulus of the material and is represented by '♈'. It is also called the modulus of rigidity.*

♈ = *Tangential stress /Shear strain*

Unit of shear modulus is N/m^{-2} *or Pressure.*

It is defined as the force per unit area over the surface of a body. It is denoted by ' P '.

i.e $P = F/A$

SI unit = Nm^2 *or Pa (Pascal)*

Atmospheric Pressure: *Atmospheric pressure at that spot is the force acting on a unit area around a location as a result of the full height of the air column of the atmosphere above it.*

Absolute Pressure: *Absolute pressure is the pressure measured in proportion to absolute zero pressure in a vacuum.*

Gauge Pressure: *Gauge pressure is the difference between absolute pressure and atmospheric pressure at a point. If the gauge pressure is above the atmospheric pressure, it is positive, otherwise negative.*

Pascal Law: *"A change in the pressure applied to an enclosed incompressible fluid is transmitted undiminished to every portion of the fluid and to the walls of its container."*
$F = p\,A$ *where*

F = *force* (N)

p = pressure (Pa, N/m^2)

A = area (m^2)

Surface Tension: *The property of a liquid due to which its free surface behaves like stretched membrane and acquires minimum surface area. It is given by force per unit length. i.e.*

$S = F / L$

Surface tension allows insects (e.g. water striders), usually denser than water, to float and stride on a water surface.

SI unit = N/m.

Applications of surface tension: *It plays an important role in many applications in our daily life as given here:*

1. *Washing clothes*
2. *Cleaning*
3. *Cosmetics*
4. *Lubricants in machines etc.*
5. *Spreading of ink, colours*
6. *Wetting of a surface*
7. *Paints, insecticides*
8. *Creating fuel-spray in automobile engines*
9. *Passing of liquid in porous media etc.*

Effect of Temperature on Surface Tension:

Surface tension decreases when temperature increases and vice versa. This is because cohesive forces decrease with an increase of molecular thermal activity. The influence of the surrounding environment is due to the adhesive action liquid molecules have at the interface.

Viscosity: *The property of liquid due to which it oppose the relative motion between the layers of fluid. It is also known as liquid friction.*

SI unit of viscosity is Pascal-second (Pas) and CGS unit is Poise.

Effect of Temperature on Viscosity:

1. In liquids the source for Viscosity is considered to be atomic bonding. As we understand that, with the increase of temperature the bonds break and make the molecule free to move. So, we can conclude that the viscosity decreases as the temperature increases and vice versa.

2. In gases, due to the lack of cohesion, the source of viscosity is the collision of molecules. Here, As the temperature increases the viscosity increases and vice versa. This is because the gas molecules utilize the given thermal energy in increasing its kinetic energy that makes them random and therefore resulting in more the number of collisions.

CHAPTER - 5

HEAT AND TEMPERATURE

Topics to be covered:

1. *Definition of heat and temperature (on the basis of kinetic theory)*
2. *Difference between heat and temperature*
3. *Principle and working of mercury thermometer*
4. *Modes of transfer of heat (Conduction, convection and radiation with examples)*
5. *Properties of heat radiation*
6. *Different scales of temperature and their relationship.*

Heat: *Heat is the form of energy that is transferred between two substances at different temperatures. The direction of energy flow is from the substance of higher temperature to the substance of lower temperature.*

Heat on the basis of kinetic theory: *According to the kinetic theory, heat of a body is total kinetic* energy of all its molecules. If a body have 'n' number of molecules having mass m and velocities *v1, v2, v3, --------,vn. Then*

Total heat energy in the body (H) = Sum of kinetic energy of all molecules

$$= \frac{1}{2} m \left(v_1^2 + v_2^2 + v_3^2 + \ldots\ldots\ldots\ldots\ldots\ldots + v_n^2 \right)$$

Temperature: *Temperature is a measure of the average kinetic energy of the particles in a system. Temperature is measured in the Kelvin or Celsius scales, with Fahrenheit. For the above given n molecules, the Temperature is written as:*

$$Temperature\ (T) = \frac{\text{Sum of kinetic energy of all molecules}}{\text{number of molecules}}$$

$$= \frac{1}{n} \{ \sqrt{[\frac{1}{2} m (v_1^2 + v_2^2 + v_3^2 + \ldots\ldots\ldots\ldots\ldots\ldots + v_n^2)]} \}$$

Difference between Heat and Temperature:

SR. NO.	Heat	Temperature

1	*Heat is a form of energy that can transfer from hot body to cold body.*	*Temperature is the degree of hotness and coldness of a body.*
2	*Heat is the total kinetic energy and potential energy obtained by molecules in an object.*	*Temperature is the average K.E of molecules in a substance.*
3	*Heat flows from hot body to cold body.*	*It rises when heated and falls down when an object is cooled down.*
4	*It has a working ability.*	*It does not have the working ability.*
5	Its SI unit is “Joule”.	*Its SI* unit is “Kelvin”.
6	*It is measured by the calorimeter.*	*It is measured by the thermometer.*
7	It is represented by “Q”.	It is represented by “T”.

Principle and working of Mercury Thermometer:

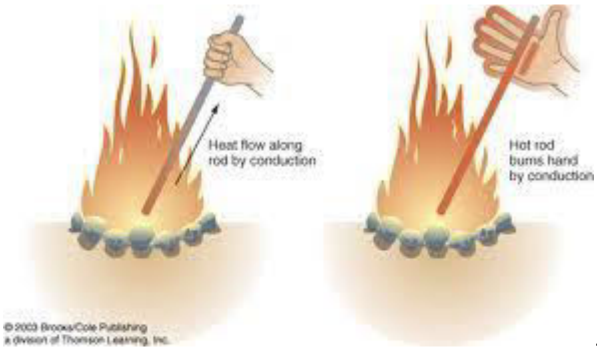
Principle: *Mercury thermometers are based on the principle that liquids expand when heated and contract when cooled. So when the temperature increases, the mercury expands and rises up the tube and when the temperature decreases, it contracts and does the opposite.*

Working: *In a mercury thermometer, a glass tube is filled with mercury and a standard temperature scale is marked on the tube. With changes in temperature, the mercury expands and contracts, and the temperature can be read from the scale, Mercury thermometers can be used to determine body, liquid and vapor temperature. Mercury thermometers are used in households, laboratory and industrial applications.*

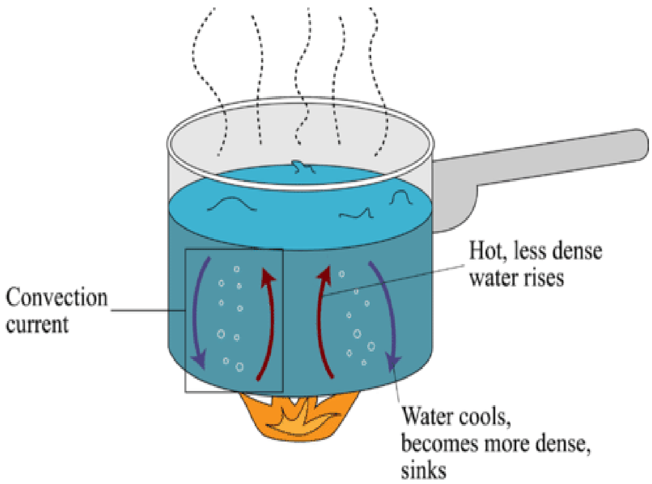
Modes of Transfer of Heat:

1. Conduction: *It is defined as that mode of transfer of heat in which the heat travels from particle to particle in contact, along the direction of fall of temperature without any net displacement of the particles.*

For example, if one end of a long metal rod (iron or brass) is heated, after some time other end of rod also becomes hot due to the transfer of heat energy from hot atoms to the nearby atoms because of conduction.

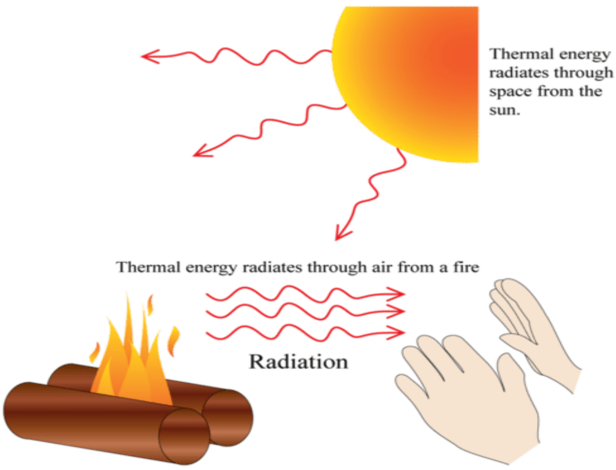


2. Convection: *The process of transmission of heat in which heat is transferred from one point to another by the physical movement of the heated particles is called convection.*



For example, if a liquid in a vessel is heated by placing a burner below the vessel, after some time the top surface of liquid also becomes warm. Other examples are heating of water, cooling of transformers, heating of rooms by heater etc.

3. Radiation*: The process of heat transfer in which heat is transmitted from one place to another without heating the intervening medium is called radiation. Thermal radiations are the energy emitted by a body in the form of radiations on account of its temperature and travel with the velocity of light. For example, We receive heat from sun by radiation process.*



Properties of Heat Radiations:

1.They do not require a medium for their propagation.
2. Heat radiations travel in straight line.
3. Heat radiations do not heat the intervening medium.
4. Heat radiations are electromagnetic waves.
5. They travel with a velocity 3×10^8 m/s in vacuum.
6. They undergo reflection, refraction, interference, diffraction and polarization.
7. They obey inverse square law.

Different scales of Temperature:

The main scales of Temperature are given as below:

1. **Celsius Scale**
2. **Kelvin Scale**
3. **Fahrenheit Scale**

Relation among the Scales of Temperature: *Temperature of a body can be converted from one scale to the other. Let*

L = lower reference point (freezing point)

H = upper reference point (boiling point)

T = temperature read on the given scale.

Now ,

Let us take a body whose temperature is determined by three different thermometers

giving readings in ℃ ,℉ *and K respectively.*

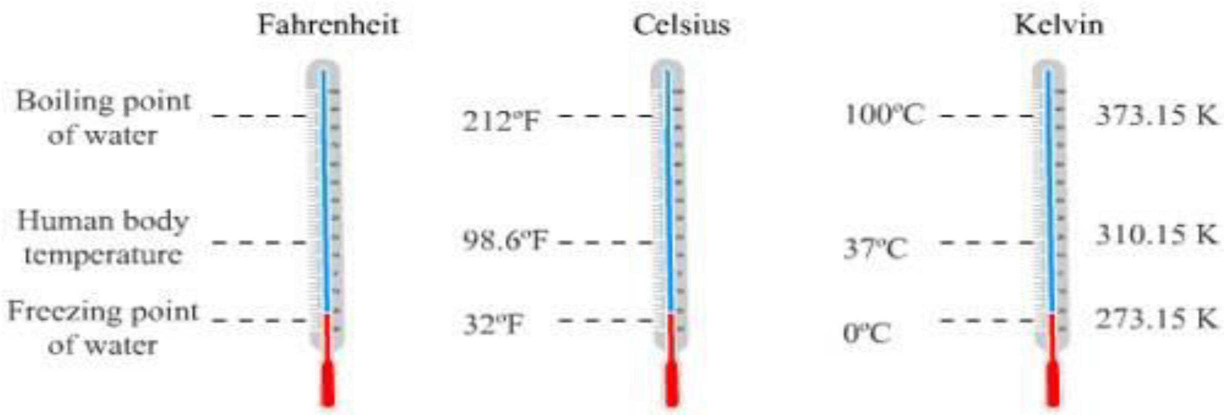


fig. Different scales of Temperature

Let T1 = C = Temperature in °C, *L1 = 0°C, H1 =100°C*

T2 = F = Temperature in °F, *L2 = 32*°F, *H2 = 212*°F

T3 = K = Temperature Kelvin, L3 = 273 K , H3 = 373K

Then

$$\frac{C-0}{100-0} = \frac{F-32}{212-32} = \frac{K-273}{373-273}$$

$$\frac{C}{100} = \frac{F-32}{180} = \frac{K-273}{100}$$

$$\frac{C}{5} = \frac{F-32}{9} = \frac{K-273}{5} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (A)$$

This is the relation among different scales of Temperature.