LEARNING MATERIAL
OF
APPLIED PHYSICS - 1

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Course Outcomes:

By the end of the course, the students are expected to learn

(i) The students are expected to acquire necessary background in Trigonometry to appreciate the importance of the geometric study as well as for the calculation and the mathematical analysis.

(ii) The ability to find the effects of changing conditions on a system.

(iii) Complex numbers enter into studies of physical phenomena in ways that most people cannot imagine.

(iv) The partial fraction decomposition lies in the fact that it provides an algorithm for computing the antiderivative of a rational function.

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Course Code	:	BS103
Course Title	:	Applied Physics –I
Number of Credits	:	3 (L: 2, T: 1, P: 0)
Prerequisites	:	High School Level Physics
Course Category	:	BS

Course Objectives:

Applied Physics includes the study of a large number of diverse topics all related to materials/things that exist in the world around us. It aims to give an understanding of this world both by observation and by prediction of the way in which such objects behave. Concrete use of physical principles and analysis in various fields of engineering and technology are given prominence in the course content. The course will help the diploma engineers to apply the basic concepts and principles to solve broad-based engineering problems and to understand different technology based applications.

Teaching Approach:

- Teachers should give examples from daily routine as well as, engineering/technology applications on various concepts and principles in each topic so that students are able to understand and grasp these concepts and principles. In all contents, SI units should be followed.
- Use of demonstration can make the subject interesting and develop scientific temper in the students. Student activities should be planned on all the topics.
- Activity- Theory - Demonstrate/practice approach may be followed throughout the course so that learning may be outcome and employability based.

Course Content:

Unit 1: **Physical world, Units and Measurements**

Physical quantities; fundamental and derived, Units and systems of units (FPS, CGS and SI units),

Dimensions and dimensional formulae of physical quantities, Principle of homogeneity of dimensions, Dimensional equations and their applications (conversion from one system of units to other, checking of dimensional equations and derivation of simple equations), Limitations of dimensional analysis.

Measurements: Need, measuring instruments, least count, types of measurement (direct, indirect), Errors in measurements (systematic and random), absolute error, relative error, error propagation, error estimation and significant figures.

Unit 2: Force and Motion

Scalar and Vector quantities – examples, representation of vector, types of vectors. Addition and Subtraction of Vectors, Triangle and Parallelogram law (Statement only), Scalar and Vector Product, Resolution of a Vector and its application to inclined plane and lawn roller.

Force, Momentum, Statement and derivation of conservation of linear momentum, its applications such as recoil of gun, rockets, Impulse and its applications.

Circular motion, definition of angular displacement, angular velocity, angular acceleration, frequency, time period, Relation between linear and angular velocity, linear acceleration and angular acceleration (related numerical), Centripetal and Centrifugal forces with live examples, Expression and applications such as banking of roads and bending of cyclist.

Unit 3: Work, Power and Energy

Work: Concept and units, examples of zero work, positive work and negative work
Friction: concept, types, laws of limiting friction, coefficient of friction, reducing friction and its engineering applications, Work done in moving an object on horizontal and inclined plane for rough and plane surfaces and related applications.

Energy and its units, kinetic energy, gravitational potential energy with examples and derivations, mechanical energy, conservation of mechanical energy for freely falling bodies, transformation of energy (examples).

Power and its units, power and work relationship, calculation of power (numerical problems).

Unit 4: Rotational Motion

Translational and rotational motions with examples, Definition of torque and angular momentum and their examples, Conservation of angular momentum (quantitative) and its applications.

Moment of inertia and its physical significance, radius of gyration for rigid body, Theorems of parallel and perpendicular axes (statements only), Moment of inertia of rod, disc, ring and sphere (hollow and solid); (Formulae only).

Unit 5: Properties of Matter

Elasticity: definition of stress and strain, moduli of elasticity, Hooke's law, significance of stress-strain curve.

Pressure: definition, units, atmospheric pressure, gauge pressure, absolute pressure, Fortin's Barometer and its applications.

Surface tension: concept, units, cohesive and adhesive forces, angle of contact, Ascent Formula (No derivation), applications of surface tension, effect of temperature and impurity on surface tension.
Viscosity and coefficient of viscosity: Terminal velocity, Stoke's law and effect of temperature on viscosity, application in hydraulic systems.

Hydrodynamics: Fluid motion, stream line and turbulent flow, Reynold's number Equation of continuity, Bernoulli's Theorem (only formula and numericals) and its applications.

Unit 6: Heat and Thermometry

Concept of heat and temperature, modes of heat transfer (conduction, convection and radiation with examples), specific heats, scales of temperature and their relationship, Types of Thermometer (Mercury thermometer, Bimetallic thermometer, Platinum resistance thermometer, Pyrometer) and their uses.

Expansion of solids, liquids and gases, coefficient of linear, surface and cubical expansions and relation amongst them, Co-efficient of thermal conductivity, engineering applications.

Learning Outcome:

After undergoing this subject, the student will be able to:

- Identify physical quantities, select their units for use in engineering solutions, and make measurements with accuracy by minimizing different types of errors.
- Represent physical quantities as scalar and vectors and solve real life relevant problems.
- Analyse type of motions and apply the formulation to understand banking of roads/railway tracks and conservation of momentum principle to describe rocket propulsion, recoil of gun etc.
- Define scientific work, energy and power and their units. Drive relationships for work, energy and power and solve related problems.
- Describe forms of friction and methods to minimize friction between different surfaces.
- State the principle of conservation of energy. Identify various forms of energy, and energy transformations.
- Compare and relate physical properties associated with linear motion and rotational motion and apply conservation of angular momentum principle to known problems.
- Describe the phenomenon of surface tension, effects of temperature on surface tension and solve statics problems that involve surface tension related forces.
- Describe the viscosity of liquids, coefficient of viscosity and the various factors affecting its value. Determine viscosity of an unknown fluid using Stokes' Law and the terminal velocity.
- Define stress and strain. State Hooke's law and elastic limits, stress–strain diagram, determine; (a) the modulus of elasticity, (b) the yield strength (c) the tensile strength, and (d) estimate the percent elongation.
- Illustrate the terms; heat and temperature, measure temperature in various processes on different scales (Celsius, Fahrenheit, and Kelvin etc.)
- Distinguish between conduction, convection and radiation; identify different methods for reducing heat losses and mode of heat transfer between bodies at different temperatures.
- State specific heats and measure the specific heat capacity of solids and liquids.

References:

1. Text Book of Physics for Class XI& XII (Part-I, Part-II); N.C.E.R.T., Delhi
2. Applied Physics, Vol. I and Vol. II, TTTI Publications, Tata McGraw Hill, Delhi.
3. Concepts in Physics by HC Verma, Vol. I & II, Bharti Bhawan Ltd. New Delhi
4. Engineering Physics by PV Naik, Pearson Education Pvt. Ltd, New Delhi
5. Engineering Physics by DK Bhhatacharya & PoonamTandan; Oxford University Press, New Delhi.
6. Comprehensive Practical Physics, Vol, I & II, JN Jaiswal, Laxmi Publications (P) Ltd., New Delhi
7. Practical Physics by C. L. Arora, S. Chand Publication.
8. e-books/e-tools/ learning physics software/websites etc.

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DIMENSION & DIMENSIONAL FORMULA OF PHYSICAL QUANTITIES-

Dimensions: **Dimensions of a physical quantity are, the powers to which the fundamental units are raised to get one unit of the physical quantity**.

The fundamental quantities are expressed with following symbols while writing dimensional formulas of derived physical quantities.

- **Mass →[M]**
- **Length→[L]**
- **Time→[T]**
- **Electric current →[I]**
- **Thermodynamic temperature →[K]**
- **Intensity of light →[cd]**
- **Quantity of matter →[mol]**

Dimensional Formula : **Dimensional formula of a derived physical quantity is the "expression showing powers to which different fundamental units are raised".**

Ex : Dimensional formula of Force F →[$M^1L^1T^{-2}$]

Dimensional equation: **When the dimensional formula of a physical quantity is expressed in the form of an equation by writing the physical quantity on the left hand side and the dimensional formula on the right hand side, then the resultant equation is called Dimensional equation.**

Ex: Dimensional equation of Energy is E = [$M^1L^2T^{-2}$] .

Derivation of Dimensional formula of a physical quantity:-

The dimensional formula of any physical quantity can be derived in two ways.

i) **Using the formula of the physical quantity** :

Ex: let us derive dimensional formula of Force .

Force F→ ma ;

substituting the dimensional formula of mass m →[M] ;

acceleration →[LT^{-2}]

We get F → [M][LT^{-2}]; **F →[**$M^1L^1T^{-2}$**]** .

ii) **Using the units of the derived physical quantity**.

Ex: let us derive the dimensional formula of momentum.

Momentum (p) → kg – mt – sec^{-1}

kg is unit of mass → [M] ;

metre (mt) is unit of length → [L] ;

sec is the unit of time →[T]

Substituting these dimensional formulas in above equation we get

p →[$M^1L^1T^{-1}$**].**

- **Quantities having no units, can not possess dimensions**:

The following physical quantities neither possess units nor dimensions.

Trigonometric ratios, logarithmic functions, exponential functions, coefficient of friction, strain, poisson's ratio, specific gravity, refractive index, Relative permittivity, Relative permeability.

• **Quantities having units, but no dimensions** :
The following physical quantities possess units but they do not possess any dimensions.

Plane angle, angular displacement, solid angle.

• **Quantities having both units & dimensions** :
The following quantities are examples of such quantities.

Area, Volume,Density, Speed, Velocity, Acceleration, Force, Energy etc.

Physical Constants : These are two types

i) Dimension less constants (value of these constants will be same in all systems of units):

Numbers, pi, exponential functions are dimension less constants.

ii) Dimensional constants (value of these constants will be different in different systems of units):

Universal gravitational constant (G),plank's constant (h), Boltzmann's constant (k), Universal gas constant (R), Permittivity of free space($\in_0$) , Permeability of free space (μ_0),Velocity of light (c).

Principle of Homogeneity of dimensions:

The term on both sides of a dimensional equation should have same dimensions. This is called principle of Homogeneity of dimensions.

(or) Every term on both sides of a dimensional equation should have same dimensions. This is called principle of homogeneity of dimensions.

Uses of Dimensional equations :

Dimensional equations are used

i) to convert units from one system to another,
ii) to check the correctness of the dimensional equations
iii) to derive the expressions connecting different physical quantities.

CHECKING THE CORRECTNESS OF PHYSICAL EQUATIONS:

According to the Principle of Homogeneity, if the dimensions of each term on both the sides of equation are same, then the physical quantity will be correct.

The correctness of a physical quantity can be determined by applying dimensions of each quantity

Example 1

To check the correctness of $v = u + at$, using dimensions

Dimensional formula of final velocity $v = [LT^{-1}]$

Dimensional formula of initial velocity $u = [LT^{-1}]$

Dimensional formula of acceleration x time, $at = [LT^{-2} \times T] = [LT^{-1}]$

Dimensions on both sides of each term is the same. Hence, the equation is dimensionally correct.

Example 2

Consider one of the equations of constant acceleration,

$$s = ut + 1/2\ at^2.$$

The equation contains three terms: s, ut and $1/2at^2$.

All three terms must have the same dimensions.

- s: displacement = a unit of length, L
- ut: velocity x time = $LT^{-1} \times T = L$
- $1/2at^2$ = acceleration x time = $LT^{-2} \times T^2 = L$

All three terms have units of length and hence this equation is dimensionally correct.

RESOLUTION OF VECTORS:

Definition:-

- **The process of splitting a vector into various parts or components is called "RESOLUTION OF VECTOR"**
- These parts of a vector may act in different directions and are called "components of vector".

A vector can be resolved into a number of components .Generally there are three components of vector .
Component along X-axis called x-component
Component along Y-axis called Y-component
Component along Z-axis called Z-component

Let us consider only two components x-component & Y-component which are perpendicular to each other. **These components are called rectangular components of vector**.

Method of resolving a vector into its rectangular components:-
Consider a vector $\vec{v}$ acting at a point making an angle ⍰⍰⍰with positive X-axis. Vector ⍰$\vec{v}$ is
represented by a line OA. From point A draw a perpendicular AB on X-axis. Suppose OB and BA
represents two vectors. Vector $\overrightarrow{OA}$ is parallel to X-axis and vector $\overrightarrow{BA}$ is parallel to Y-axis. Magnitude
of these vectors are V_x and V_y respectively. By the method of head to tail we notice that the sum of these vectors is equal to vector $\vec{v}$ .Thus V_x and V_y are the rectangular components of vector $\vec{v}$.

V_x = Horizontal component of $\vec{V}$.

V_y = Vertical component of $\vec{V}$.

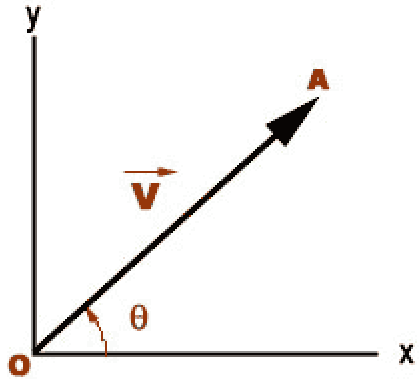

figure 01

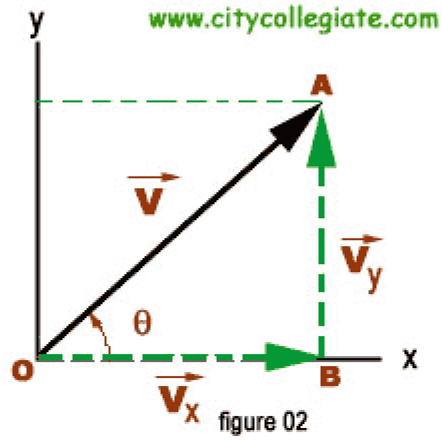

figure 02

MAGNITUDE OF HORIZONTAL COMPONENT:

Consider right angled triangle □□□□

$$\cos\theta = \frac{\overline{OB}}{\overline{OA}}$$

$$\overline{OB} = \overline{OA}\cos\theta$$

$$\boxed{V_x = V\cos\theta}$$

MAGNITUDE OF VERTICAL COMPONENT:

Consider right angled triangle □□□□

$$\sin\theta = \frac{\overline{AB}}{\overline{OA}}$$

$$\overline{AB} = \overline{OA}\sin\theta$$

$$\boxed{V_y = V\sin\theta}$$

DOT PRODUCT AND CROSS PRODUCT OF VECTORS :-

DOT PRODUCT:

The Dot Product of two vectors $\vec{A}$ and $\vec{B}$ is denoted by $\vec{A}.\vec{B}$

$$\mathbf{A} \cdot \mathbf{B} = \|\mathbf{A}\| \, \|\mathbf{B}\| \cos\theta,$$

Where θ is the angle between **A** and **B**.

In particular, if **A** and **B** are orthogonal, then the angle between them is 90° and

$$\mathbf{A} \cdot \mathbf{B} = 0.$$

At the other extreme, if they are codirectional, then the angle between them is 0° and

$$\mathbf{A} \cdot \mathbf{B} = \|\mathbf{A}\| \, \|\mathbf{B}\|$$

This implies that the dot product of a vector **A** by itself is

$$\mathbf{A} \cdot \mathbf{A} = \|\mathbf{A}\|^2,$$

which gives

$$\|\mathbf{A}\| = \sqrt{\mathbf{A} \cdot \mathbf{A}},$$

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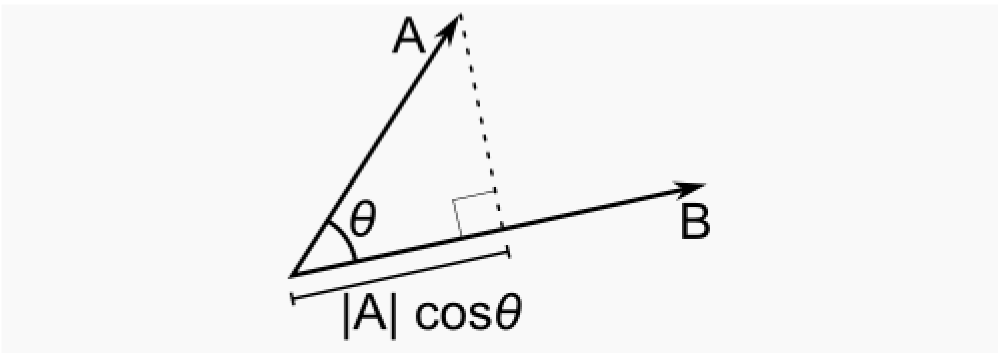
Scalar projection and first properties



The scalar projection (or scalar component) of a vector **A** in the direction of vector **B** is given by

$$A_B = \|\mathbf{A}\| \cos\theta$$

Where θ is the angle between **A** and **B**.

In terms of the geometric definition of the dot product, this can be rewritten

$$A_B = \mathbf{A} \cdot \widehat{\mathbf{B}}$$

Where $\widehat{\mathbf{B}} = \mathbf{B}/\|\mathbf{B}\|$ is the unit vector in the direction of **B**.

The dot product is thus characterized geometrically by

$$\mathbf{A} \cdot \mathbf{B} = A_B\|\mathbf{B}\| = B_A\|\mathbf{A}\|.$$

The dot product, defined in this manner, is homogeneous under scaling in each variable, meaning that for any scalar α,

$$(\alpha\mathbf{A}) \cdot \mathbf{B} = \alpha(\mathbf{A} \cdot \mathbf{B}) = \mathbf{A} \cdot (\alpha\mathbf{B}).$$

The dot product also satisfies a distributive law, meaning that

$$\mathbf{A} \cdot (\mathbf{B} + \mathbf{C}) = \mathbf{A} \cdot \mathbf{B} + \mathbf{A} \cdot \mathbf{C}.$$

$\mathbf{A} \cdot \mathbf{A}$ is never negative and is zero if and only if $\mathbf{A} = \mathbf{0}$.

Properties of scalar product of vectors.

1. **Commutative:**

   $$\mathbf{a} \cdot \mathbf{b} = \mathbf{b} \cdot \mathbf{a}.$$

   which follows from the definition (ϑ is the angle between **a** and **b**):

   $$\mathbf{a} \cdot \mathbf{b} = \|\mathbf{a}\|\|\mathbf{b}\|\cos\theta = \|\mathbf{b}\|\|\mathbf{a}\|\cos\theta = \mathbf{b} \cdot \mathbf{a}$$

2. **Distributive over vector addition:**

   $$\mathbf{a} \cdot (\mathbf{b} + \mathbf{c}) = \mathbf{a} \cdot \mathbf{b} + \mathbf{a} \cdot \mathbf{c}.$$

3. **Bilinear**:

   $$\mathbf{a} \cdot (r\mathbf{b} + \mathbf{c}) = r(\mathbf{a} \cdot \mathbf{b}) + (\mathbf{a} \cdot \mathbf{c}).$$

4. **Scalar multiplication:**

   $$(c_1\mathbf{a}) \cdot (c_2\mathbf{b}) = c_1c_2(\mathbf{a} \cdot \mathbf{b})$$

5. **Orthogonal:**

   Two non-zero vectors **a** and **b** are *orthogonal* if and only if **a** · **b** = 0.

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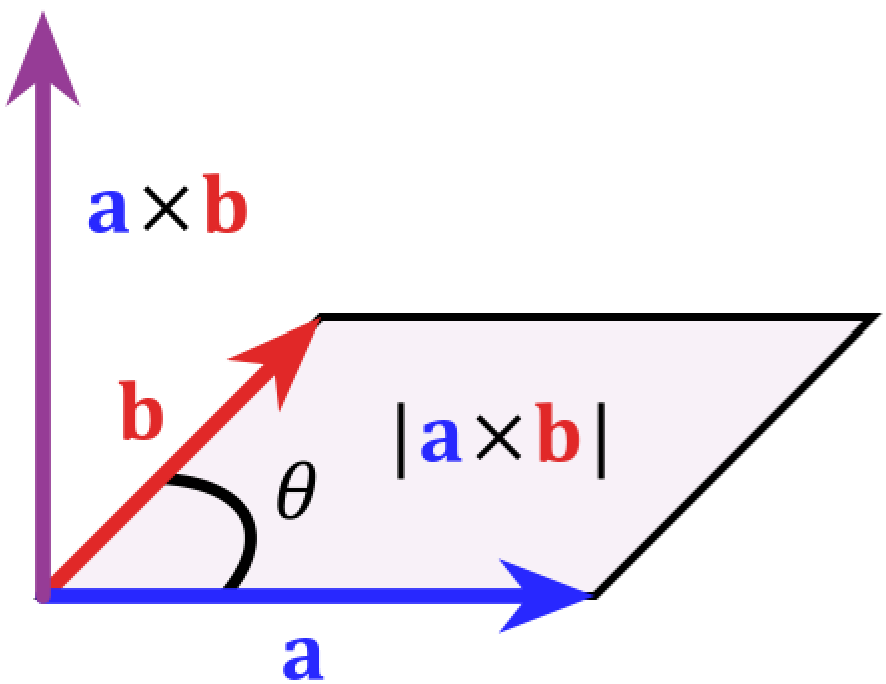
CROSS PRODUCT :

The cross product of two vectors **a** and **b** is defined only in three-dimensional space and is denoted by **a** × **b**.

The cross product **a** × **b** is defined as a vector **c** that is perpendicular to both **a** and **b**, with a direction given by the right-hand rule and a magnitude equal to the area of the parallelogram that the vectors span.



The cross product is defined by the formula

$$\mathbf{a} \times \mathbf{b} = \|\mathbf{a}\| \, \|\mathbf{b}\| \sin\theta \; \mathbf{n}$$

where ϑ is the angle between **a** and **b** in the plane containing them (hence, it is between 0° and 180°),

a and **b** are the magnitudes of vectors **a** and **b**,

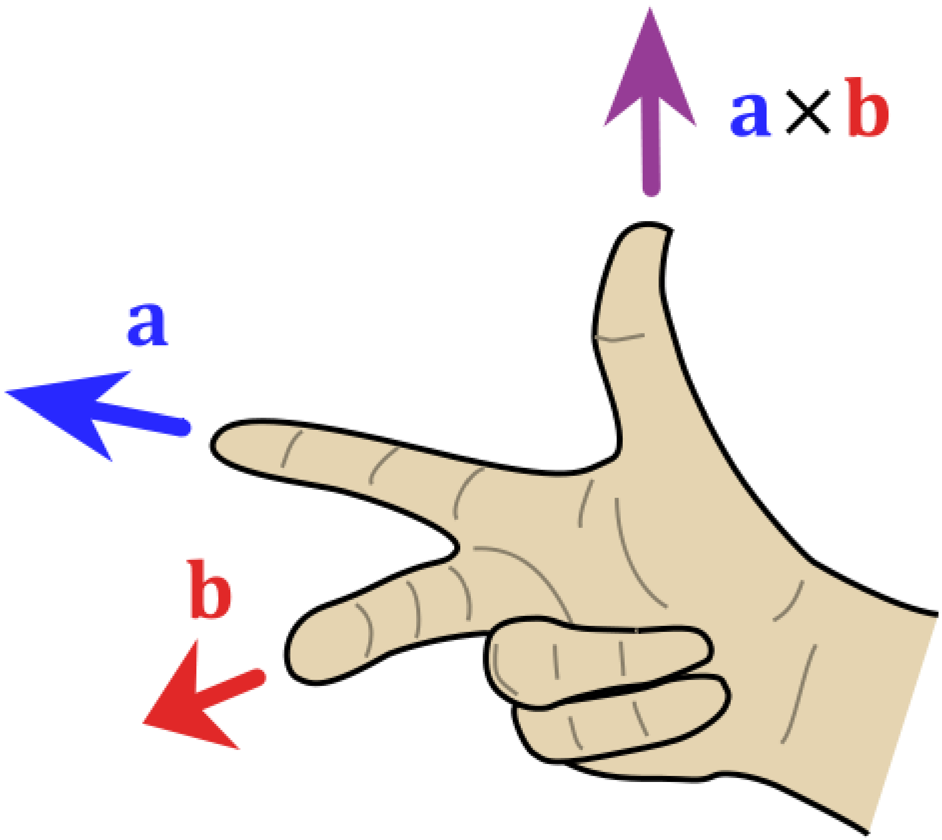
and **n** is a unit vector perpendicular to the plane containing **a** and **b** in the direction given by the right-hand rule (illustrated).

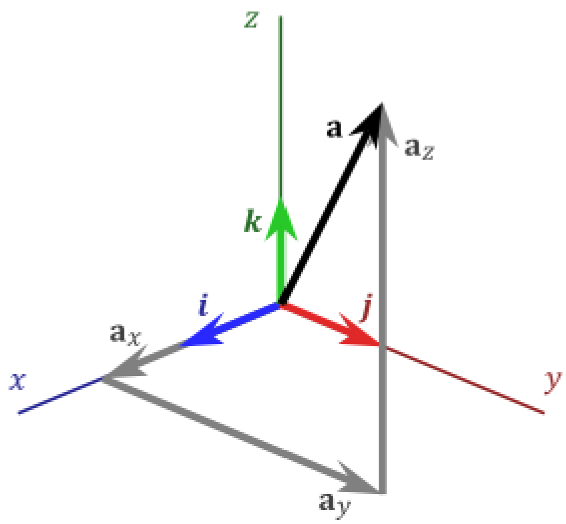
If the vectors **a** and **b** are parallel (i.e., the angle ϑ between them is either 0° or 180°), by the above formula, the cross product of **a** and **b** is the zero vector **0**.

By convention, the direction of the vector **n** is given by the right-hand rule, where one simply points the forefinger of the right hand in the direction of **a** and the middle finger in the direction of **b**. Then, the vector **n** is coming out of the thumb

Using this rule implies that the cross-product is anti-commutative, i.e., $\mathbf{b} \times \mathbf{a} = -(\mathbf{a} \times \mathbf{b})$.

Pointing the forefinger toward **b** first, and then pointing the middle finger toward **a**, the thumb will be forced in the opposite direction, reversing the sign of the product vector.





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The standard basis vectors **i**, **j**, and **k** satisfy the following equalities:

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

which imply, by the anticommutativity of the cross product, that

$$\mathbf{k} \times \mathbf{j} = -\mathbf{i}$$
$$\mathbf{i} \times \mathbf{k} = -\mathbf{j}$$
$$\mathbf{j} \times \mathbf{i} = -\mathbf{k}$$

The definition of the cross product also implies that

$\mathbf{i} \times \mathbf{i} = \mathbf{j} \times \mathbf{j} = \mathbf{k} \times \mathbf{k} = \mathbf{0}$ (the zero vector).

$$\mathbf{u} = u_1\mathbf{i} + u_2\mathbf{j} + u_3\mathbf{k}$$
$$\mathbf{v} = v_1\mathbf{i} + v_2\mathbf{j} + v_3\mathbf{k}$$

Their cross product **u** × **v** can be expanded using distributivity:

$$\begin{aligned}\mathbf{u} \times \mathbf{v} = &(u_1\mathbf{i} + u_2\mathbf{j} + u_3\mathbf{k}) \times (v_1\mathbf{i} + v_2\mathbf{j} + v_3\mathbf{k}) \\ = &u_1v_1(\mathbf{i} \times \mathbf{i}) + u_1v_2(\mathbf{i} \times \mathbf{j}) + u_1v_3(\mathbf{i} \times \mathbf{k}) \\ &+ u_2v_1(\mathbf{j} \times \mathbf{i}) + u_2v_2(\mathbf{j} \times \mathbf{j}) + u_2v_3(\mathbf{j} \times \mathbf{k}) \\ &+ u_3v_1(\mathbf{k} \times \mathbf{i}) + u_3v_2(\mathbf{k} \times \mathbf{j}) + u_3v_3(\mathbf{k} \times \mathbf{k})\end{aligned}$$

$$
\begin{aligned}
\mathbf{u}\times\mathbf{v} =& u_1v_1\mathbf{0} + u_1v_2\mathbf{k} - u_1v_3\mathbf{j} \\
& - u_2v_1\mathbf{k} - u_2v_2\mathbf{0} + u_2v_3\mathbf{i} \\
& + u_3v_1\mathbf{j} - u_3v_2\mathbf{i} - u_3v_3\mathbf{0} \\
=& (u_2v_3 - u_3v_2)\mathbf{i} + (u_3v_1 - u_1v_3)\mathbf{j} + (u_1v_2 - u_2v_1)\mathbf{k}.
\end{aligned}
$$

$$
\begin{aligned}
s_1 &= u_2v_3 - u_3v_2 \\
s_2 &= u_3v_1 - u_1v_3 \\
s_3 &= u_1v_2 - u_2v_1
\end{aligned}
$$

$$
\mathbf{u}\times\mathbf{v} = \begin{vmatrix} u_2 & u_3 \\ v_2 & v_3 \end{vmatrix}\mathbf{i} - \begin{vmatrix} u_1 & u_3 \\ v_1 & v_3 \end{vmatrix}\mathbf{j} + \begin{vmatrix} u_1 & u_2 \\ v_1 & v_2 \end{vmatrix}\mathbf{k}
$$

The magnitude of the cross product can be interpreted as the positive area of the parallelogram having **a** and **b** as sides

$$A = \|\mathbf{a}\times\mathbf{b}\| = \|\mathbf{a}\|\,\|\mathbf{b}\|\sin\theta.$$

PROPERTIES OF CROSS PRODUCT:

- If the cross product of two vectors is the zero vector, (**a** × **b** = **0**), then either of them is the zero vector, (**a** = **0**, or **b** = **0**) or both of them are zero vectors, (**a** = **b** = **0**), or else they are parallel or antiparallel, (**a** || **b**), so that the sine of the angle between them is zero, (ϑ = 0° or ϑ = 180° and sinϑ = 0).

- The self cross product of a vector is the zero vector, i.e., **a** × **a** = **0**.

- The cross product is anticommutative,

$$\mathbf{a}\times\mathbf{b} = -\mathbf{b}\times\mathbf{a},$$

- distributive over addition,

$$\mathbf{a}\times(\mathbf{b}+\mathbf{c}) = (\mathbf{a}\times\mathbf{b}) + (\mathbf{a}\times\mathbf{c}),$$

- and compatible with scalar multiplication so that

$$(r\mathbf{a})\times\mathbf{b} = \mathbf{a}\times(r\mathbf{b}) = r(\mathbf{a}\times\mathbf{b}).$$

Unit 3: Force and motion

State of rest: If the position of an object is not changing with time with respect to its surroundings, then it is in the state of rest.
State of motion: If the position of an object is changing with time with respect to its surroundings, then it is at the state of motion.
First law of motion: Every body continues in its state of rest or state of uniform motion along a straight line unless it is compelled by an external force to change that state.
Inertia: It is the inability of an object to change its original state.
Inertia of rest: It is the inability of an object to change its state of rest to the state of motion, e.g.; A person standing in a bus falls backward as the bus starts to move forward.
Inertia of motion: It is the inability of an object to change its state of motion to the state of rest, e.g. A person standing in a moving bus falls forward as the bus stops its motion.
Force: It is the physical quantity that changes or tends t change the state of a system. It is a vector quantity, its SI unit is newton (N) and the dimensional formula is $[M^1L^1T^{-2}]$.
1 newton = 1 kgm/s^2.
Momentum: It is defined as the product of mass and velocity. It is a vector quantity with the direction along the direction of velocity. Its SI unit is kgm/s and the dimensional formula is $[M^1L^1T^{-1}]$.
p= mv
Second law of motion: The rate of change of momentum of a body is directly proportional to the impressed force and it takes place in the same direction of force.
Proof for the second law of motion:

$$initialmomentum\ p_i = mu$$

$$finalmomentum\ p_f = mv$$

$$chngeofmomenntum\ \delta p = mv - mu$$

$$rateofchngeofmomenntum \frac{dp}{dt} = \frac{p_f - p_i}{t}$$

$$\frac{dp}{dt} = \frac{mv - mu}{t} = m\frac{(v-u)}{t}$$

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

Third law of motion:
To every action, there is an equal and opposite reaction; it exists as action-reaction pairs.
Force of action= - Force of reaction
Law of conservation of momentum:
The law of conservation of momentum states that when two or more bodies collide, the sum of the momenta before their impact is equal to the sum of the momenta after the collision.

$$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$$

Derivation for proving the law of conservation of momentum
If the mass m_2 exert a force on the mass m_1, then
Initial momentum of the mass m_1; $p_{1_i} = m_1u_1$
Final momentum of the mass m_1;$p_{1_f} = m_1v_1$
Rate of change of momentum of the mass m_1 =>$\frac{dp_1}{dt} = \frac{m_1v_1 - m_1u_1}{t} = F_{reaction}$
Initial momentum of the mass m_2; $p_{2_i} = m_2u_2$
Final momentum of the mass m_2; $p_{2_f} = m_2v_2$

Rate of change of momentum of the mass m_2 => $\frac{dp_2}{dt} = \frac{m_2v_2 - m_2u_2}{t} = F_{action}$

According to the 3rd law of motion

Force of action= - Force of reaction

$$F_{action} = -F_{reaction}$$

$$\frac{m_2v_2 - m_2u_2}{t} = -(\frac{m_1v_1 - m_1u_1}{t})$$

$$m_2v_2 - m_2u_2 = -(m_1v_1 - m_1u_1)$$

$$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$$

Recoil of gun

The backward movement of a gun while firing a bullet is called the recoil of a gun. It is an example of the law of conservation of momentum.

Derivation for the recoil velocity of a gun:

Let the M and m are the masses of gun and bullet and V and v are the velocities of the gun and the bullet respectively,

As the $V = 0, v = 0$, the initial momentum $p_i = 0$

According to the conservation of momentum; $p_i = p_f$

Hence $MV + mv = 0$

Recoil velocity of gun $V = -\left(\frac{mv}{M}\right)$

Force required to stop the gun:

Initial velocity of the gun (the recoil velocity) $= u = -\left(\frac{mv}{M}\right)$

Final velocity = 0

Distance moved before stopping the gun by the shoulder = s

Substituting the values in the formula $v^2 = u^2 - 2as$(- ve sign indicate the retardation)

$$0 = (\frac{mv}{M})^2 - 2as$$

$$a = \frac{m^2v^2}{2sM^2}$$

$$Force = massxacceleration$$

$$F = Mx\frac{m^2v^2}{2sM^2}$$

$$F = \frac{m^2v^2}{2sM}$$

Rocket propulsion:

The propulsion of rocket is an example of the law of conservation of momentum. The combusted fuels are ejected out at a very high velocity as the form of gases gives a thrust on the rocket to move upward. Its motion is also an example of a system with varying mass as the combusted fuels and casing are removed during the propulsion. It gives a considerable increase in the velocity.

Impulse (I):

It is the product of the force and the duration time it exerts. It is equivalent to the change in momentum. I = F t

Derivation for proving the impulse is equal to the change in momentum

$$I = Ft$$

$$F = ma = \frac{m(v-u)}{t}$$

$$I = Ft = tx\frac{m(v-u)}{t}$$

$$I = m(v-u) = mv - mu$$

Work:
It is defined as the product of force and the component of displacement along the direction o force.
$W = F.s$Or$W = Fscos\theta$. Its SI unit is jule and the dimensional formula is [$M^1L^2T^{-2}$].
One joule: 1 joule is the work done by a force of 1N when its point of application is displaced through one meter in the direction of force.
In CGS system, erg is the unit of work, 1 erg = 10^{-7} joule
Power: It is the rate of doing work.
Power $P = \frac{W}{t}$
But $W = F.s$
Hence $P = \frac{F.s}{t}$ but $\frac{s}{t} = v$
Hence power $P = Fv$
Energy: It is the capacity of doing work. SI unit of energy is joule. 1 J = 1 kgm^2/s^2.
Kinetic energy: It is the energy possessed by a body by the virtue of its motion. It can be found by using the formula $KE = \frac{1}{2}mv^2$
Potential energy: It is the energy possessed by a body by the virtue of its position or atomic configuration. It can be found by using the formula $PE = mgh$(h represent the height of the object from the ground)

Relation between the kinetic energy and the momentum:

$$KE = \frac{1}{2}mv^2$$

$$KE = \frac{1}{2}mv^2\frac{m}{m}$$

$$KE = \frac{1}{2m}m^2v^2$$

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

$$p = \sqrt{2mKE}$$

Chapter 3

WORK, POWER AND ENERGY

Learning objective: After going through this chapter, students will be able to;

- *Understand work, energy and power, their units and dimensions.*
- *Describe different types of energies and energy conservation.*
- *Solve relevant numerical problems*

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

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

$$Work = \text{Force} \times \text{Displacement}$$

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

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.

$$1J = 10^7 \text{ ergs}$$

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, $\theta = 30$

$$W = FS \cos\theta$$

$$W = 50 \times 10 \times \cos 30°$$

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

$$= 612.4 \text{ J}$$

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

θ = 90°

Distance = 20 m

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

$W = 0$

Thus, work done is zero.

Example3. A man weighing 50 kg carries a load of 10 kg on his head. Find the work done when he goes (i) 15 m vertically up (ii) 15 m on a levelled path on the ground.

Sol. Mass of the man, $m_1 = 50$ kg

Mass carried by a man, $m_2 = 10$ kg

Total mass $M = m_1 + m_2 = 50 + 10 = 60$ kg.

When the man goes vertically up,

Height through which he rises, h = 15 m

W = mgh = 60 × 9.8 × 15 = 8820 J

When the man goes on a levelled path on the ground

W= FS Cosθ

As $\theta = 90^o$, therefore, $\cos 90^o = 0$

Hence W= F×S×0 =0

3.2 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 (J), CGS system - erg

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

Transformation of Energy

The phenomenon of changing energy from one form to another form 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.): the e*nergy possessed by the body by virtue of its motions* is called kinetic energy.

For example (*i*) running water (*ii*) 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).

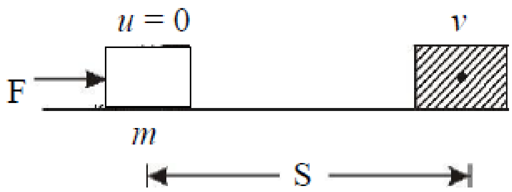

Figure: 3.1

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, $W = FS$

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

Potential Energy (P.E.): *the 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.

$W = FS$

Work done = Force × height

$= mg \times h = mgh$

This work done is stored in the form of gravitational potential energy.

Hence Potential energy $= mgh$.

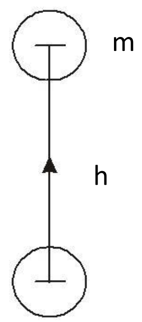

Figure: 3.2

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.

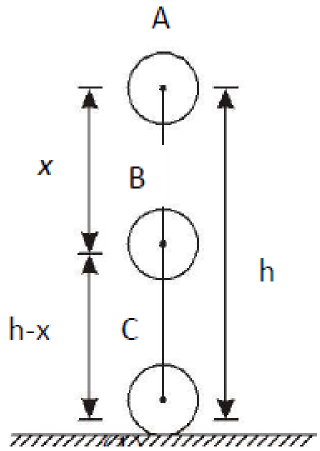

Figure: 3.3

According to Fig. 3.3

At position A:

Initial velocity of body (u) = 0

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

P. E. = mgh

Total Energy = K.E + P.E

= 0 + mgh

= $\boldsymbol{mgh}$ ------------- (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 $V^2 - U^2 = 2aS$

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

or $u^2 = 2gx$

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

or 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.

Example 4 A spring extended by 20 mm possesses a P.E. of 10 J. What will be P.E., if the extension of spring becomes 30 mm?

Sol. $h = 20 \text{ mm} = 20 \times 10^{-3}$ m

$g = 9.8 \text{ ms}^{-2}$, m =?

P.E = mgh = 10 J

i.e., $m \times 9.8 \times 20 \times 10^{-3} = 10$ J

$$m = \frac{10}{9.8\text{x}20\text{x}10^{-3}}$$

m =51.02 kg

When extension is 30 mm *i.e.,* 30×10^{-3} m, then

$P.E = mgh$

$= 51.02 \times 9.8 \times 3 \times 10^{-3} = 15.0$ J

3.6 POWER (DEFINITION, FORMULA AND UNITS)

Power is defined as the *rate at which work is done* by a force. T*he 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)

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

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

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 metres high in 12 second. Find;

(i) Total work done by him. 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

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

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

* * * * * *

Chapter 4

ROTATIONAL MOTION

Learning objective: After going through this chapter, students will be able to;

- *Define rotational motion and parameters like; torque, angular momentum and momentum conservation.*
- *Describe Moment of inertia and radius of gyration.*
- *Solve relevant numerical problems.*

4.1 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.

4.2 DEFINITION OF TORQUE AND ANGULAR MOMENTUM

Torque (τ)

It is measured as 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,

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

Where F is external force and r is perpendicular distance.

Unit: newton (N)

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

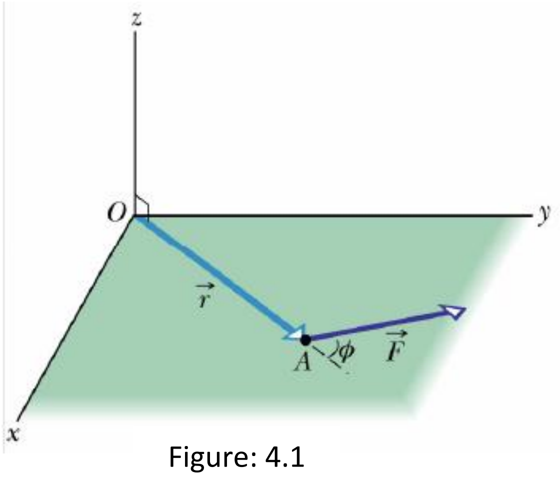

Figure: 4.1

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. It is vector quantity.

L = momentum × perpendicular distance

$L = p \times r$

or $L = mvr$

Unit: Kg m^2/sec

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

4.3 LAW OF CONSERVATION OF ANGULAR MOMENTUM

When no external torque acts on a system of particles, then the total angular momentum of the system always remains constant.

Let I be moment of inertia and ω the angular velocity, then angular momentum is given as

$$L = I\omega$$

Also the torque is given by

$$\tau = \frac{dL}{dt}$$

If no external torque acts on the body, then $\tau = 0$

$$\text{Hence } \tau = \frac{dL}{dt} = 0$$

Thus L is constant (as derivative of constant quantity is zero).

Hence, if no external torque acts on system, the total angular momentum remains conserved.

Examples:

(i) An ice skater who brings in her arms while spinning spins faster. Her moment of inertia is dropping (reducing the moment of arm) so her angular velocity increases to keep the angular momentum constant

(ii) Springboard diver stretches his body in between his journey.

5.4 MOMENT OF INERTIA AND ITS PHYSICAL SIGNIFICANCE

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 ..., m_n be the masses of particles at distance r_1, r_2, r_3... r_n from the axis of rotation respectively (Fig. 4.2).

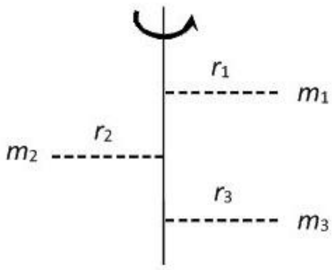

Figure: 4.2

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.

Radius of Gyration (K)

It may be defined as *the distance of a point from the axis of rotation at which whole mass of the body is supposed to be concentrated, so that moment of inertia about the axis remains the same*. It is denoted by K

If the mass of the body is M, the moment of inertia (I) of the body in terms of radius of gyration is given as,

$$I = MK^2 \qquad \text{---------- (1)}$$

Expression for Radius of Gyration

Let m_1, m_2, m_3 ..., m_n be the masses of particles at distance r_1, r_2, r_3... r_n from the axis of rotation respectively (Fig. 4.3).

Then Moment of Inertia of whole body

$$I = m_1r_1^2 + m_2r_2^2 + ...+m_nr_n^2$$

If mass of all particles is taken same, then

$$I = m\,(r_1^2 + r_2^2 + ...+r_n^2)$$

Multiply and divide the equation by n (number of particle)

$$\Rightarrow I = \frac{mxn(r_1^2 + r_2^2 + ...+ r_n^2)}{n}$$

or $$I = \frac{M\,(r_1^2 + r_2^2 + ...+ r_n^2)}{n} \qquad \text{---------- (2)}$$

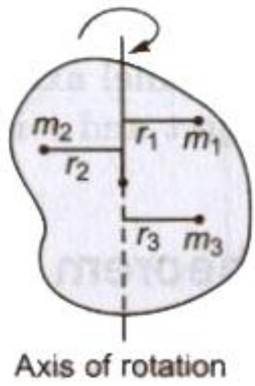

Figure: 4.3

(M=m×n, is total mass of body)

Comparing equation (1) and (2) , we get

$$MK^2 = \frac{M\,(r_1^2 + r_2^2 + ...+ r_n^2)}{n}$$

Or $$K^2 = \frac{(r_1^2 + r_2^2 + ...+ r_n^2)}{n}$$

$$K = \sqrt{\frac{(r_1^2 + r_2^2 + ...+ r_n^2)}{n}}$$

Thus, radius of gyration may also be defined as the root mean square (r.m.s.) distance of particles from the axis of rotation.

Unit: metre.

Example 1. What torque will produce an acceleration of 2 rad/s^2 in a body if moment of inertia is 500 kg m^2?

Sol. Here, I = 500 kg m^2

α = 2 rad/s^2

Now, torque $\tau = I \times \alpha$

= 500 kgm^2 × 2 rad/s^2 = 1000 kg m^{2}s^{-2}

= 1000 Nm or J

Example2. An engine is rotating at the rate of 1500 rev. per minute. Find its angular velocity.

Sol. Here, Revolution per minute of engine, n= 1500

Angular velocity $\omega = 2\pi n$

Or $$\omega = 2 \times \frac{22}{7} \times \frac{1500}{60}$$

$$\omega = 157.1 \text{ rad/s}$$

Example 3. How large a torque is needed to accelerate a wheel, for which I = 2 kgm^2, from rest to 30 r.p.s in 20 seconds?

Sol. Here, Moment of inertia, I = 2 kgm^2

R.P.S after 20 sec, n = 30

Initial velocity, $\omega_1 = 0$

Final velocity, $\omega_2 = 2 \text{ x } \pi \text{ x } 30 = 188.4$ rad/s.

Angular acceleration = $\frac{\omega_2 - \omega_1}{t} = \frac{188.4 - 0}{20}$ = 9.43 rad/s^2.

Now, torque, $\tau = I \times \alpha$

= 2 kg m^2× 9.43 rad/s^2

= 18.86 Nm or J

Example 4. If a point on the rim of wheel 4 m in diameter has a linear velocity of 16 m/ s, find the angular velocity of wheel in rad/sec.

Sol. Radius of wheel (R) = $\frac{\text{Diameter}}{2} = \frac{4}{2}$ = 2 m

From the relation $v = r\omega$

$$\omega = \frac{v}{r} = \frac{16}{2} = 8 \text{ rad/s.}$$

Angular velocity of wheel is 8 rad/s.

* * * * *

Chapter 5
PROPERTIES OF MATTER

Learning objective: After going through this chapter, students will be able to;

- *Understand elasticity, deforming force, restoring force etc.*
- *Define stress, strain, Hook's law, modulus of elasticity, pressure etc..*
- *Describe surface tension, viscosity and effect of temperature on these.*
- *Understand fluid motion and nature of flow.*

5.1 DEFINITION OF ELASTICITY, DEFORMING FORCE, RESTORING FORCE, EXAMPLE OF ELASTIC AND PLASTIC BODY

Elasticity*:* It is the property of solid materials to return to their original shape and size after removal of deforming force.

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.

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 do not return to its original shape after a deformation. Examples are Polyethylene, Polypropylene, Polystyrene and Polyvinyl Chloride (PVC).

5.2 DEFINITION OF STRESS AND STRAIN WITH THEIR TYPES

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

1. **Normal Stress**: If deforming force acts normal (perpendicular) to the surface of the body then the stress is normal stress.

2. **Tangential Stress:** If deforming force acts tangentially to the surface of the body then the stress is tangential stress.

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:

(i) Longitudinal strain:

If the deforming force produces a change in length only, the strain produced is called longitudinal strain or tensile strain. It is defined as *the ratio of change in length to the original length.*

$$\text{Longitudinal strain} = \frac{\text{Change in length}(\Delta l)}{\text{original length}(l)}$$

(ii) **Volumetric strain**: It is defined as *the ratio of the change in volume to the original volume*.

$$\text{Volumetric strain} = \frac{\text{Change in volume}(\Delta V)}{\text{original volume}(V)}$$

(iii) Shearing strain:

It is defined as *the ratio of lateral displacement of a surface under the tangential force to the perpendicular distance between surfaces*

$$\text{Shearing strain} = \frac{\text{Lateral Displacement}}{\text{Distance between surfaces}}$$

$$= \frac{\Delta L}{L} = \tan \Phi$$

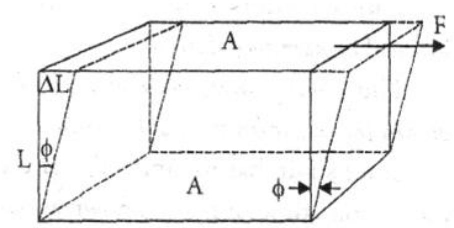

Figure: 5.1

The shearing strain is also defined as the angle in radian through which a plane perpendicular to the fixed surface of a rectangular block gets turned under the effect to tangential force.

Units of strain:

Strain is a ratio of two similar physical quantities, it is unitless and dimensionless.

5.3 HOOK'S LAW, MODULUS OF ELASTICITY

Hook's law: *Within elastic limits, the stress and strain are proportional to each other*.

Thus, Stress ∝ Strain

Stress = E × Strain

Where E is the proportionality constant and is known as modulus of elasticity.

Modulus of Elasticity: *The ratio of stress and strain is always constant and called as modulus of elasticity*.

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

$$Y = \frac{F/A}{\Delta l/l} = \frac{F \times l}{A \times \Delta l}$$

The unit of Young's modulus is the same as that of stress i.e., Nm^{-2} or pascal (Pa)

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

$$K = \frac{F/A}{\Delta V/V} = \frac{F \times V}{A \times \Delta V}$$

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

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

$$\eta = \frac{\text{Tangential stress}}{\text{Shear strain}}$$

$$\eta = \frac{F/A}{\Delta L/L} = \frac{F \times L}{A \times \Delta L}$$

The SI unit of shear modulus is Nm^{-2}or Pa.

5.4 PRESSURE

Pressure*:* It *is* defined *as the force acting per unit area over the surface of a body.*

$$P = \frac{F}{A}$$

SI unit is Nm^{-2} or Pa

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*.
Or *it states that liquid enclosed in a vessel exerts equal pressure in all the directions*.

5.5 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.

$$T = \frac{F}{l}$$

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

SI unit is N/m.

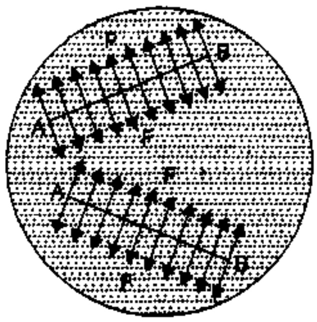

Figure: 5.2

Applications of surface tension in daily life
It plays an important role in many applications in our daily life.

- Washing clothes
- Cleaning
- Cosmetics
- Lubricants in machines
- Spreading of ink, colours
- Wetting of a surface
- Action of surfactants
- Paints, insecticides
- Creating fuel-spray in automobile engines
- Passing of liquid in porous media
- Spherical shape of water droplets.

Effect of Temperature on Surface Tension

In general, *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.

5.6 VISCOSITY

The property of liquid due to which it oppose the relative motion between its layers. 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

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***.

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.

5.7 FLUID MOTION, STREAM LINE AND TURBULENT FLOW

Fluid Motion: A liquid in motion is called fluid. There are two types of fluid motions; streamline and turbulent.

Streamline Flow: *Flow* of a fluid in which its velocity at any point of given cross section is same. It is also called laminar flow.

Turbulent flow: It is type of fluid (gas or liquid) flow in which the speed of the fluid at given cross section is continuously undergoing changes in both magnitude and direction.

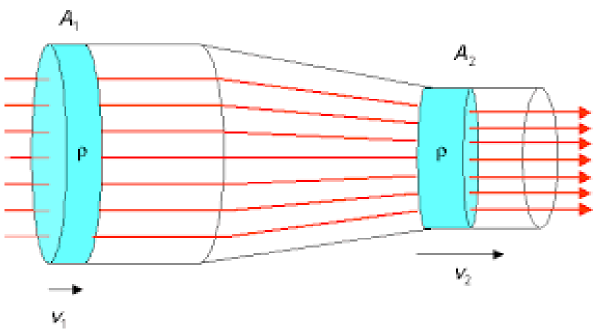

Figure: 5.3

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Chapter 6
HEAT AND THERMOMETRY

Learning Objectives: *After going through this chapter, the students will be able to:*

- *Define heat and temperature; understand the difference between heat and temperature;*
- *Describe principles of measuring temperature and different temperature scales,*
- *Enlist properties of heat radiations and various modes of transfer of heat.*

6.1 HEAT AND TEMPERATURE

All objects are made of atoms or molecules. These molecules are always in some form of motion (linear, vibrational or rotational) and possess kinetic energy by virtue of their motion. The hotter an object is, faster will be the motion of the molecules inside it and hence more will be its kinetic energy. Heat of an object is the total energy of all the individual molecules of which the given object is made. It is a form of thermal energy. When the object is heated, its thermal energy increases, means its molecules begin to move more violently. Temperature, on the other hand, is a measure of the average heat or thermal energy of the molecules in a substance.

Heat is the form of energy which produces the sensation of warmth or coldness.

The cgs unit of heat is the calorie (cal) - *defined as the amount of heat required to raise the temperature of 1g of water through 1^oC.* The S.I. unit of heat energy is the joule (J) The relation between these two units is:

$$1 \text{ cal} = 4.18 \text{ J.}$$

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 molecule having mass *m* and velocities v_1, v_2, v_3, --------, v_n respectively, then

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

$$H = K\left(\frac{1}{2}mv_1^2 + \frac{1}{2}mv_2^2 + \frac{1}{2}mv_3^2 + \dots\dots + \frac{1}{2}mv_n^2\right)$$; where K is thermal constant.

When the body is heated, the kinetic energy of each molecule inside it increases due to increase in their velocity. This results in the increase of total kinetic energy of the body and in turn represents total heat of the body.

Temperature

Temperature is the degree of hotness or coldness of the body. It is the average kinetic energy of all the molecules of which the given body is made and is given by the expression;

$$T = \frac{K\left(\frac{1}{2}mv_1^2 + \frac{1}{2}mv_2^2 + \frac{1}{2}mv_3^2 + \dots\dots + \frac{1}{2}mv_n^2\right)}{n}$$

Units of temperature are; fahrenheit (^oF), celsius (^oC) and kelvin (K). Kelvin is the S.I. unit of temperature.

6.2 DIFFERENCE BETWEEN HEAT AND TEMPERATURE:

Heat	Temperature
Heat is energy that is transferred from one body to another as the result of a difference in temperature	Temperature is a measure of degree of hotness or coldness
It is total kinetic energy of all the molecules	It is average kinetic energy of all the molecules
It depends on quantity of matter	It does not depend on quantity of matter
It is form of energy (Thermal)	It is measure of energy
S.I. unit is joule	S.I. unit is kelvin

6.3 PRINCIPLES OF MEASUREMENT OF TEMPERATURE:

Measurement of temperature depends on the principle that *properties (physical/ electrical/ chemical) of material changes with change in temperature*. A device that utilizes a change in property of matter to measure temperature is known as thermometer. Temperature is a principle parameter that needs to be monitored and controlled in most engineering applications such as heating, cooling, drying and storage. Temperature can be measured via a diverse array of sensors. All of them infer temperature by sensing some change in a physical characteristic; be it a thermal expansion, thermoelectricity, electrical resistance or thermal radiation. There are four basic types of thermometers, each working on a different principle:

1. Mechanical (liquid-in-glass, bimetallic strips, bulb & capillary, pressure type etc.)
2. Thermo-electric (Thermocouples)
3. Thermo-resistive (RTDs and thermistors)
4. Radiative (Infrared and optical pyrometers).

Each produces a different scale of temperature which can be related to one another. Commonly used thermometers are mercury thermometer, platinum resistance thermometer, thermo-electric and pyrometers. Liquid thermometers can measure temperature upto 300^oC. Resistance thermometers can go upto 1200^oC while thermo-electrics are used for measuring temperature as high as 3000^oC. For still higher temperatures pyrometers (very hot furnaces) are used.

6.4 DIFFERENT SCALES OF TEMPERATURE AND THEIR RELATIONSHIP

In general, there are three scales of temperature measurement. The scales are usually defined by two fixed points; temperature at which water freezes and the boiling point of water as defined at sea level and standard atmospheric pressure.

a) Fahrenheit Scale: It was given by physicist Daniel Gabriel Fahrenheit in 1724. It uses the degree fahrenheit (symbol: °F) as the unit. On this scale, freezing point of water is taken as the lower fixed point (32°F) and boiling point of water is taken as upper fixed point (212°F). The interval between two points is divided into 180 equal parts. Each division is 1^o F.

This scale is used for clinical and meteorological purpose.

b). Celsius Scale: This scale was given by Anders Celsius in 1742. On this scale, freezing point of water is taken as the lower fixed point (marked 0°C) and boiling point of water is taken as upper fixed point (marked 100°C). The interval between two points is divided into 100 equal parts. Each division is 1^oC.

This scale is used for common scientific, clinical, meteorological and technological work.

c). Kelvin Scale: This scale defines the SI base unit of temperature with symbol K. On this scale freezing point of water is taken as the lower fixed point (273K) and boiling point of water is taken as upper fixed point (373K). The interval between two points is divided into 100 equal parts. Each division is 1K.

On scale $1^oC = 1\ K$

This is the natural scale of temperature also called the ***absolute temperature scale***. The scale is based on ideal gas thermometer.

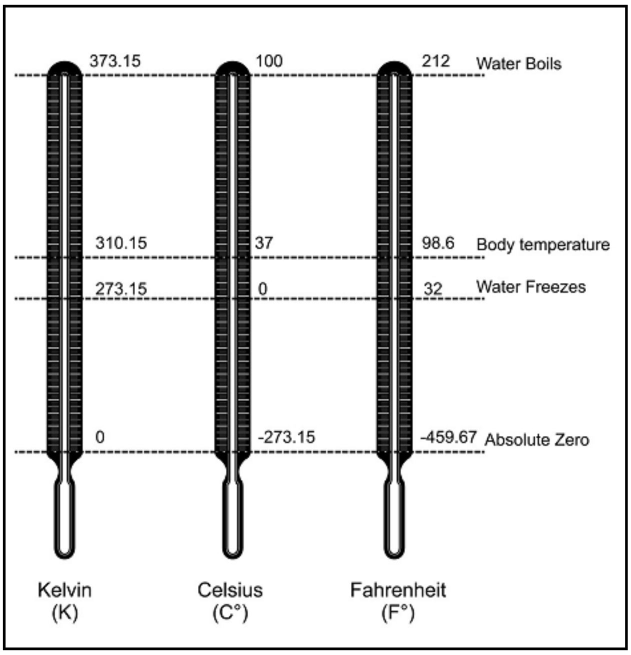

Figure 6.1 Temperature scales

Absolute Zero: Absolute zero is the temperature at which all molecular motions come to stand still i.e. net kinetic energy becomes zero. It is taken as zero kelvin (-273^o C). At absolute zero temperature, the pressure (or volume) of the gas goes to zero. This may implies that if the temperature is reduced below -273.15°C, the volume becomes negative which is obviously not possible. Hence -273.15°C is the lowest temperature that can be achieved and therefore called the absolute zero of temperature. The interval on the scale is the same as on the celsius scale ($1\ K = 1\ ^oC$) and two scales can be related as.

$$K = {}^oC + 273.15$$

Thus on absolute scale of temperature, water freezes at 273.15K and boils at 373.15K.

Triple Point of water: The triple point is that point on a pressure versus temperature graph which corresponds to the equilibrium among three phases of a substance i.e. gas, liquid and solid.

Triple point of pure water is at 273.16K. It is unique and occurs at single temperature and single pressure.

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 $\frac{T-L}{H-L}$ = Relative temperature w.r.t. both reference point.

Let us take a body whose temperature is determined by three different thermometers giving readings in ^oC, ^oF and K respectively.

Let $T_1 = C$ = Temperature in ^oC, $L_1 = 0°C$ $H_1 = 100°C$

$T_2 = F$ = Temperature in^oF, $L_2 = 32°F$ $H_2 = 212°F$

$T_3 = K$ = Temperature Kelvin, $L_3 = 273$ K $H_3 = 373K$

We can write,

$$\left(\frac{T_1-L_1}{H_1-L_1}\right)=\left(\frac{T_2-L_2}{H_2-L_2}\right)=\left(\frac{T_3-L_3}{H_3-L_3}\right)$$

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

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

$$\boxed{\frac{C}{5}=\frac{F-32}{9}=\frac{K-273}{5}}$$

6.5 MODES OF TRANSFER OF HEAT

When two bodies having different temperatures are brought close together, the heat flows from body at higher temperature to body at lower temperature. Heat may also flow from one portion of body to another portion because of temperature difference. The process is called transfer of heat. There are three modes by which heat is transferred from one place to another. These are named as conduction, convention and radiations.

(i) 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 become hot. This is due to the transfer of heat energy from hot atoms to the nearby atoms. When two bodies have different temperatures and are brought into contact, they exchange heat energy and tend to equalize the temperature. The bodies are said to be in *thermal equilibrium*. This is the mode of heat transfer in solids.

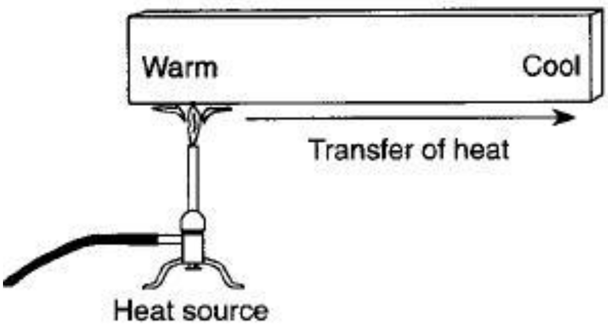

Figure 6.2: Conduction

ii) 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 become warm. This is because the speed of atoms or molecules increases when liquid or gases are heated. The molecule having more kinetic energy rise upward and carry heat with them. Liquids and gases transfer heat by convection. Examples are heating of water, cooling of transformers, see breeze, heating of rooms by heater etc.

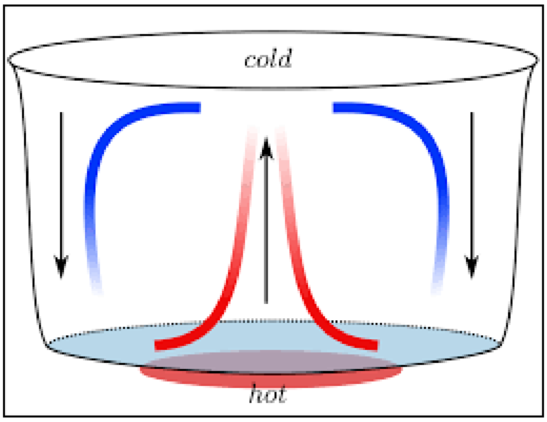

Figure 6.3: Convection

(iii) Radiation: The process of heat transfer in which *heat is transmitted from one place to another in the form of Infra-Red radiation, 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. We receive heat from sun by radiation process. All the bodies around us do emit these radiations. These radiations are the electromagnetic waves.

6.6 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.

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