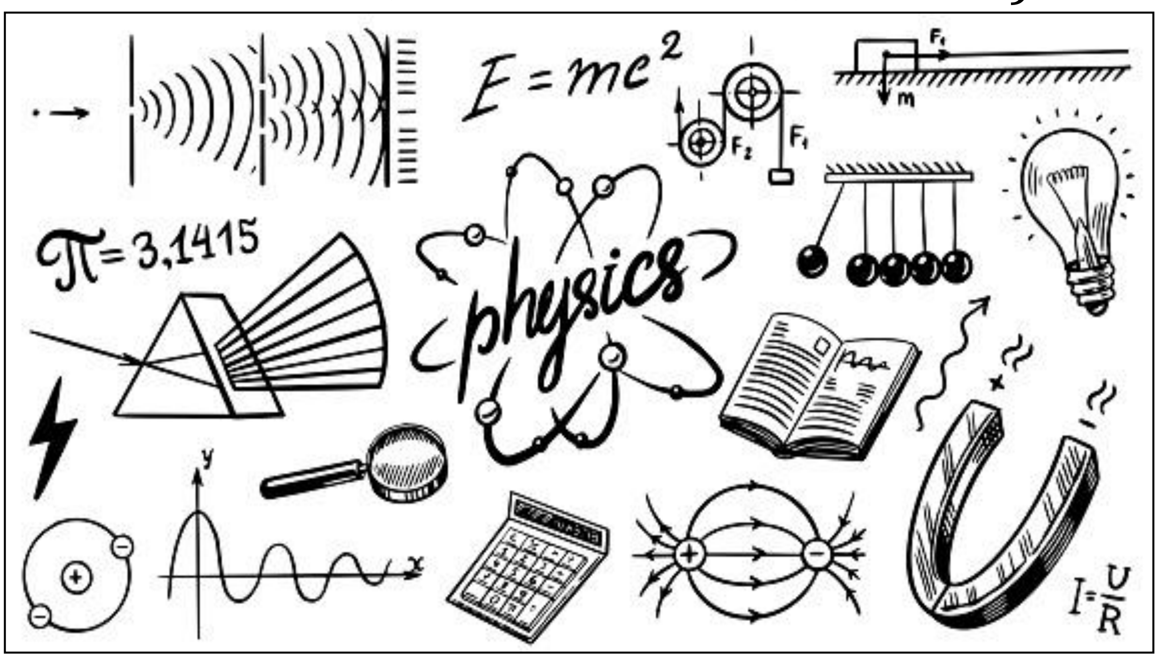
BHADRAK ENGINEERING SCHOOL & TECHNOLOGY (BEST),
ASURALI, BHADRAK

Engineering Physics (Th: 02-a)

(As per the 2018-19 syllabus prepared by the SCTE&VT, Bhubaneswar, Odisha)



First/Second Semester

Common to all Engg. Courses

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ENGINEERING PHYSICS

CHAPTER-WISE DISTRIBUTION OF PERIODS & MARKS

UNIT	TOPIC	Periods as per Syllabus	EXPECTED MARKS
1	UNITS AND DIMENSIONS	03	07
2	SCALARS AND VECTORS	03	04
3	KINEMATICS	06	12
4	WORK & FRICTION	05	10
5	GRAVITATION	05	10
6	OSCILLATIONS & WAVES	06	07
7	HEAT & THERMODYNAMICS	07	12
8	OPTICS	04	11
9	ELECTROSTATICS & MAGNETOSTATICS	07	15
10	CURRENT ELECTRICITY	06	12
11	ELECTROMAGNETISM & ELECTROMAGNETIC INDUCTION	05	05
12	MODERN PHYSICS	03	05
Total		**60**	**110**

UNIT 1
UNITS AND DIMENSIONS

Learning Objectives:

1.1 Physical quantities - (Definition).
1.2 Definition of fundamental and derived units, systems of units (FPS, CGS, MKS and SI units).
1.3 Definition of dimension and Dimensional formulae of physical quantities.
1.4 Dimensional equations and Principle of homogeneity.
1.5 Checking the dimensional correctness of Physical relations.

Physics explains the law of nature in a special way. This explanation includes a quantitative description, comparison, and measurement of certain physical quantities. To measure or compare a physical quantity we need to fix some standard unit and dimension of the quantity. In this chapter we will discuss the basic concept of Units and Dimensions and its application to various physical problems.

1.1 Physical quantities

Law of physics can be expressed through certain measurable quantities which are called as Physical quantities.

Physical quantities are divided into two categories.

(1) Fundamental Quantities
(2) Derived Quantities

1.1.1 Fundamental Quantities

Fundamental quantities are those that do not depend on any other physical quantities for their measurements. There are different systems of units which will be discussed in the coming sections. In each system of units, there are a set of defined fundamental quantities and fundamental units. Mass (M), length (L) and Time (T) are some of the examples of fundamental quantities.

1.1.2 Derived Quantities

The physical quantities which are expressed in terms of other physical quantities are called as Derived Quantities.

Example- Velocity=Length/Time; Acceleration=Velocity/Time=Length/(Ti me)^2

Force = Mass X Acceleration = Mass X Length/(Time)^2

1.2 Unit

Unit is a standard which is used to measure a physical quantity.

1.2.1 Fundamental Units

Fundamental units are those units which are independent and not related to each other. The units of fundamental quantities are called as Fundamental Units. Example – The unit of length is meter. So, meter is an example of fundamental unit. Similarly, second is the fundamental unit of time and kg is the fundamental unit of mass.

1.2.2 Derived Units

The units of the physical quantities which can be expressed in terms of fundamental units are called as Derived Units.

Example- Area = length X breadth = metre X metre = $(\text{metre})^2$ Velocity = displacement/time=metre/second

1.2.3 Systems of Units

A complete set of units, both fundamental and derived for all physical quantities is called a system of units.

The following systems of units are commonly in use.

1.2.3(A) F. P. S. System

Fundamental quantities	UNIT	Symbol
1. Length	Foot	ft
2. Mass	Pound	Lb
3. Time	Second	S

1.2.3(B) C. G. S. System

Fundamental quantities	UNIT	Symbol
1. Length	Centimeter	c.m
2. Mass	Gramme	g
3. Time	Second	S

1.2.3(C) M. K. S. System

Fundamental quantities	UNIT	Symbol
1. Length	meter	M
2. Mass	Kilogram	kg
3. Time	Second	S

1.2.3(D) SI Units (Systeme International d'Unites or International System of Units)

In C.G.S and M.K.S. system, there are three fundamental quantities e.g. mass, length, and time and accordingly three fundamental units., which are insufficient to measure some physical quantities. Therefore in 1971, the International Bureau of Weights and Measures decided a system of units which is known as International System of Units and abbreviated as SI System. It is based on the seven fundamental units and two supplementary units.

1.2.3(D)(i) Fundamental Units

The fundamental units used to measure in SI System,are given in the following table.

Fundamental Physical Quantity	Name of the Unit	Symbol of the Unit
(1) Length	Metre	m
(2) Mass	Kilogram	kg
(3) Time	Second	S
(4) Temperature	Kelvin	K
(5) Electric Current	Ampere	A
(6) Quantity Of Substances	Mole	
(7) Luminous intencity		mol
	Candla	cd

1.2.3(D)(ii) Supplementary units

The supplementary units of SI System, are given in the following table.

Supplementary Physical Quantity	Name of the Unit	Symbol of the Unit
(1) Angle	Radian	Rad
(2) Solid angle	Steradian	Sr

1.3.1 DIMENSIONS

Dimensions are the power to which the fundamental units/ quantities be raised in order to represent a physical quantity.

Example:- (1) Area = length X breadth = L X L = $[L^2] = [M^0L^2T^0]$

Here 0, 2, and 0 are the dimensions of Area with respect to mass, length and time.

(2) $\text{Velocity} = \frac{\text{Displacement}}{Time} = \frac{[L]}{[T]} = [L^1T^{-1}] = [M^0L^1T^{-1}]$

Here 0, 1, and -1 are the dimensions of velocity with respect to mass, length and time.

1.3.2 DIMENSIONAL FORMULA

Dimensional formula is a formula which tells us, how and which fundamental units must be used to express a physical quantity.

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

Example:- (1) Volume(V) = length X breadth X height = L X L X L = $[L^3]$ => $V = [M^0L^3T^0]$

This is the dimensional formula of volume.

And 0, 3, and 0 are the dimensions of volume with respect to mass, length and time.

(2) Momentum = mass X velocity =$[M^1][L^1T^{-1}] = [M^1L^1T^{-1}]$

(3) Force = mass X acceleration = $[M^1][L^1T^{-2}] = [M^1L^1T^{-2}]$

(4) Moment of a force = force X distance = $[M^1L^1T^{-2}][L^1] = [M^1L^2T^{-2}]$

(5) Work = force X distance = $[M^1L^1T^{-2}][L^1] = [M^1L^2T^{-2}]$

Sl. No	Physical Quantity	Formula	Dimensional Formula	S.I Unit
1	Area (A)	Length x Breadth	[M0L2T0]	m2
2	Volume (V)	Length x Breadth x Height	[M0L3T0]	m3
3	Density (d)	Mass / Volume	[M1L-3T0]	kgm-3
4	Speed (s)	Distance / Time	[M0L1T-1]	ms-1
5	Velocity (v)	Displacement / Time	[M0L1T-1]	ms-1
6	Acceleration (a)	Change in velocity / Time	[M0L1T-2]	ms-2
7	Acceleration due to gravity (g)	Change in velocity / Time	[M0L1T-2]	ms-2
8	Linear momentum (p)	Mass x Velocity	[M1L1T-1]	kgms-1
9	Force (F)	Mass x Acceleration	[M1L1T-2]	N (Newton) (kgms-2)
10	Work (W)	Force. Displacement	[M1L2T-2]	J (Joule) (kgm2s-2)
11	Energy (E)	Work	[M1L2T-2]	J
12	Impulse (I)	Force x Time	[M1L1T-1]	Ns
13	Pressure (P)	Force / Area	[M1L-1T-2]	Nm-2
14	Power (P)	Work / Time	[M1L2T-3]	W (Watt)
15	Universal constant of gravitation (G)	Force x (Distance)2 (Mass)2	[M-1L3T-2]	Nm2kg-2
16	Thrust (F)	Force	[M1L1T-2]	N
17	Tension (T)	Force	$[M^1L^1T^{-2}]$	N
18	Stress	Force / Area	[M1L-1T-2]	Nm-2
19	Strain	Change in dimension / Original dimension	No dimensions $[M^0L^0T^{-0}]$	No unit
20	Angle (θ) Angular displacement	Arc length / Radius	No dimensions $[M^0L^0T^{-0}]$	Rad
21	Angular velocity(**ω**)	Angle / Time	$[M^0L^0T^{-1}]$	rad s^{-1}
22	Angular acceleration(**α**)	Angular velocity / Time	$[M^0L^0T^{-2}]$	rad s^{-2}
23	Wavelength(λ)	Length of a wavelet	$[M^0L^1T^0]$	M
24	Frequency(f)	Number of vibrations/second or 1/time Period	$[M^0L^0T^{-1}]$	Hz or s^{-1}
25	Angular momentum (J)	Moment of inertia x Angular velocity	$[M^1L^2T^{-1}]$	kgm^2s^{-1}

1.4.1 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.

Example:- Work(W) = Force X displacement

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

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

$$\Rightarrow W = [M^1L^2T^{-2}] \text{ ---------- (i)}$$

This equation is known as dimensional equation.

1.4.1 Use of dimensional analysis

Dimensional analysis has following three uses.

(i) To convert the value of a physical quantity from one system to another.

(ii) To derive a relation between various physical quantities.

(iii) To check the correctness of a given relation.

1.4.2 Principle of Homogeneity

It states that the dimensional formula of every term on both sides of a correct relation must be same.

OR,

The dimensions of each of the terms of a dimensional equation on both sides should be the same.

1.5 Checking the dimensional correctness of Physical relations.

To check the correctness of a relation, we find the dimensional formula of every term on both sides of the relation. If the dimensions are same then the relation is said to be dimensionally correct.

Example (1):- To check the correctness of given relation.

$s = ut + \frac{1}{2}at^2$

Solution: - Given relation is $s = ut + \frac{1}{2}at^2$

Dimensional formula of s = Displacement = $[L^1] = [M^0L^1T^0]$ - (i)

Dimensional formula of ut = $[M^0L^1T^{-1}]\,[T^1] = [M^0L^1T^0]$ ----------- (ii)

Dimensional formula of $\frac{1}{2}at^2 = [M^0L^1T^{-2}]\,[T^2] = [M^0L^1T^0]$ -------------------- (iii)

From the above equations we get dimensional formula of every term are same. Therefore, according to Principle of Homogeneity the given relation is dimensionally correct.

Example (2):- To check the correctness of given relation.

$v = u + at$

Solution:- Given relation is $v = u + at$

Dimensional formula of v = final velocity = $[M^0L^1T^{-1}]$ (i)

Dimensional formula of u = initial velocity = $[M0L1T{-}1]$ (ii)

Dimensional formula of at = $[M0L1T{-}2]\,[T1] = [M0L1T{-}1]$ (iii)

From the above equations we get dimensional formula of every term are same. Therefore, according to Principle of Homogeneity the given relation is dimensionally correct.

Example (3):- To check the correctness of given relation.

$v^2 - u^2 = 4as$

Solution:- Given relation is $v^2 - u^2 = 4as$

Dimensional formula of $v^2 = [M^0L^1T^{-1}]^2 = [M^0L^2T^{-2}]$ -------- (i)

Dimensional formula of $u^2 = [M^0L^1T^{-1}]^2 = [M^0L^2T^{-2}]$ -----------------(ii)

Dimensional formula of 2as= $[M^0L^1T^{-2}][L^1] = [M^0L^2T^{-2}]$-- (iii)

From the above equations we get dimensional formula of every term are same. Therefore, according to Principle of Homogeneity the given relation is dimensionally correct.

Question:- To check the correctness of following relation.

$$T = 2\pi\sqrt{\frac{l}{g}}$$

where g=acceleration due to gravity and l=length of thread, t= time period.

LHS: [T] = $[M^0L^0T^1]$

RHS: $2\pi\sqrt{\frac{l}{g}} = \sqrt{\frac{l}{g}} = \sqrt{\frac{[L^1]}{[LT^{-2}]}} = \sqrt{[T^2]} = [T]$ = $[M^0L^0T^1]$

From the above equation we get that the dimensional formula of the terms on both the sides are same. Therefore according to Principle of Homogeneity the given relation is dimensionally correct.

VERY SHORT ANSWER QUESTIONS

1. Name two quantities which are dimensionless in nature.
   Ans. Angle and strain.
2. Name two quantities which have dimensional formula [$M^1L^{-1}T^{-2}$]
   Ans. Pressure and Stress.
3. Obtain the dimension of (i) pressure (ii) Kinetic Energy
   Ans.(i) [$M^1L^{-1}T^{-2}$] and (ii) [$M^1L^2T^{-2}$]

4. What is meant by a unit?

   Ans. Unit is a standard which is used to measure a physical quantity.

5. Write the dimensional formula of force and work.

   Ans. Force = [$M^1L^1T^{-2}$] and Work = [$M^1L^2T^{-2}$]

6. Write down the dimensional formula for Gravitational constant. [W-18, 19]

   Ans. [$M^{-1}L^3T^{-2}$]

7. Write the fundamental units in S.I. system. [S/W- 18, S- 19, W-20]

   Ans: Meter, Kilogram, Second, Kelvin, Ampere, Mole & Candela.

SHORT ANSWER QUESTIONS

1. Check the correctness of the equation, $T = 2\pi\sqrt{\frac{l}{g}}$. [W- 16, 17, 19; S-19]
2. Prove that the dimensions of kinetic energy and potential energy are same.
3. Check the correctness of the following [W-18, 20]

   I. $v^2 - u^2 = 2as$

   II. $s = ut + \frac{1}{2}\ at^2$

UNIT 2

SCALARS AND VECTORS

Learning objectives

2.1 Scalar and Vector quantities (definition and concept), Representation of a Vector – examples, types of vectors.

2.2 Triangle and Parallelogram law of vector Addition (Statement only). Simple Numerical.

2.3 Resolution of Vectors — Simple Numerals on Horizontal and Vertical components.

2.4 Vector multiplication (scalar product and vector product of vectors).

We have come across with different types of physical quantities, in one dimensional motion, only two directions are possible. So directional aspect of the quantities like position, displacement, velocity and acceleration can be taken care by using positive and negative signs. But in the case of motion in two dimensions (plane) or three dimensions (space), an object can have large number of directions. In order to deal with such situation effectively, we need to introduce the concept of scalar and vector quantities.

In this chapter we shall discuss the definition of scalar and vector quantities, its applications to solve different physical problems and how they can be multiplied.

2.1 Scalar Quantities and Vector Quantities

The physical quantities are classified into two categories

(i) Scalar Quantities

(ii) Vector quantities.

2.1.1 Scalar quantities

The quantities which have only magnitude are known as scalar quantities.

Example- mass, length, volume, time, distance, speed, density, energy, temperature, electric charge, electric potential etc.

2.1.2 Vector quantities

The quantities which have both magnitude and direction are known as vector quantities.

Example- Displacement, velocity, acceleration, force, momentum, electric field, magnetic field, magnetic moment etc.

2.1.3 Vector

A directed line segment is called as vector. When it is written over the head of a physical quantity, then it represents a vector quantity.

2.1.4 Representation of a vector

A vector „$\vec{A}$‟ can be represented by an arrow OP‟ of finite length directed from initial point O to the terminal point P. The length of arrow represents the magnitude of vector and the arrow head denotes the direction of the vector. A vector is written with an arrow head over its symbol like „$\vec{A}$‟. The magnitude of given vector is represented by modulus of vector ($|\vec{A}|$) or simply „A‟.

2.1.4 Types of vector

There are different types of vectors.

(i) Null vector:-

It is a vector having zero magnitude and an arbitrary direction. It is represented by a point or dot (•). When a null vector is added or subtracted from a given vector, the resultant vector is same as the given vector. Dot product of a null vector with any other vector is always zero. Cross product of a null vector with any other vector is also a null vector

Unit vector

Any vector whose magnitude is one unit is called as a unit vector. A unit vector only specifies the direction of given vector. A unit vector in the direction of vector „$\vec{A}$" is written as $\hat{A}$ and is read as „A cap".

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

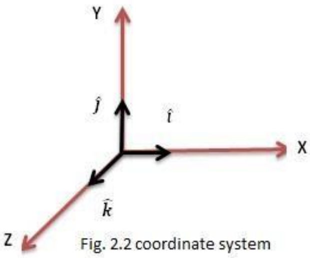

Fig. 2.2 coordinate system

In three dimensional coordinate system, unit vectors along positive X, Y and Z-axes are usually represented by $\hat{i}$, $\hat{j}$ and $\hat{k}$ respectively. These unit vectors are mutually Perpendicular to each other (Fig.2.2)

(ii) Collinear vectors

Vector having a common line of action are called as collinear vectors. There are of two types of collinear vectors.

(a) Parallel vectors ($\theta=0^0$)

Two vectors acting along same direction irrespective of their magnitude are called as parallel vectors. Vectors „$\vec{A}$" and „$\vec{B}$" shown in fig. 2.3 are parallel vectors. Angle between them is zero.

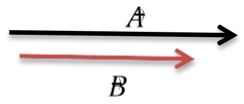

Fig. 2.3 Parallel vectors

(b) Anti-parallel vectors

($\theta=180^0$):-Two vectors acting along opposite direction irrespective of their magnitude are called as anti-parallel vectors. Vectors „$\vec{A}$" and „$\vec{B}$" shown in fig 2.4 are anti-Parallel vectors. Angle between them is 180^0.

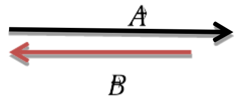

Fig. 2.4 Anti-Parallel vectors

(iii) Perpendicular vectors ($\theta=90^0$)

Two vectors are said to be perpendicular when they are normal to each other (irrespective of their magnitude). Vectors „$\vec{A}$" and „$\vec{B}$" shown in fig 2.5 are Perpendicular vectors. Angle between them is 90^0.

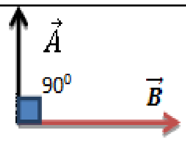

Fig. 2.5 Perpendicular vectors

(iv) Equal vectors

Two vectors are said to be equal if they possess Same magnitude and direction. " and „B" Vectors „A Shown in fig. 2.6 are equal vectors. All equal vectors are parallel vectors.

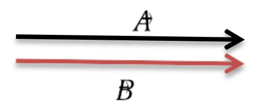

Fig. 2.6 Equal vectors

(v) Negative vector

A vector is said to be negative vector of another one if they possess same magnitude and opposite direction. Vectors „$\bar{\mathbf{A}}$" and „$\bar{\mathbf{B}}$" shown in fig. 2.7 are negative vector to each other. All negative vectors are anti-parallel vectors.

Co-initial vectors

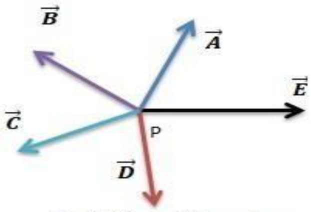

Fig. 2.8 Co-initial vectors

A number of vectors are said to be co-initial when they have common initial point. Vectors „$\overline{\mathbf{A}}$‟, „$\overline{\mathbf{B}}$‟, „$\overline{\mathbf{C}}$‟,„$\overline{\mathbf{D}}$‟ and „$\overline{\mathbf{E}}$‟ shown in fig 2.8 are co-initial vectors, started from a common point P.

(vi) Co-planar vectors

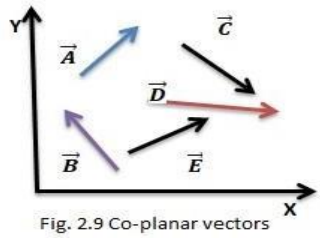

Fig. 2.9 Co-planar vectors

A number of vectors are said to be co-planar when they are lying in the same plane. Vectors „$\overline{\mathbf{A}}$‟, „$\overline{\mathbf{B}}$‟, „$\overline{\mathbf{C}}$‟,„$\overline{\mathbf{D}}$‟ and „$\overline{\mathbf{E}}$‟ shown in fig 2.9 are co-planar vectors, present ithe same plane.

(vii) Position Vector

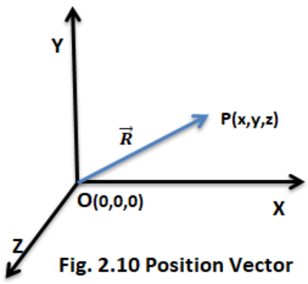

Fig. 2.10 Position Vector

Vectors that indicate the position of a point in acoordinate system is called as position vector. Let point P(x,y,z) present in three coordinate system then„ **R**‟ is the Position vector of point P from the origin O (0,0,0) as shown in the fig 2.10.

Position vector can be written as

$$\overline{\mathbf{R}} = x\hat{i} + y\hat{j} + z\hat{k}$$

2.2 Addition of vectors

Vectors cannot be added according to the simple algebra, because vectors have magnitude along with direction. So vector can be added as follows.

2.2.1 Triangle law of vector addition

It is a law for the addition of two vectors. It can be stated as follows:
"If two vectors acting simultaneously on a body are represented in magnitude And direction by two adjacent sides of a triangle taken in same order, th the resultant vector is represented in magnitude and direction by third si of that triangle taken in opposite order"

$$\vec{R} = \vec{A} + \vec{B}$$

It can be mathematically proved that:

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

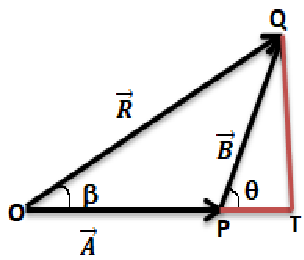

Fig. 2.11 Vector addition by Triangle law

2.2.2 Parallelogram's law of vector addition

Two vectors can also be added by using parallelogram's law of vector addition. It can be stated as follows:

"If two vectors acting simultaneously on a body are represented in magnitude And direction by two adjacent sides of a parallelogram drawn from a point, then the resultant vector is represented in magnitude and direction by the diagonal of the parallelogram passing through that point".

(

2.3 Resolution of Vectors in a plane-

The process of splitting a vector into various parts or components is called resolution of vector.

Resolution of a vector is the process of obtaining the component vectors which when combined according to the law of vector addition, produce the given vector.

Let $\vec{OP}$ $(=\vec{R})$ be the position vector of point P(x,y) in XY-plane(Fig. 2.13).From P draw the perpendiculars PQ and PB on X-axis and Y-axis respectively. It makes an angle θ with X-axis.

Let $\hat{i}$ and $\hat{j}$ are the unit vectors along x-axis and Y-axis respectively.

Consider $\vec{R}$ resolves into two components horizontal $\vec{R_x}$ along X- axis and vertical component $\vec{R_y}$ along Y-axis.

According to triangle law of vector addition in triangle OPQ we can write

$\vec{R} = \vec{R_x} + \vec{R_y}$

$\Rightarrow \vec{R} = \hat{i}R_x + \hat{j}R_y$ -------- (i)

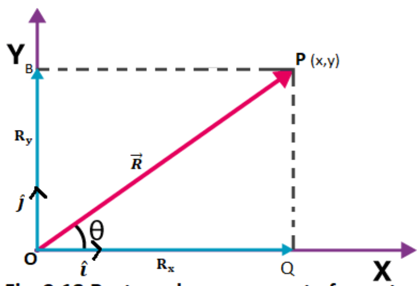

Fig. 2.13 Rectangular component of a vector

In the $\triangle$OPQ, $\cos\theta = \frac{OQ}{OP}$

$\Rightarrow \cos\theta = \frac{R_x}{R}$

$\Rightarrow R_x = R\cos\theta$ --------------(ii)

Again in $\triangle$OPQ, $\sin\theta = \frac{QP}{OP} = \frac{OB}{OP}$

$\Rightarrow \sin\theta = \frac{R_y}{R}$

$\Rightarrow R_y = R\sin\theta$ ---------------(iii)

Now putting the values of equation (ii) and (iii) in equation (i), we get:

$$R = \hat{i}R\cos\theta + \hat{j}R\sin\theta$$

2.4 VECTOR MULTIPLICATION

There are two ways in which two vectors can be multiplied together.

(i) Scalar Product or Dot product
(ii) Vector Product or Cross product

2.4.1 Scalar product or Dot product

Dot product between two vectors is defined as the product of their magnitude and the cosine of the smaller angle between them.

It is written by putting a dot (•) between two vectors. The result of this product does not possess any direction. Hence it is also called as Scalar product.

Consider two vectors $\overline{\boldsymbol{A}}$ and drawn from a point and inclined to each other at angle as shown in the Fig.2.14.

Dot product

$$\overline{\mathbf{A}} \cdot \overline{\boldsymbol{B}} = \boldsymbol{AB} \ \mathbf{cos}\, \boldsymbol{\theta}$$

For , $\theta = 90^0$

$\vec{A}.\vec{B} = AB\cos\theta = AB\cos 90^0 = AB \times 0 = 0 \quad [\cos 90^0 = 0]$

Thus the dot product of two non-zero vectors, which are perpendicular to each other is always zero.

Since $\hat{i}, \hat{j}$ and $\hat{k}$ are mutually perpendicular to each other

$$\hat{i}\cdot\hat{j} = \hat{j}\cdot\hat{k} = \hat{k}\cdot\hat{i} = 0$$

For , $\theta = 0^0$

$\vec{A}.\vec{B} = AB\cos\theta = AB\cos 0^0 = AB \times 1 = AB \qquad [\cos 0^0 = 1]$

$$\hat{i}\cdot\hat{i} = \hat{j}\cdot\hat{j} = \hat{k}\cdot\hat{k} = 1$$

(i) Dot product in terms of rectangular component

Let A_x, A_y, A_z and B_x, B_y, B_z are the rectangular components of $\cos\alpha + \cos\beta = 2\cos\frac{1}{2}(\alpha+\beta)\cos\frac{1}{2}(\alpha-\beta)$ two vectors $\vec{A}$ and $\vec{B}$ respectively.

Then $\vec{A} = A_x\hat{i} + A_y\hat{j} + A_z\hat{k}$

And $\vec{B} = B_x\hat{i} + B_y\hat{j} + B_z\hat{k}$

$$\vec{A}\cdot\vec{B} = (A_x\hat{i} + A_y\hat{j} + A_z\hat{k})\cdot(B_x\hat{i} + B_y\hat{j} + B_z\hat{k})$$

$$= A_xB_x(\hat{i}\cdot\hat{i}) + A_xB_y(\hat{i}\cdot\hat{j}) + A_xB_z(\hat{i}\cdot\hat{k})$$

$$+ A_yB_x(\hat{j}\cdot\hat{i}) + A_yB_y(\hat{j}\cdot\hat{j}) + A_yB_z(\hat{j}\cdot\hat{k})$$

$$+ A_zB_x(\hat{k}\cdot\hat{i}) + A_zB_y(\hat{k}\cdot\hat{j}) + A_zB_z(\hat{k}\cdot\hat{k})$$

Since, $\hat{i}\cdot\hat{j} = \hat{j}\cdot\hat{i} = 0$,
$\hat{i}\cdot\hat{k} = \hat{k}\cdot\hat{i} = 0$,
$\hat{j}\cdot\hat{k} = \hat{k}\cdot\hat{j} = 0$,
$\hat{i}\cdot\hat{i} = \hat{j}\cdot\hat{j} = \hat{k}\cdot\hat{k} = 1$

$$= A_xB_x(1) + A_xB_y(0) + A_xB_z(0)$$

$$+ A_yB_x(0) + A_yB_y(1) + A_yB_z(0)$$

$$+ A_zB_x(0) + A_zB_y(0) + A_zB_z(1)$$

$$\Rightarrow \vec{A}\cdot\vec{B} = A_xB_x + A_yB_y + A_zB_z$$

Therefore dot product of two vectors is defined as the sum of the product of their rectangular components along the three coordinate axes.

Problem -1

If $\vec{A} = 3\hat{i} + 2\hat{j} + 5\hat{k}$ and $\vec{B} = 4\hat{i} + 3\hat{j} + 7\hat{k}$

Find the dot product between A & B

Solution:- Here given **Ax=3, Ay=2, Az=5** and **Bx=4, By=3, Bz=7**

We know that , $\vec{A} \cdot \vec{B} = \mathbf{A_x B_x} + A_y \mathbf{B_y} + A_z B_z$

= (3 X 4)+(2 X 3) +(5 X 7)

= 12 + 6 + 35 = 5

Problem(2):-

Find the dot product between $\vec{A} = 2\hat{i} + 5\hat{j} + \hat{k}$ and $\vec{B} = 3\hat{i} - \hat{j} + \hat{k}$

Solution:- Here given **Ax=2, Ay=5, Az=6** and **Bx=3, By=-6, Bz=1**

We know that $\vec{A} \cdot \vec{B} = A_x B + A_y B_y + A_z B_z$

= 2 X 3 + 5 X (-6) + 6 X 1

= 6-30+6=-18

Problem(3):-

Find the dot product between A&B $\vec{A} = 5\hat{\imath} + 2\hat{J} + 3\hat{k}$ and $\vec{B} = 2\hat{\imath} - 3\hat{J}$

Solution:- Here given **Ax=5, Ay=2, Az=3** and **Bx=2, By=-3, Bz=0**

We know that $\bar{A} \cdot \bar{B} = A_x B + A_y B_y + A_z B_z$

= 5 X 2 + 2 X (-3) + 3 X 0

= 10-6+0=4

Problem (4):-

Find the dot product between $\bar{A} = \hat{\imath} + 2\hat{k}$ and $\bar{B} = 3\hat{\imath} + 4\hat{J} + k$

Solution:- Here given **Ax=6, Ay=0, Az=2** and **Bx=3, By=4, Bz=6**

We know that $\bar{A} \cdot \bar{B} = + + A_z B_z$

= 6 X 3 + 0 X 4 + 2 X 6

= 18+0+12=30

Problem (5):-

Find the dot product between $\bar{A} = 3\hat{\imath} + 2\hat{J}$ and $\bar{B} = 4\hat{\imath} + 3\hat{J}$

Solution:- Here given **Ax=3, Ay=2, Az=0** and **Bx=4, By=3, Bz=0**

We know that $\bar{A} \cdot \bar{B} = + + A_z B_z$

= 3 X 4 + 2 X 3 + 0 X 0

= 12+6+0=18

2.4.2 Cross product or Vector product

Cross product of two vectors are defined as a single vector whose magnitude is equal to the product of their individual magnitude and sine of the smaller angle between them and is directed along the normal to the plane containing

It is written by putting a cross (×) between two vectors. The resultant of this product possesses a direction. Hence it is also called as vector product.

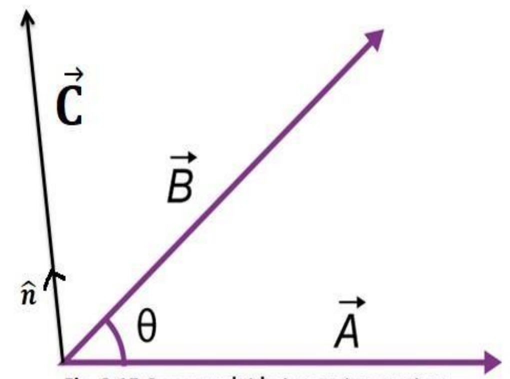

Fig. 2.15 Cross produt between two vectors

Consider two vectors $\vec{A}$ and $\vec{B}$ drawn from a point and inclined to each other at angle θ as shown in the Fig.2.15.

Cross product of $\vec{A}$ and $\vec{B}$ is given by

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

Where $\hat{n}$ is the unit vector of $\vec{C}$ directed perpendicular to the plane containing $\vec{A}$ and $\vec{B}$.

Right hand thumb rule:-

Imagine the normal to the plane (PQRS) containing $\vec{A}$ and $\vec{B}$ to be held by your right hand with the thumb erect. If the fingers curl directed from $\vec{A}$ to $\vec{B}$ then the direction of the thumb gives the direction of $\vec{A} \times \vec{B}$.

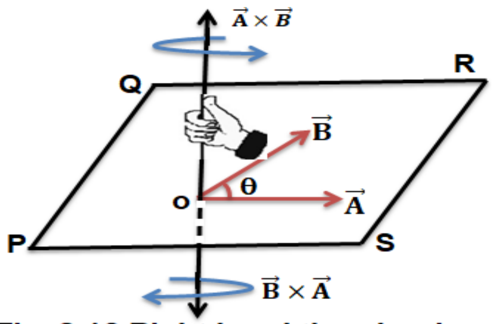

Fig. 2.16 Right hand thumb rule for cross product

For two perpendicular vectors $\vec{A}$ and $\vec{B}$, the angle between them θ $=90^0$

$\vec{A} \times \vec{B} = AB \sin\theta \, \hat{n} = AB \sin 90^0 \hat{n} = (AB)(1)\hat{n} = AB\hat{n}$ $[\sin 90^0 = 1$

$\Rightarrow |\vec{A} \times \vec{B}| = AB$

Thus, the magnitude of the cross productof two perpendicular vectors is equal to the product of their individual magnitude.

Since $\hat{i}$, $\hat{j}$ and $\hat{k}$ are unit vectors mutually perpendicular to each other (Fig.2.2).

$\hat{i} \times \hat{j} = \hat{k}$ $\qquad \hat{j} \times \hat{i} = -\hat{k}$

$\hat{j} \times \hat{k} = \hat{i}$ $\qquad \hat{k} \times \hat{j} = -\hat{i}$

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

$\hat{k} \times \hat{i} =$

For two parallel vectors $\vec{A}$ and $\vec{B}$, the angle between them $\theta = 0^0$

$\vec{A} \times \vec{B} = AB \sin\theta \, \hat{n} = AB \sin 0^0 \hat{n} = (AB)(0)\hat{n} = (0)\hat{n} = null\ vector$

$[\sin 0^0 = 0]$

Cross product of two equal vectors is always a null vector.

$|\hat{i} \times \hat{i}| = |\hat{j} \times \hat{j}| = |\hat{k} \times \hat{k}| = 0$

Cross product in terms of rectangular component

Let A_x, A_y, A_z and B_x, B_y, B_z are the rectangular components of two vectors $\vec{A}$ and $\vec{B}$ respectively.

Then $\vec{A} = A_x\hat{i} + A_y\hat{j} + A_z\hat{k}$

And $\vec{B} = B_x\hat{i} + B_y\hat{j} + B_z\hat{k}$

$\therefore \vec{A} \times \vec{B} = (A_x\hat{i} + A_y\hat{j} + A_z\hat{k}) \times (B_x\hat{i} + B_y\hat{j} + B_z\hat{k})$

$= A_xB_x(\hat{i} \times \hat{i}) + A_xB_y(\hat{i} \times \hat{j}) + A_xB_z(\hat{i} \times \hat{k})$

$+ A_yB_x(\hat{j} \times \hat{i}) + A_yB_y(\hat{j} \times \hat{j}) + A_yB_z(\hat{j} \times \hat{k})$

$+ A_zB_x(\hat{k} \times \hat{i}) + A_zB_y(\hat{k} \times \hat{j}) + A_zB_z(\hat{k} \times \hat{k})$

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

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

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

$|\hat{i} \times \hat{i}| = |\hat{j} \times \hat{j}| = |\hat{k} \times \hat{k}| = 0$

$= A_xB_x(0) + A_xB_y(\hat{k}) + A_xB_z(-\hat{j})$

$+ A_yB_x(-\hat{k}) + A_yB_y(0)$

$+ A_yB_z(\hat{i}) + A_zB_x(\hat{j})$

$+ A_zB_y(-\hat{i}) + A_zB_z(0)$

$\Rightarrow \vec{A} \times \vec{B} = (A_yB_z - A_zB_y)\hat{i} + (A_zB_x - A_xB_z)\hat{j} + (A_xB_y - A_yB_x)\hat{k}$

The cross product in terms of rectangular component of two can also be written in the form of determinant, as follows

$$\vec{A} \times \vec{B} = \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ A_x & A_y & A_z \\ B_x & B_y & B_z \end{vmatrix}$$

Problem(1):-

Find the Cross product between $\vec{A} = 3\hat{\imath} + 2\hat{J} + 5\hat{k}$ and $\vec{B} = 4\hat{\imath} + 3\hat{J} + 7\hat{k}$

Solution:- Here given **Ax=3, Ay=2, Az=5** and **Bx=4, By=3, Bz=7**

We know that, $\vec{A} \times \vec{B} = (AyBz - AzBy)\hat{i} + (AzBx - AxBz)\hat{J} + (AxBy - AyBx)\hat{k}$

$= (2 \times 7 - 5 \times 3)\hat{i} + (5 \times 4 - 3 \times 7)\hat{j} + (3 \times 3 - 2 \times 4)k$

$= (14 - 15)\hat{i} + (20 - 21)\hat{j} + (9 - 8)\hat{k}$

$= -\hat{i} - \hat{j} + \hat{k}$

Problem(2):-

Find the cross product between $\vec{A} = 2\hat{\imath} + 5\hat{J} + 6\hat{k}$ and $\vec{B} = 3\hat{\imath} - 6\hat{J} + \hat{k}$

Solution:

Given, **Ax=2, Ay=5, Az=6** and **Bx=3, By= -6, Bz=1**

We know that ,

$\vec{A} \times \vec{B} = \hat{\imath}\{5 \times 1 - 6 \times (-6)\} - \hat{j}(2 \times 1 - 6 \times 3) + \hat{k}\{2 \times (-6) - 5 \times 3\}$

$= \hat{\imath}(5 + 36) - \hat{j}(2 - 18) + \hat{k}(-12 - 15)$

$= \hat{\imath}(41) - \hat{j}(-16) + \hat{k}(-27)$

$= 41\hat{\imath} + 16\hat{j} - 27\hat{k}$

POSIBLE SHORT QUESTIONS

1. Define Scalar and Vector Quantity? Give one example of each of them.

Ans.

2.1.1 Scalar quantities

The quantities which have only magnitude are known as scalar quantities.

Example- mass, length, volume, time etc.

Vector quantities

The quantities which have both magnitude and direction are called vector quantities.

Ex- Displacement, velocity, force etc.

2. State the triangle law of vector addition. [w-18,S-19]

Ans.

"If two vectors acting simultaneously on a body are rep resented in magnitude and direction by two adjacent sides of a triangle taken in same order, then the resultant vector is represented in magnitude and direction by third side of that triangle taken in opposite order".

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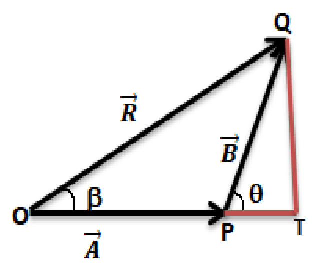


Fig. 2.11 Vector addition by Triangle law

3. Find the dot product between $\vec{A}= 3\hat{\imath} + 2\hat{J} + 3\hat{k}$ and $\vec{B} = 5\hat{\imath} - 3\hat{J}$

Ans.

Given, **Ax=3, Ay=2, Az=3** and **Bx=5, By= -3, Bz=0**

We know that $\vec{A}.\vec{B}= AxBx + AyBy + AzBz$

$= 3 \text{ X } 5 + 2 \text{ X } (-3) + 3 \text{ X } 0 = 15-6+0= 9$

4. State the parallelogram law of vector addition . [w-18,19]

Ans.

"If two vectors acting simultaneously on a body are represented in magnitude And direction by two adjacent sides of a parallelogram drawn from a point, then the resultant vector is represented in magnitude and direction by the diagonal of the parallelogram passing through that point".

UNIT-3

KINEMATICS

LEARNING OBJECTIVE

3.1 *Concept of Rest and Motion.*

3.2 *Displacement, Speed, Velocity, Acceleration & Force*

(Definition, Formula, Units & Dimension).

3.3 *Equation of motion under gravity (Upward & Downward motion).*

3.4 *Circular motion -: Angular Displacement, Angular velocity &*

Angular Acceleration (Definition, Formula, & Units).

3.5 *Relation between (i) linear and angular velocity*

(ii) Linear and angular acceleration.

3.6 *Define Projectile, Examples of projectile.*

3.7 *Expression for Equation Trajectory, Time of Flight, Maximum Height*

And Horizontal Range for a projectile fired at an angle θ.

Condition for maximum Horizontal Range.

Motion is common to everything in the universe. We walk, run, and ride a bicycle. Even when we are sleeping, air moves into and out of our lungs and blood flows in arteries and veins. We see leaves falling from trees and water flowing down a dam. Automobiles and planes carry people from one place to the other. Motion is change in position of an object with time. In this chapter we are going to discuss basic concept of kinematics (i.e., study of motion of bodies without the consideration of the force involved).

3.1 CONCEPT OF REST AND MOTION

REST- Body is said to be rest if its position does not change w.r.t to surrounding.

MOTION- A body is said to be in motion if its changes its position w.r.t the Surroundings.

3.2 Displacement, Speed, Velocity, Acceleration & Force

(Definition, Formula, Units & Dimension).

DISPLACEMENT- Displacement is a vector connecting between initial and Final Position of the body and directed away from initial position towards Final position.

Unit S.I- meter (m)

Dimension [S] = [$M^0 L^1 T^0$]

Speed (v)- The distance travelled by the body in unit time is called speed.

$\therefore$ Speed = $\frac{distance}{time} = \frac{s}{t}$

- S.I unit is meter/sec (m/s)
- Dimension- [v] = [$M^0 L^1 T^{-1}$]

<u>Velocity</u> ($\vec{v}$)

The rate of change of displacement is called velocity.

$\therefore$ Velocity = $\frac{displacement}{time} = \frac{\vec{s}}{t}$

- S.I unit is meter/sec (m/s)
- Dimension- [$\vec{v}$] = [$M^0 L^1 T^{-1}$]

<u>Acceleration ($\overrightarrow{a}$)</u>

The rate of change of velocity is called acceleration.

$\therefore$ acceleration = $\frac{change\ in\ velocity}{change\ in\ time}$

$\Rightarrow \vec{a} = \frac{d\vec{v}}{dt}$

- Its S.I unit is m/s^2
- Dimension- [$\vec{a}$] =[$M^0 L^1 T^{-2}$]

Force ($\vec{F}$)

Force is an external agent capable of changing state of rest or state of motion of a body.

∴ Force = mass × acceleration

⇒ F = m × a

- Its S.I unit is kg m/s^2 or N and CGS unit is g cm/s^2 or dyne
- Dimension- [F] = [$M^1 L^1 T^{-2}$]

3.3 Equation of motion under gravity (Upward & Downward motion).

Upward

Considering body thrown upward from a point o with initial velocity u at time t = 0. It reaches a point p after t sec and acquire a velocity v due to the uniform acceleration due to the gravity (g).

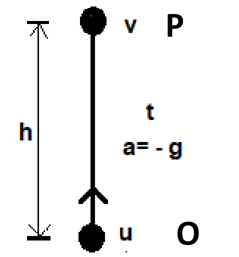


Fig. 3.2 a body is thrown in to a height

The equation of motion under gravity in upward direction

We can write

(a) v = u – gt

(b) h = ut – ½ gt^2

(c) $v^2 = u^2 - 2gh$

This is the maximum height reached by the object when thrown an initial velocity u.

Downward motion

Considering a body falling freely from a point O with initial velocity u. It reaches a point P after t sec and acquire a velocity v due to Uniform acceleration due to gravity g.

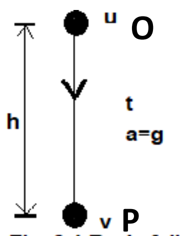


Fig. 3.1 Body fall from a height

Here v = final velocity, h = height of the object

The equation of motion under gravity in downward direction

We can write (a) v = u + gt, (b) $h = ut + \frac{1}{2}$ at^2

(c) $v^2 = u^2 + 2gh$

3.4 Circular motion -: Angular Displacement, Angular velocity & Angular acceleration

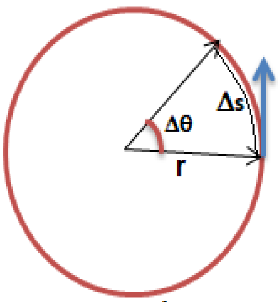


Fig. 3.3 Circular motion

A body is said to be in circular motion if it moves in such a way that its Distance from a fixed point remains constant.

<u>Angular displacement($\Delta\theta$)</u>

- Angular displacement of a body is defined as the angle turned by its radius vector.
- It is a vector quantity and its direction along the axis of rotation.
  $\therefore \Delta\theta = \frac{\Delta s}{r}$
- Its S.I unit is radian (rad).

<u>Angular velocity(ω)</u>

- Angular velocity of a body is defined as the rate of change of angular displacement.

$$\boxed{\omega = \frac{d\theta}{dt}}$$

- It is a vector quantity and its direction is along the direction of displacement.
- Its S.I unit is radian/sec (rad/s)

<u>Angular acceleration(α)</u>

- Angular acceleration of a body is defined as the rate of change of angular velocity.

$$\boxed{\alpha = \frac{d\omega}{dt}}$$

- It is a vector quantity and acts along the axis of rotation.
- Its S.I unit is radian/sec^2(rad/s^2).

3.5 Relation between linear and angular velocity

We know that,

the angular velocity $\omega = \frac{d\theta}{dt}$

$$\Rightarrow \omega = \frac{1}{r}\ \frac{ds}{dt}$$

$$\Rightarrow \omega = \frac{1}{r} v \qquad ,(\ ;\ v = \frac{ds}{dt}\ )$$

$$\Rightarrow v = \omega \times r$$

Relation between linear and angular acceleration:-

We know that

$$\alpha = \frac{d\omega}{dt}$$

$$\Rightarrow \alpha = = \frac{1}{r}\ \frac{dv}{dt}$$

$$\Rightarrow \alpha = \frac{1}{r}\ a \qquad ,(;\ a = \frac{dv}{dt}\ )$$

$$\Rightarrow a = \alpha \times r$$

3.6 Projectile motion

Projectile is a body thrown with an initial velocity in the vertical plane and then It moves in two dimensions under the action of gravity without being propelled by any mechanical work.

Example-

(1) a cricket ball thrown into the space.

(2) A fruit falling from a tree.

(3) A bullet fired from a gun

(4) A bag dropped from an aeroplane.

3.7 Projectile fired at an angle θ with the horizontal.

Considering a projectile fired from a point O with a velocity u at an angle θ with horizontal. The projectile rises to the maximum height H at the point P and falls back at Q, lying on the same level of projection.

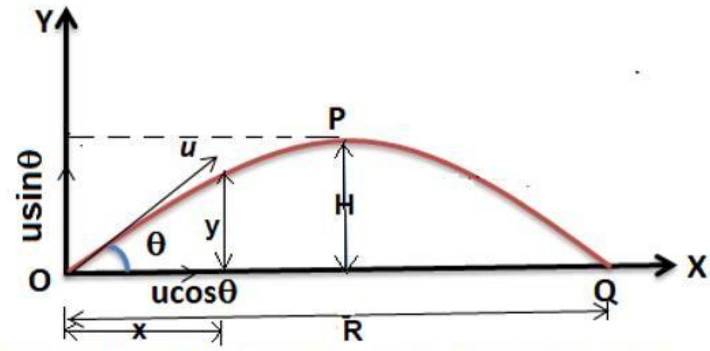


Fig. 3.4 Projectile fired at an angle θ with horizontal

Here u has two components i.e. u cosθ (horizontal component) and u sinθ (vertical component)

(1) Equation of trajectory

It is an equation with horizontal and vertical components of the projectile.

For horizontal component

Applying equation of motion, $s = ut + \frac{1}{2}at^2$

$$\Rightarrow = ucos\theta\ t + \frac{1}{2} \times 0 \times t^2$$, (; s= x, u= ucosθ,a=0)

$$\Rightarrow t = \frac{x}{ucos\theta} \quad \ldots\ldots..(1)$$

For vertical equation of motion

Applying equation of motion, $s = ut + \frac{1}{2}at^2$

$$\Rightarrow y = u\ sin\theta\ t - \frac{1}{2}gt^2$$, (; s = y, u = $u\ sin\theta$, a= -g)

$$\Rightarrow y = u\ sin\theta.\frac{x}{ucos\theta} - \frac{1}{2}\ g\ (\frac{x}{ucos\theta})^2, (;\ t = \frac{x}{ucos\theta})$$

$$\Rightarrow y = x\ tan\theta - \frac{g}{u^2cos^2\theta} \times x^2 \ \ldots\ldots\ldots..(2)$$

This is the equation of trajectory

(2) Maximum height:-

It is the maximum distance travelled by the projectile in vertical direction

Here , $s = H, u = u\,sin\theta, v = 0, a = -g$

Applying equation of motion,

$$v^2 - u^2 = 2as$$

$$\Rightarrow \; 0 - u^2 sin^2\theta = -2gH$$

$$\Rightarrow \; H = \frac{u^2 sin^2\theta}{2g} \quad \text{………………(3)}$$

(3) Time of flight :-

(a) Time of Ascent (t)

It is the time taken by the projectile to reach the maximum height from the point of projection.

Here, $u = u\,sin\theta, v = 0, a = -g,$

Applying the equation of motion,

$$v = u + at$$

$$\Rightarrow 0 = u\,sin\theta - g\,t$$

$$\Rightarrow \; t = \frac{u\,sin\theta}{g} \quad \text{……………..(4)}$$

(b) Time of Descent(t)

It is the time taken by the projectile to reach the level of projection From the maximum height.

Total time of Flight(T)

It is the total time taken by the projectile to come back to the ground from which it was projected.

$$T = 2t \; \Rightarrow T = 2\frac{usin\theta}{g} \quad \text{…………………….(5)}$$

(4) Horizontal Range(R)

It is the distance travelled by the projectile in the horizontal direction during its time of flight. The horizontal range is travelled due to horizontal component of velocity which is uniform.

$$R = horizontal\ velocity\ \times time\ of\ flight$$

$$\Rightarrow R = u\cos\theta\ \times 2\frac{u sin\theta}{g}$$

$$\Rightarrow R = \frac{u^2 2sin\theta.cos\theta}{g} = \frac{u^2\sin 2\theta}{g}$$ ....(6), $[\sin 2\theta = 2\sin\theta.\cos\theta]$

⁎⁎ condition for maximum horizontal range($R_{\max}$)

We know that, R = $\frac{u^2\sin 2\theta}{g}$

When sin 2θ is maximum, horizontal range will be maximum,

$\Rightarrow$ Sin 2θ = 1

$\Rightarrow$ Sin 2θ = sin 90

$\Rightarrow$ 2θ = 90 $\Rightarrow$ θ = 45^o

Then, we can write,

$(R_{\max}) = \frac{u^2}{g}$ .... (7)

∴ The maximum horizontal range travelled by the projectile fired at an angle θ = 45^o.

Possible Short Questions

1. What is the condition for maximum horizontal range? [17,19-W,19-S]

Ans. We know that, R = $\frac{u^2\sin 2\theta}{g}$

When sin 2θ is maximum, horizontal range will be maximum,

$\Rightarrow$ Sin 2θ = 1

$\Rightarrow$ Sin 2θ = sin 90

$\Rightarrow$ 2θ = 90 $\Rightarrow$ θ = 45^o

∴ The maximum horizontal range travelled by the projectile fired at an angle θ = 45^o.

2. Derive the relation between linear velocity and angular velocity.

[18,19,20-W,19-S]

Ans. We know that,

the angular velocity $\omega = \frac{d\theta}{dt}$

$\Rightarrow \omega = \frac{1}{r}\ \frac{ds}{dt}$

$\Rightarrow \omega = \frac{1}{r} v$,(; $v = \frac{ds}{dt}$)

$\Rightarrow v = \omega \times r$

3. Derive the relation between linear and angular acceleration. [2020-W]

Ans. We know that

$\alpha = \frac{d\omega}{dt}$

$\Rightarrow \alpha = = \frac{1}{r}\ \frac{dv}{dt}$

$\Rightarrow \alpha = \frac{1}{r}\ a$, (; a = $\frac{dv}{dt}$)

$\Rightarrow a = \alpha \times r$

4. A body possessing an initial velocity of 10 m/s moves an acceleration 2 m/s^2. Calculate its velocity at the end of 4 sec.

Ans.

Given, = 10 m/s , a = 2 m/s^2 , t = 4 s, v = ?

Applying equation of motion

$v = u + at$

$\Rightarrow$ v = 10 + 2× 4 =18 m/s.

Possible Long Question

1. Derive expressions for equation of trajectory, time of flight, maximum height and horizontal range of a projectile fired with initial velocity at an angle θ with horizontal. [16,17,18,19-W,19-S]

UNIT- 4
WORK AND FRICTION

Learning objectives

4.1 *Work – Definition, Formula & SI units.*

4.2 *Friction – Definition & Concept.*

4.3 *Types of friction (static, dynamic), Limiting Friction (Definition with Concept).*

4.4 *Laws of Limiting Friction (Only statement, No Experimental Verification).*

4.5 *Coefficient of Friction – Definition & Formula, Simple Numerical.*

4.6 *Methods to reduce friction.*

4.1 WORK

Work is said to be done if the force applied on a body displaces the body and the force has a component along the direction of displacement. Work is a scalar quantity and is the dot product of two vectors Force and Displacement.

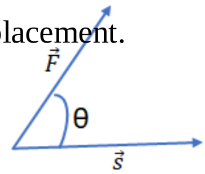


Figure 4.1

$W = \vec{F}.\vec{s} = Fscos\theta$

Where, W = work done

F = magnitude of the force

s = magnitude of the displacement

θ = angle between the force and displacement

- If, θ = 0°, then $W = Fscos0° = +Fs$.
  Here, Force and Displacement are in the same direction and work done is *positive,* which means work is said to be done *upon* the body.

  Example: An object falling freely under the action of gravity, Kicking a football, A car moving forward etc.

- If θ = 90° , then $W = Fs\cos 90° = 0$,
  Here, Force and Displacement are perpendicular to each other and no work is done.

  Example: A person carrying a box over his head and walking in the horizontal direction. In this case, *work done by the force of gravity* is zero.

- If θ = 180°, then $W = Fs\ cos\ 180° = -Fs$.
  Here, Force and Displacement are in the opposite direction and *Negative* work is done means work is done *by* the body.

Example: Work done by the force of friction is negative.

Pushing a car up a hill, when it is sliding down, Brakes applied to a moving car, Object pulled over a rough horizontal surface etc.

- When the force is applied without any displacement, then also work done is zero. W = F x 0 = 0

  Example: A person sitting on a chair and studying a book, Pushing a wall etc

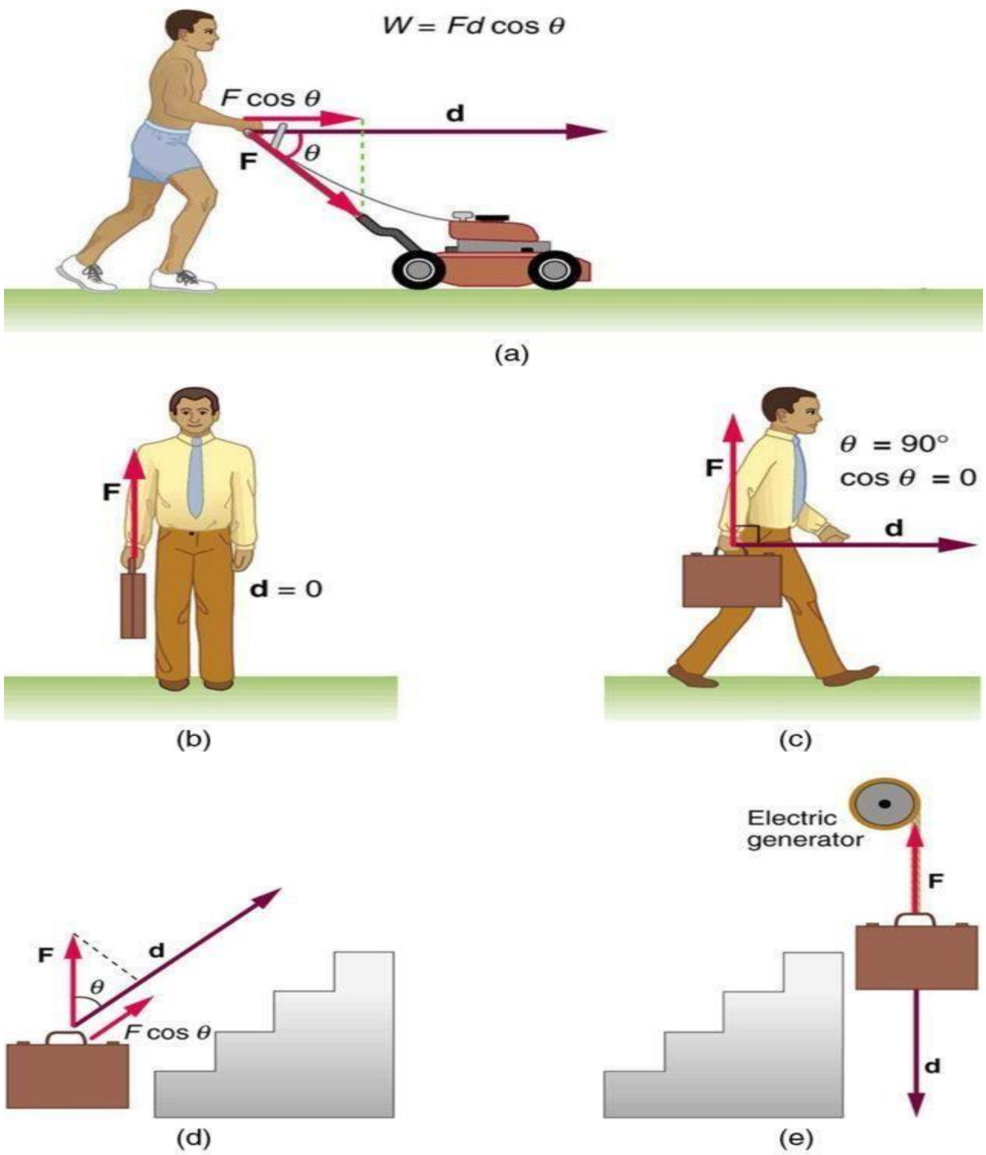
Unit

The SI unit of work is Joule (J) and the CGS unit is Erg.

The SI unit and dimensions of work and energy are same.

Dimension

$$[W] = [F][s][cos\theta] = [MLT^{-2} \times L = ML^2T^{-2}$$



. Examples of work. (a) Positive work-The work done by the force on this lawn is $Fd \cos\theta$. here $\cos\theta$, the component of the force is in the direction of motion.

(b)Zero work- A person holding a briefcase does no work on it, because there is no motion. (c) Zero work- The person moving the briefcase horizontally at a constant speed does no work on it, as Force and Displacement act Perpendicular to each other.(d) Positive work- Work is done on the briefcase by carrying it up stairs at constant speed, because there is a component of force **F** in the direction of the motion. (e) Negative Work- Here the work done on the briefcase by the generator is negative, because **F** and **d** are in opposite directions.

4.2FRICTION

Let us say there is an *almirah* placed on the *floor*. One person tries to push it. He exerts force, the almirah does not move in the beginning. Then, the person increases force little by little and at one point the almirah starts to move.

Let us analyse this situation. When the person is applying force, the force must have some effect (the force must create acceleration). But *apparently* there is no effect. Why is it happening? It is because when the person is applying force, the *floor* is exerting an equal amount of force on the almirah. Hence, the effect of force is getting cancelled. When the person is increasing the force, the force on the almirah by the floor is increasing too. However, there is a *limit* to the force by the floor. Once, it is reached, the almirah starts to move. However, when the almirah is moving, the floor is still applying force on the almirah. The force tries to oppose the motion of the almirah. In this example, the force on the almirah by the floor arising because of the contact between them is *frictional force*.

In this chapter, we will formally discuss the concept of friction, the types of friction and the laws regarding friction.

Definition:

The force which opposes or tend to oppose the relative motion between two surfaces in contact is called as force of friction.

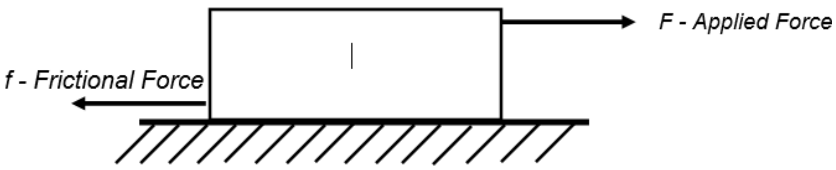


Figure 4.2

Force of friction is created because of the inter-locking of two surfaces in contact.

4.2 TYPES OF FRICTION

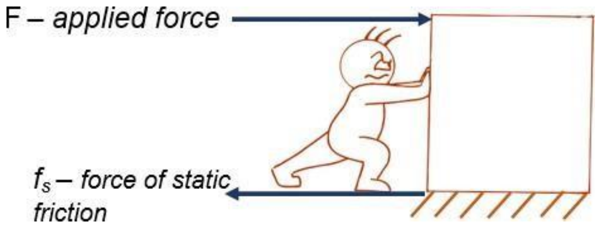
Friction can be classified into four types.

1. Static Friction- Static Friction is the opposing force exists between a surface and object at rest. Example- A book on a table.
2. Kinetic (dynamic) friction-Dynamic Friction is the opposing force created when two solid surfaces slide/ move over one another. Example- writing on paper or pushing a chair across the floor. Walking on the road.
3. Rolling friction - Rolling friction is the opposing force created between moving surfaces when one rolls over another. Example- Car moving on road, Rolling a ball down the lane
4. Fluid friction (viscosity)- Fluid friction is the opposing force created when something tries to move on or through the gas or liquid. Example- Pushing up water backward while Swimming.

In this chapter we will focus on static and dynamic friction and the laws regarding them.

1. Static Friction

- The force of friction which comes into play when there is no relative motion between two surfaces in contact is called as force of static friction. Force of static friction is equal and opposite to the applied force till the body is at rest.
- For example, a person or a group of persons are trying to push a heavy object. Initially, a small force is applied, and the magnitude of force is increased gradually. The magnitude of static friction increases gradually



too. As long as the object is in static condition, the floor exerts an equal and opposite force on the object. As in the below figure, the applied force is towards the right, hence the frictional force is towards the left.

Figure 4.3

- Static friction is a self-adjusting force.
- The maximum value of static friction is called the **limiting friction**.

$$f_L = \mu_s R \text{..........................} (1)$$

Where, f_L − force of limiting friction
μ_s − coefficient of static friction
R − Normal reaction

Once the limiting friction is reached, the body starts to move, and kinetic friction comes to picture.

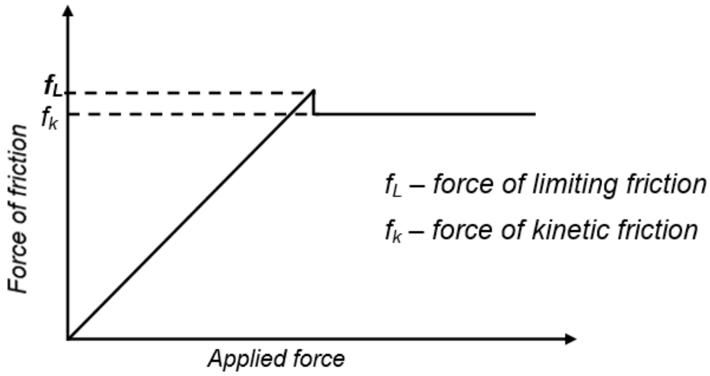


Figure 4.4

2. Kinetic (dynamic) Friction

The force of friction, which comes into play when there is relative motion between two surfaces in contact is called as force of kinetic friction or dynamic friction or sliding friction. The direction of the frictional force is always opposite to the direction of motion, for which the relative slipping is opposed by the friction.

Hence, $f = \mu_k R$ ------------------- (2)

Where, f_k − force of kinetic friction
μ_k − coefficient of kinetic friction
R − Normal reaction

4.4. LAWS OF LIMITING FRICTION

Statements about factors upon which the force of limiting friction between two surfaces depends, are termed as laws of limiting friction. They are stated as below.

i. The direction of force of friction is always opposite to the direction of motion.
ii. The force of limiting friction depends on the nature and state of polish of the surfaces in contact and act tangentially to the interface between the two surfaces.
iii. The magnitude of limiting friction f_L is directly proportional to the magnitude of the normal reaction R between the two surfaces in contact.

$$f_L \propto R$$

iv. The magnitude of the limiting friction between two surfaces is independent of the area and shape of the surfaces in contact as long as the normal reaction remains same.

4.5. COEFFICIENT OF FRICTION

- The frictional force (f) is directly proportional to the normal reaction force (R) and the proportionality constant μ is called the coefficient of friction.

$$\mu = \frac{f}{R}$$

- Hence, the coefficient of friction is defined as the ratio of the friction force to the normal force.
- The coefficient of friction is determined experimentally.
- As the unit and dimension of frictional force and normal force are same, μ is unit and dimensionless.
- The coefficient of friction depends on the nature of the bodies in contact, their materialand the surface roughness.

Example 1:

A box of mass 30 kg is pulled on a horizontal surface by applying a horizontal force. If the coefficient of dynamic friction between the box and the horizontal surface is 0.25, find the force of friction exerted by the horizontal surface on the box.

Answer:

Mass m = 30 kg, = 0.25

Normal Reaction R = mg

$$f_k = \mu_k R \Rightarrow \ = \mu_k mg = 0.25 \times 30 \times 9.8 = 73.5\ Newton$$

Example 2:

A body of mass 10 kg is placed on a rough horizontal surface at rest. The coefficient of friction between the body and the surface is $\mu = 0.1$. Find the force of friction acting on the body.

Answer:

Since, the body is at rest, the force of static friction will come into play which is equal to applied force.

Since, applied force is zero, the force of static friction is zero.

Example 3:

Find the force of friction in situation as shown in the below figure. Take g = 10 m/s^2

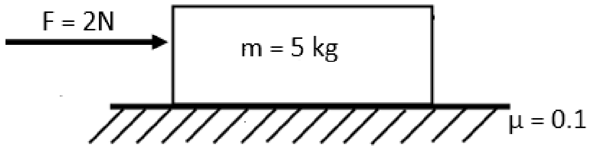


Figure 4.5

The magnitude of limiting friction $f_L = \mu R = 0.1 \times 5g = 5N$
We see, the applied force is smaller than the force of limiting friction i.e., $F < F_L$
So, the force of static friction = magnitude of applied force = 2 N.

4.6 METHODS TO REDUCE FRICTION

The following methods can be used to reduce friction when friction creates hurdle in the performance of machines or for similar necessary reasons

i. By polishing or rubbing

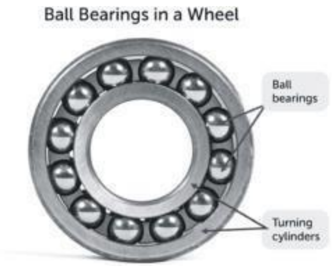
The roughness of a surface can be reduced by rubbing or polishing it. The polishing makes a surface smooth and reduces friction.

ii. Lubrication or use of talcum powder

Friction can be reduced by using lubricants like oil and grease or talcum powder as they form a thin film between different parts of a machine. This film covers up the pores & the lumps present on the surfaces of different parts, and hence improves the smoothness.

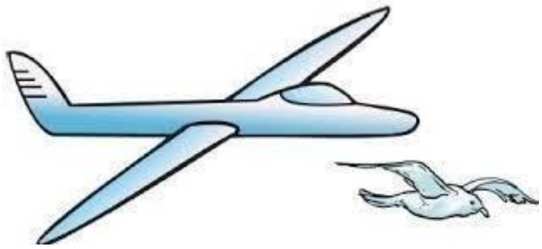
iii. **By converting sliding friction to rolling friction:**

Rolling friction is lesser than sliding friction. Hence, ball bearings can be placed between the moving parts of a machine to avoid direct contact between them. This reduces friction.



iv. **Streamlining:**

The objects that move in fluid, for example, bullet train, ship, boat or aeroplane, the shape of the body can be streamlined to reduce the



friction between the body and the fluid.

Possible short questions (2 marks each)

1. Define work. Write its unit. [W-18]

Ans. Work is said to be done if the force applied on a body displaces the body and the force has a component along the direction of displacement. Work is a scalar quantity and is the dot product of two vectors Force and Displacement.

Unit

Joule (J) in S.I System

Erg in CGS System

2.What is dynamic friction? [W-20]

Ans. The force of friction which comes into play when there is relative motion between two Surfaces In contact is called as dynamic friction.

3. Define coefficient of friction. Write its unit and dimension.

Ans. It is defined as the ratio of force of limiting friction to the normal reaction. It has no unit and no dimension.

4. Define Static friction and limiting friction.

Ans.The force of friction which comes into play when there is no relative motion in between two surfaces is known as Static friction.

Possible Long questions (5 marks each)

1.State the laws of limiting friction. [W-16,17,18,19]

2.Write down the methods to reduce friction. [W-18,9,20]

UNIT 5

GRAVITATION

Learning objectives

5.1 Newton's Laws of Gravitation – Statement and Explanation.

5.2 Universal Gravitational Constant (G)- Definition, Unit and Dimension.

5.3 Acceleration due to gravity (g)- Definition and Concept.

5.4 Definition of mass and weight.

55 Relation between g and G.

5.6 Variation of g with altitude and depth (No derivation – Only Explanation).

5.7 Keller's Laws of Planetary Motion (Statement only).

We throw a ball upward, it goes to a certain height, then it comes back towards the earth. The ripened fruit of a tree comes down in a straight line. The fruit does not go side wise or diagonally. So, the question is what makes these objects fall. Is there something which is pulling the fruit? Is it earth that is pulling? Now, again the question is if earth can pull a fruit, can it pull the moon too? So, in a sentence, is the nature of force acting between the earth and moon and that between earth and fruit same? Thinkers, philosophers, scientists have pondered over these questions deeply and have gifted us with simplified ideas about the laws of nature. In this chapter we will discuss the basic and fundamental classical laws in the field of gravitation.

5.1 Newton's Law of gravitation

Each body in the universe attracts every other body with a force which is directly proportional to the product of their masses and inversely proportional to the square of the distance between them.

Let m_1 and m_2 be the masses of two point-objects and the distance

between them be r. Then, $F \propto m_1 m_2$

$$F \propto \frac{1}{r^2}$$

$$\Rightarrow F = G\frac{m_1 m_2}{r^2} \text{------------} (1)$$

Where, G = universal gravitational constant = $6.67\times 10^{-11} Newton\ m^2 kg^{-2}$

force of attraction increases and with increasing distance between them, the force of attraction decreases.

5.2 Universal gravitational constant (G)

The universal gravitational constant can be understood and defined from the mathematical expression of gravitational force (equation 1).

If $m_1 = m_2 = 1$ unit and $r = 1$ unit, then $|\vec{F}| = G$

(1 unit mass = 1 kilogram or 1 gram or 1 pound; 1 unit distance = 1 meter or 1 centimeter or1 feet depending on the system of unit)

Definition:

The universal gravitational constant can be defined as the Gravitational force of attraction between two unit masses placed unit distance apart in the universe.

Unit:

From equation

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

Dimension:

$$[G] = \frac{[F][r]^2}{[m_1]\times[m_2]} = \frac{[MLT^{-2}]\times[L^2]}{[M^2]} = [M^{-1}L^3T^{-2}]$$

5.1. Acceleration due to gravity (g):

5.1.1 : Gravitational force of earth

The Earth by virtue of its mass, attracts each body towards its *centre*. This is the reason an object thrown upward falls back in a straight line and a projectile projected with certain initial velocity also falls back to earth after traversing a curved path.

Galileo Galilei after performing a series of experiment showed that all object falls with a constant acceleration if left to fall freely. The numerical value of g is approximately 9.8 m/s^2 in SI, 980 cm/s^2 in C.G.S or 32 ft/s^2 in F.P.S system near the Earth‟s surface. The value changes with altitude and depth from the surface of earth.

5.3.2. Unit and dimension:

The unit of g is m/s^2in SI unit and the dimension is same as that of acceleration i.e. $[M^0L^1T^{-2}]$.

5.2. Mass and weight:

Mass

- Mass of any object is the amount of matter that an object possesses.
- Mass is constant irrespective of place and time.
- Mass can never be zero
- The unit of mass is g, kg etc.
- Mass is a scalar quantity.

Weight (W)

- Weight of an object is the measurement of the gravitational force acting on the object; W = mg.
- The value of weight depends on the value of „acceleration due to gravity‟ at the place and is not constant.
- Weight can be zero where acceleration due to gravity becomes zero.
- The unit of weight is Newton and Dyne .
- Weight is a vector quantity. It is directed towards the centre of earth.

5.5 Relation between g and G:

Suppose the mass of the Earth = M, Mass of the object on the surface of

the earth = m, Radius of earth= R.

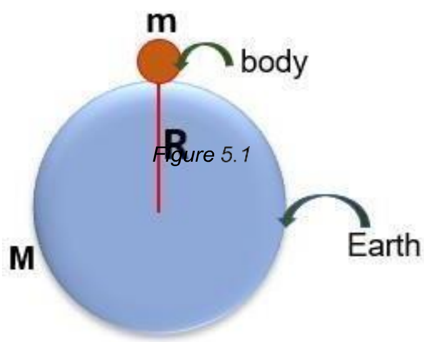


Figure 5.2

Then, the magnitude of the gravitational force acting on the mass m by Earth is

$$F = G \frac{Mm}{R^2} \text{..............................} (2)$$

If the acceleration of the object is g, then according to Newton‟s 2nd Law,

$$F = mg \text{..............................} (3)$$

Equation 4 describes the relationship between acceleration due to gravity (g) and universal gravitational constant (G).

Example 1

A mass of 2 kg experiences a weight of 18N on a planet. What is the value „g" on the planet?

Answer:

Weight = mg = 18 N, $g = \frac{18}{m} = \frac{18}{2} = 9$ ms^{-2}

Example 2

Find the force of gravitational attraction between two neutrons whose centres are 10^{-12}m apart. Given G =6.67 × 10^{-11} Nm^2kg^{-2}, mass of neutron = 1.67 × 10^{-27} kg

Answer:

Here, $m_1 = m_2 = 1.67 \times 10^{-27}\ kg$, $r = 10^{-12}$m, G =6.67 × 10^{-11} Nm^2kg^{-2}

So, $F = G\frac{m_1m_2}{r^2} = 6.67 \times 10^{-11}\frac{(1.67 \times 10^{-27})^2}{10^{-24}} = 1.8 \times 10^{-40}\ N$

Example 3

Two bodies of masses 2 kg (body A) and 5 kg (body B) are placed separated by a distance of 0.4 m. Assuming the only forces acting between them are due to gravitational interaction, find their initial accelerations.

Answer:

The two bodies will experience gravitational force F which are equal in magnitude and opposite in direction

$F = G\frac{m_1 m_2}{r^2} \Rightarrow F = 6.67 \times 10^{-11}\frac{2 \times 5}{0.4^2} = 41.7 \times 10^{-10}$ N

If a_1 and a_2 are the initial accelerations of body A and B respectively,

$$a_1 = \frac{F}{m_1} = \frac{41.7 \times 10^{-10}}{2} = 20.85 \times 10^{-10}\ \text{m/s}^2$$

$$a_2 = \frac{F}{m_2} = \frac{41.7 \times 10^{-10}}{5} = 8.34 \times 10^{-10}\ \text{m/s}^2$$

Example 4:

A body weighs 90 kg wt on the surface of the earth. How much will it weigh on the surface of the mars if its radius is ½ and mass 1/9 of the earth.

Answer:

Given, Mass of Mars = M_m =1/9 Mass of Earth = 1/9 M_e

Radius of Mars = R_m = ½ Radius of Earth = ½ R_e

Weight of body on the earth= W_e = mg_e = $m\frac{GM_e}{R_e^2}$ = 90 kg wt

Weight on mars, W_m = mg_m = ?

Where g_e and g_m are acceleration due to gravity on earth and mars, respectively.

$$g_m = \frac{GM_m}{R_m^2} = \frac{G\frac{M_e}{9}}{\frac{R_e^2}{4}} = \frac{4}{9} \times \frac{GM_e}{R_e^2} = \frac{4}{9} g_e$$

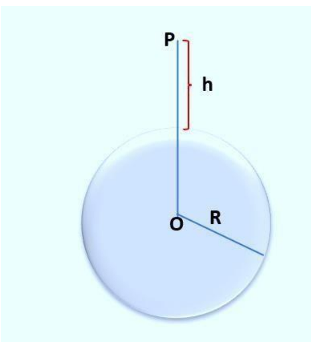
where M_e and M_m are the masses of earth and mars, respectively and R_e and R_m are the respective radii.

So, $w_m = mg_m = \frac{4}{9} mg_e = \frac{4}{9} \times 90 = 40\ kg\ wt.$

5.6 Variation of g with altitude and depth

a: Variation with altitude

Let us represent earth as shown in the below figure.



An object of mass m is placed at P at a height h from the Earth‟s surface. Let us denote g = acceleration due to gravity at the Earth‟s surface.

$$\text{So, } g = \frac{GM}{R^2}$$

where, M = mass of earth R = Radius of earth

Now, the value of acceleration due to gravity at a height h from the Earth‟s surface = g'

$$\text{So, } g' = \frac{GM}{(R+h)^2} = \frac{GM}{R^2(1+\frac{h}{R})^2} = \frac{g}{(1+\frac{h}{R})^2} = (1+\frac{h}{R})^{-2}$$

If h<<R, then, only the first two terms of the binomial expansion of $(1+\frac{h}{R})^{-2}$ are considered and higher powers of h can be neglected.

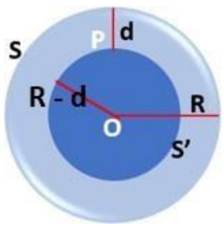
$$\text{i.e. } (1+\frac{h}{R})^{-2} \cong 1 - \frac{2h}{R}$$

$$\text{So, } g' \cong (1 - \frac{2h}{R}) \text{..} (5)$$

From equation 5, it is clear that ***the acceleration due to gravity decreases with increasing height.***

b: Variation with depth:

Let us represent earth as follows. Let the surface of earth (the sphere) be called S.



Let g = acceleration due to gravity on the surface of the earth

and g' =acceleration due to gravity at depth d below the surface of earth

$$\text{Now, } g = \frac{GM}{R^2}$$

$$\text{Here, M} = \frac{4}{3}\pi R^3 \rho,$$

where, ρ =mass density of earth,

R = radius of earth

$$\text{So, } g = \frac{G}{R^2} \times \frac{4}{3}\pi R^3 = \frac{4}{3}\pi R \rho G \text{ --------- (6)}$$

$$\text{Similarly, } g' = \frac{4}{3}(R-d) \text{ --------------(7)}$$

Dividing equation 7 by 6,

$$\frac{g'}{g} = \frac{R-d}{R}$$

$$\Rightarrow g' = g\left(1 - \frac{d}{R}\right)$$

R

Hence, **the value of acceleration due gravity decreases with increasing depth.**

So, the value of acceleration due to gravity is maximum at the surface of the earth.

At the centre of the earth, where d= R, g′ becomes zero. So, the weight of the body (mg‟) becomes zero at the centre of the earth.

Example 5:

A body has a weight 81N on the surface of the earth. How much will it weigh when taken to height equal to half of the radius of earth?

Answer:

Let F1 be the weight (gravitational attraction on the body due to earth) of body on the earth surface.

$$F_1 = \frac{GMm}{R^2} \text{ ----------------------- } (8)$$

Here, M= mass of earth, m = mass of the body and R= radius of the earth

When, taken to a height R/2 from the surface, the distance „x‟ of the body from the centre of earth is $x = R + \frac{R}{2} = \frac{3R}{2}$

Weight F_2 at this place is $F_2 = \frac{GMm}{x^2} = \frac{GMm}{\left(\frac{3R}{2}\right)^2} = \frac{4}{9}\frac{GMm}{R^2}$ -----------------(9)

Dividing equation 9 by 8,

$$\frac{F_2}{F_1} = \frac{4}{9}$$

As F1= 81N. $F_2 = \frac{4}{9} \times 81N = 36$ N

Example 6:

A mass of 5 kg is weighed on a balance at the top of a tower 20 m high. The mass is then suspended from the pan of the balance by a fine wire 20 m long and is reweighed. Find the change in the weight in milligram. (Given radius of earth = 6330 km).

Answer:

m = 5 kg, h = 20 m =

0.02 km R = 6330 km

Now, $\frac{g^F}{g} = 1 - \frac{2h}{R} \Rightarrow g' = g - \frac{2hg}{R} \Rightarrow g - g' = \frac{2hg}{R}$

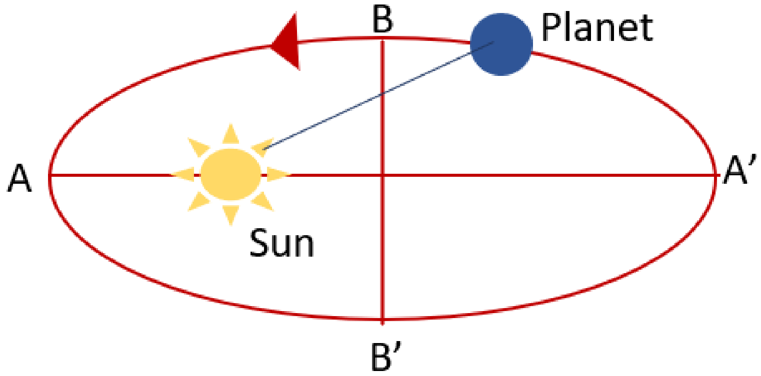
So, change in weight = $mg - mg' = \frac{2mhg}{R} = \frac{2\times5\times0.02\times g}{} = 3.09 \times 10^{-4}$ N

5.7 Kepler‟s Law of Planetary Motion:

Keller's laws of planetary motion are the laws describing the motion of planets around the sun.

1st law (Law of Elliptical orbit):

All the planets revolve in elliptical orbits with the Sun situated at one of its foci.The point at which the planet is close to the sun is known as perihelion and the point at which the planet is farther from the sun is known as aphelion.



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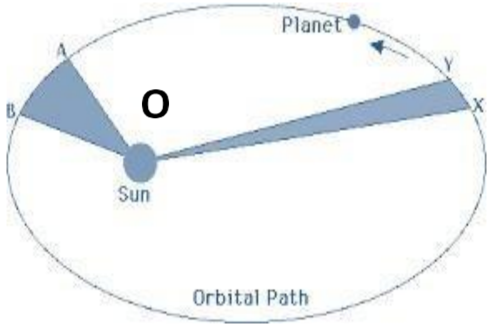
In the figure, AA‟ is the major axis of the ellipse with length 2R and BB‟ is the minor axis with length 2b.

Since the focus of an ellipse is not equidistant from the point of orbit, the distance of planet varies from certain minimum to maximum value. Here, the rotation is the reason of season change from summer (nearer the sun) to winter (farther from the sun) and repetition of same year after year.

The first law explains the change of season.

2nd law (Law of areal velocity)

The areal velocity of the planet is constant. That means, the line joining the sun to the planet sweeps equal area in equal interval of time.



According to the law :

If the planet moves from X to Y in time t and from A to B in the same time interval t later, then the area OAB = area OXY.

=> AB x OA = XY x OX

From the figure it is clear that : OA <

OX Therefore ; AB > XY

Since the areal velocity is constant, the time taken by planet to move from A to B = the time taken by planet to move from X to Y.

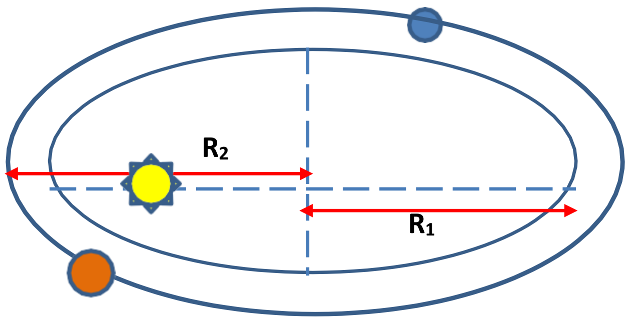
Since AB > XY , the planet moves faster when travels from A to B and moves slower when travels from X to Y. Thus the orbital velocity of planet is not uniform. It is maximum when the planet is nearest to sun (summer season) and minimum when the planet is away from the sun at a maximum distance (winter season).

3^{rd} law (Law of time period)

The square of the time period of a planet is proportional to the cube of the semi major axis of the ellipse.

$$T^2 \alpha \; R^3$$

Where T = time period of the orbiting planet and R = semi-major axis of the elliptic orbital



If two planets revolve around sun in two separate orbits with respective semi major axes as $R1$ and $R2$, then the time period of the planets are related to $R1$ and $R2$ as shown in given figure.

POSSIBLE SHORT QUESTIONS

1. Define universal Gravitational constant. [W-18,20,S-18,19]
   Ans. **The universal gravitational constant is defined as the Gravitational force of attraction between two unit masses placed unit distance apart in the universe.**
2. Write the S.I unit and dimension of universal Gravitational constant. [W-18,20 ,S-18,19]
   Ans. unit

   S.I unit is N.m^2/kg^2 or N.$m^2.kg^{-2}$

   Dimension

   [G]=[$M^{-1}L^3T^{-2}$]

POSSIBLE LONG QUESTIONS

1. State and explain Newton's law of Gravitation. [S,W-19]
2. Derive the relation between g and G. [W-16,17,18,19]
3. State Kepler's laws of planetary motion. [W-16,17,18,19, S-19]
4. Explain the variation of acceleration due to gravity (g) with [W-17,20]
   (i) Altitude (ii) Depth

UNIT 6

OSCILLATIONS AND WAVES

LEARNING OBJECTIVES

6.1Simple Harmonic Motion (SHM) - Definition & Examples.

6.2 Expression (Formula/Equation) for displacement, velocity, acceleration of abody/ particle in SHM.

6.3. Wave motion – Definition & Concept.

6.4 Transverse and longitudinal wave motion —Definition, Examples &Comparison.

6.5 Definition of different wave parameters (Amplitude, Wavelength, Frequency,Time Period.

6.6 Derivation of Relation between Velocity, Frequency and Wavelength of awave

6.7 Ultrasonic – Definition, Properties & Applications.

6.1 SIMPLE HARMONIC MOTION (SHM)

Let us understand oscillation and simple harmonic motion by taking real-life examples. In *Raja* festival, we swing. We sit comfortably at rest, then go up in one direction to an extreme point and then in the opposite direction to another extreme point. You might also have seen simple pendulum especially in old types of wall clock (see below figure) which moves to and fro about the center. The swing and the pendulum are said to execute oscillation.

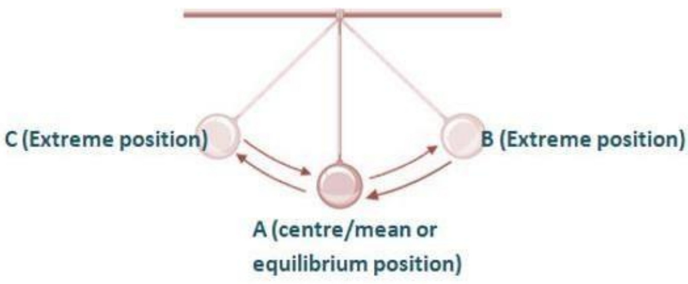


Figure 6.1a

Figure 6.1b

Definition:-

Simple Harmonic Motion (SHM) is defined as the type of periodic motion in which the restoring force is proportional to the displacement from its mean position of rest and always directed towards the mean position.

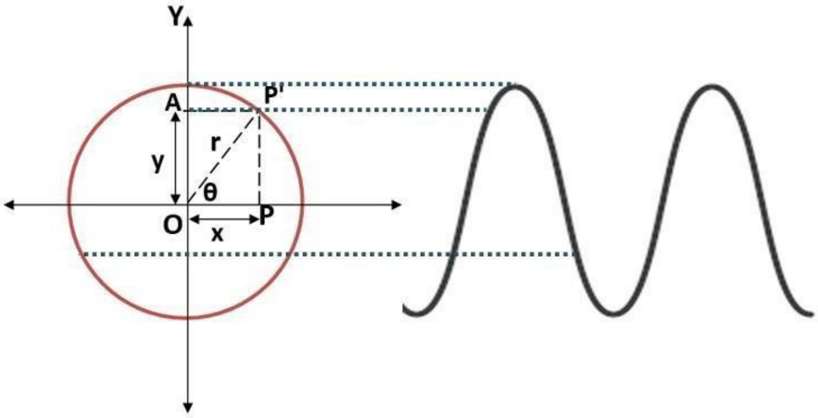
Let, a particle is displaced by a distance y from its mean position and „F‟ is the restoring force tends to bring the body to its mean position due to elasticity.
For a small displacement, the force is proportional to the displacement and opposes the increase of displacement.
Hence, F a (-) y,
Restoring force F = mass x acceleration
=> Ma = -K y,
K = Proportionality constant called force constant
=> a = - (K/m) y => a a - y,
The negative sign shows that acceleration is always directed towards the mean position as it opposes the increase in displacement.
Thus in Simple Harmonic Motion acceleration (a) is directly proportional to the displacement (y) and is always directed towards the

Example:

i. Motion of simple pendulum
ii. Motion of a spring-block system
iii. Vibration of stretched string
iv. Bungee-jumping
v. Swing Cradle etc

6.2 EXPRESSION FOR DISPLACEMENT, VELOCITY, ACCELERATION OF APARTICLE EXECUTING SHM

Let us consider a particle moving in a uniform circular motion with a constant angular velocity ω.



The projection of the motion of particle makes a simple harmonic motion along the diameter of the circle of reference.

Figure 6.2

The projection of the particle at time t = 0 is O.
At an instant of time t, the projection of the particle at P' is A. Then, OA = y = displacement of the particle at time t
OP' = radius of the reference circle = r
Then, θ = angular displacement & $Angular\ velocity = \omega = \frac{\theta}{t} \Rightarrow \theta = \omega t$

a. Equation of Displacement:

In the right angled triangle OPP', $\sin = \frac{PP^F}{0P^F} = \frac{y}{r} =$

$$\Rightarrow y = r\ sin\theta = r \sin \omega t$$

Where, r = amplitude of SHM

b. Equation of Velocity:

$$v = \frac{dy}{dt} = \frac{d}{dt}(r\sin\omega t) = r\frac{d}{dt}(\sin\omega t) = r\,\omega\cos\omega t$$

$$\Rightarrow v = r\omega\cos\omega t = r\omega\sqrt{1-\sin^2\omega t} = \omega\sqrt{r^2-y^2}$$

So, at mean position, y = 0, So, $v = \omega\sqrt{r^2-0^2} = r\omega$ which is maximum. At extreme positions, y = $\pm r$, So, $v = \omega\sqrt{r^2-r^2} = 0$ which is minimum.

Hence, a particle executing SHM has zero velocity at the extreme positions and maximum velocity at the mean position.

c. Equation of Acceleration:

$$a = \frac{dv}{dt} = \frac{d}{dt}(r\omega\cos\omega t) = r\omega\frac{d}{dt}(\cos\omega t) = -r\omega^2\sin\omega t$$

$$\Rightarrow a = -\omega^2(r\sin\omega t) = -\omega^2 y$$

Hence, $a \quad -y$ (proved)

Now, $|a| = \omega^2 y$

At the mean position, y= 0, $a = 0$; minimum

At extreme positions, y = ±, $|a| = \omega^2 r$; maximum

Hence, a particle executing SHM has zero acceleration at the mean position and maximum acceleration at the extreme positions.

Example 1:

If a particle executes simple harmonic motion of period 8 s and amplitude 0.40 m, find the maximum velocity and acceleration.

Answer:

Here, T = 8 s.

So, m = $\frac{2}{T} = \frac{2}{8} = \frac{}{4}$ rad s^{-1}

r = 0.40 m

Maximum velocity = or = $\frac{}{}$ 0.40× $\frac{\pi}{4}$ = 0.3142 ms^{-1}

Maximum acceleration = m^2 r = $\left(\frac{}{4}\right)^2$ × 0.40 = 0.2467 ms^{-2}

6.3 WAVE MOTION

In the previous subsection we studied about the oscillation of single particle. Now let us study a situation where there is a collection of particles and the motion of one particle affects other. The simplest and relatable example is when we throw a stone into a pond which creates a

Figure 6.3

Now, the question is what is propagating? Is it the water particles which are moving themselves? This can be tested by putting a small paper on the water. We can see that the paper will execute an „up and down" motion. Hence, it can be inferred that the water particles are moving up and down where the disturbance is propagated outwards.

When there is a disturbance in a medium, due to elasticity of the particle of the medium, the particles execute to and fro motion about their mean position, as a result the energy as well as momentum transfer from one particle to another and so on. In this way wave is produced.

When the wave propagates, the particles of the medium are not moving along with the wave, but they are vibrating about the mean position.

6.4 TRANSVERSE AND LONGITUDINAL WAVE MOTION

- The type of wave in which the particle of the medium vibrates perpendicular to the direction of propagation is called transverse wave.
- It results in the formation of crest and trough

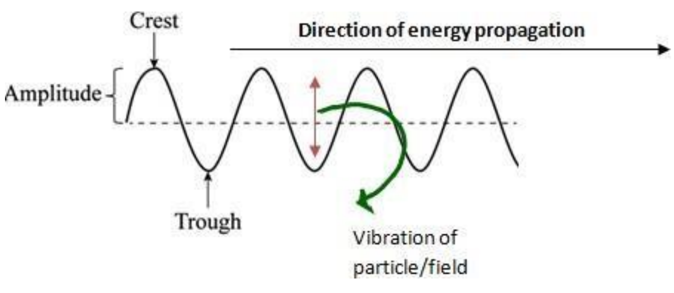


Figure 6.4

- The distance between two consecutive crests or troughs is called as wavelength (λ).
- Density of medium does not vary.
- Electromagnetic wave is a kind of transverse wave for which

Longitudinal wave:

- The type of wave in which the particles of the medium vibrate parallel to the direction of propagation is called longitudinal wave.
- It results in the formation of compression and rarefaction (figure 6.5).
- The distance between two consecutive centers of compressions or rarefactions is called wavelength (λ).
- Density of medium is higher at compression and lowest at rarefaction.
- Longitudinal wave needs medium for its propagation.
- Example, Sound wave

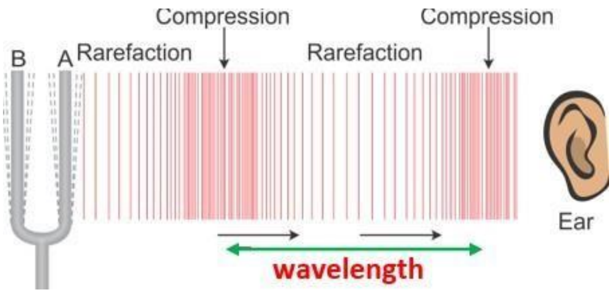


Figure 6.5

	Transverse Wave		Longitudinal Wave
1	In a transverse wave motion, the particles Of the medium/field vibrate in a direction perpendicular to the direction of propagation of the wave. For example, electromagnetic wave.	1	In a longitudinal wave motion, the particles of the medium vibrate in a direction parallel to the direction of propagation of the wave. For example, sound wave.
2	The region of maximum upward displacement is called the crest and the maximum downward displacement is called trough.	2	Longitudinal wave is propagated via compression and rarefaction.
3	Electromagnetic wave is a kind of transverse wave which may travel without a material medium.	3	Longitudinal wave needs a medium for its propagation.
4	Density of the medium does not vary	4	Density of the medium is higher at Compression and lower at rarefaction.

6.5 DEFINITION OF DIFFERENT WAVE PARAMETERS

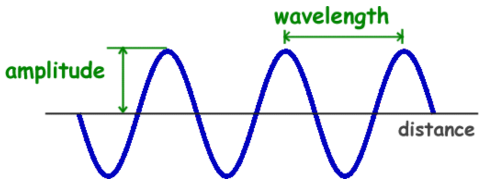


Figure 6.6

Amplitude:

The amplitude of a wave is a measure of the maximum displacement of the wave from its equilibrium position in either side. (Figure 6.6).

The amplitude is a measure of the intensity of the wave. To be particular, intensity is the square of amplitude.

SI Unit --Meter
Dimension (L)

Wavelength (λ):

It is the linear distance covered during one full wave or one full cycle. SI Unit Meter
Dimension - (L)

The distance over which the shape of a wave repeats is called its wavelength. It is the distance between successive points of the same phase on the wave, such as two adjacent crests, troughs, or zero crossings (figure 6.6).

Time Period (T):

Time taken by a particle of the medium to describe or complete one full wave is called Time- period.
SI Unit --- Second
Dimension - (T)

Frequency (f):

It is the number of complete waves/full cycles described by the particle in 1 second.

$\therefore$ frequency = 1 / Time period

SI Unit -- Cycles/Second = sec^{-1} = HERTZ (Hz)

Wave Velocity (v):

The linear distance covered or travelled by a wave per unit time (in 1 sec) SI UnitMeter /second

Dimension------(L/T) or (LT^{-1})

6.6 RELATION BETWEEN VELOCITY, FREQUENCY AND WAVELENGTH

The wave velocity (v) is defined as the distance covered by a wave

per unit time. We know, the distance covered in a time period T is the

wavelength λ

So, the distance covered in unit time is $\frac{\lambda}{T}$

$$\text{That means } v = \frac{\lambda}{T}$$

$$\text{But, } f = \frac{1}{T}$$

$$\Rightarrow v = f\lambda \text{---------------} (6)$$

Equation 6 depicts the relationship between velocity, frequency and wavelength.

Example 2:

A broadcasting station radiates at a frequency 710 kHz. What is the wavelength in meter? Given the wave velocity of waves = $3 \times 10^8\ m/s$

Answer:

f = 710 kHz = $710 \times 10^3 s^{-1}$. v = $3 \times 10^8\ m/s$

$$\lambda = \frac{v}{f} = \frac{3 \times 10^8}{710 \times 10^3} = 422.5\ m$$

6.7 ULTRASONICS

The branch of Physics which deals with study of ultrasonic waves is called Ultrasonic.

The sound wave having frequency above 20 kHz or 20,000 Hz are known as Ultrasonic waves.

The sound audible to human ear lies in the frequency range of 20 Hz to 20 kHz. The sound wave with higher frequency i.e., in the range of 20 kHz to several GHz is called ultrasonic waves.

Properties:

- Ultrasonic waves possess high frequency and hence high energy.
- As ultrasonic waves are sound waves, they require material medium for their propagation.
- With high energy, ultrasonic waves produce heating effect in the medium through which they pass.
- Ultrasonic wave can accelerate chemical reactions.

Application:-

- In sonar system, ultrasonic waves are used to estimate the depth of ocean.
- Ultrasonic is used to locate divers, fish and to detect sunk ships and other under water bodies. This is done by sending high intense ultrasonic pulses and by detecting the reflected wave.
- Ultrasonic is used in scanning to detect any anomaly in the internal organs.
- Ultrasonic waves can be used for localized destruction of unwanted body cells or bacteria.
- Ultrasonic drills are used for shaping, cutting and machining of materials.
- Ultrasonic baths are heavily used in industries and laboratories for cleaning remote parts of machineries.
- Fine particles of dust, smoke and ash coagulate when they are subjected to ultrasonic

POSSIBLE SHORT QUESTIONS

1. State two application of ultrasonic. [16,18,19-W,19-S]

Ans- Echo sounding, Flaw detection, congratulation, ultra sonic welding and cleaning.

2. Define transverse wave. [2018(w)]
Ans- This is the type of wave where vibration of the particles of a medium is normal to the direction of wave propagation.

3. How are the velocity, frequency and time period of a wave related?
Ans- We know that

$$\text{Velocity} = \frac{wavelength}{time\ period} = \frac{\lambda}{T} =$$

$$V = f \times \lambda$$

POSSIBLE LONG QUESTIONS

1. Distinguish between transverses wave and the longitudinal wave.
[2017(w),2018(w),2019(w)]

2. Write down ultrasonic and write its properties.
[2018(w) , 2019(w),]

3. Obtain equations for
(i) Displacement
(ii) Velocity.
(iii) Acceleration of a body executing simple harmonic motion (S.H.M)

UNIT-7

HEAT AND THERMODYANAMICS

LEARNING OBJECTIVES

7.1 Heat and Temperature – Definition and Difference.

7.2 Units of heat (F.P.S, C.G.S, M.K.S & S.I).

7.3 Specific Heat (concept,definition,unit,dimension and simple numerical).

7.4 Change of state (concept) and

Latent Heat (concept,definition, unit,dimension and simple numerical).

7.5 Thermal Expansion – Definition and concept.

7.6 Expansion of solids (concept).

7.7 Coefficient of linear, superficial and cubical expansion of solids –

Definition and Units.

7.8 Relation between α, β *and* γ.

7.9 Work and Heat – concept and Relation.

7.10 Joules Mechanical Equivalent of Heat (Definition and Unit).

7.11 First law of Thermodynamics (Statement and concept only).

7.1 Heat and Temperature

Heat

⇒ Heat is the form of energy which is transferred from one point to another without any mechanical energy.

⇒ The part of internal energy which is transferred from one body to other due to temperature difference Is called heat.

⇒ Energy possessed by the body due to its molecular vibration is called heat energy.

Temperature

⇒ The degree of hotness or coldness is called temperature.

⇒ Temperature is the condition which determines the direction of hat flow when two bodies are fixed together.

⇒ Temperature is a macroscopic quantity.

⇒ Units – Centigrade, Fahrenheit, Kelvin.

⇒ Dimension - [Temperature] = $[M^0 L^0 T^0 K^1]$.

Difference between Heat and Temperature

Heat	Temperature
⇒ Heat is the form of energy which is transferred from one point to other without any mechanical work.	⇒ Temperature is the degree of hotness or coldness of a body.
⇒ It is the total energy of the constituent molecules of an object.	⇒ It is the measure of average kinetic energy of the molecules of an object.
⇒ It is a cause.	⇒ It is an effect.
⇒ It is a derived quantity.	⇒ It is a fundamental quantity.
⇒ Its S.I unit is joule(J).	⇒ Its S.I unit is Kelvin(K).

7.2 Units of Heat

Heat is measured in following units.

System of units	Units
F.P.S	British thermal unit(Btu)
C.G.S	Calorie (cal.)
M.K.S	Kilo calorie (K.cal.)
S.I	Joule(J)

7.3 Specific Heat

⇒ The amount of heat intake by the body depends upon mass of the body and rise in temperature and nature of the substance.

Let H = Amount of heat intake by the body

m = mass of the body

$\Delta\theta$ = rise in temperature

Now $H \alpha m$, $H \alpha \Delta\theta$

$\therefore H \alpha m \Delta\theta$

$\Rightarrow H = m s \Delta\theta$; s = proportionality constant

= specific heat

⇒ If m =1 unit , $\Delta\theta$ = 1 unit , then S = H

∴ Specific heat of substance is defined as the amount of heat required to rise the temperature of unit mass of substance through 1^o c.

⇒ Unit

Cal/g c , k.cal/kg c , J/ kg k (S.I.)

⁕ S (ice) = 0.5 cal/g °C = 0.5 k.cal/kg °C = 2100 J/kg k

⁕ S (water) = 1 cal/g °C = 1 k.cal/kg °C = 4200 J/kg k

⁕ S (steam) = 0.4 cal/g °C = 0.4 k.cal/kg °C = 1680 J/kg k

⇒ <u>Dimension</u> $[S] = \left[\frac{H}{m\Delta\theta}\right] = \left[\frac{M^1L^2T^{-2}}{M^1K^1}\right] = [M^0L^2T^{-2}K^{-1}]$

⇒ Specific heat of substance at its melting point and boiling point is infinity.

∴ $S = \frac{H}{m\Delta\theta} = \infty$, (such that $\Delta\theta = 0$).

Problem-1.

A substance of 4 kg requires 40 k.cal of heat for rise in its temperature of 15 ℃ to 25 ℃. Calculate the specific heat of the substance and gives its nature.

Ans. Given,

H = 40 k.cal , m = 4 kg , $\Delta\theta = 25 - 15 = 10$ ℃ , S = ?

We know, $S = \frac{H}{m\,\Delta\theta} = \frac{40}{4\times10} = 1$ k.cal / kg ℃

∴ the given substance is water.

⁂ Out of solid and liquid, water has maximum specific heat.

⁂ Out of solid, liquid and gas, Hydrogen has maximum specific heat.

Problem-2.

If the specific heat of gold is 129 J/kg.k.Then what quantity of heat is required to raise the temperature of 100 gm of gold by 50 k ?

Ans. Given,

S = 129 J/kg.k , m = 100 gm = 0.1 kg , , $\Delta\theta = 50$ k

The amount of heat required, $H = S\,m\,\Delta\theta = 129 \times 0.1 \times 50 = 645$ J.

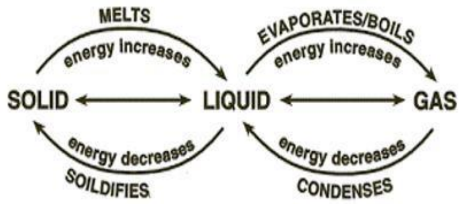
∴ The heat is required 645 J.

7.4 <u>Change of state</u> :

⇒ Every substance exists in various forms of solid , liquid and gases called phases of matter.

⇒ conversion of one phase to another phase by pressure and temperature is known change of state.

⇒ The transition from solid to liquid state is called Melting and transition from liquid to Solid state is called Freezing.



⇒ The transition from liquid to gaseous state is called vaporization and transition from gaseous state to liquid state is called Condensation.

⇒ The transition from solid to gaseous state is called Sublimation and the transition From gaseous state to solid state is called Deposition.

<u>LATENT HEAT</u>(L):-

⇒ The amount of heat required to change the state of substance at constant temperature is called latent heat.

⇒ This is so named as there is no change in temperature, when state of the substance Changes.

⇒ let,

H = Amount of heat intake by the body.

m = mass of the body

During phase change we can write,

$H \propto m$

⇒ $H = mL$, L = Latent heat.

$\therefore$ $\boxed{L = H/m}$

⁎ The amount of heat required to change the state of unit mass of substance at Constant temperature is called latent heat.

⇒ unit:- cal./g , k .cal./kg , J/kg (S.I.)

⇒ Dimension:- $[L] = \left[\frac{H}{m}\right] = \left[\frac{M^1L^2T^{-2}}{M^1}\right] = [M^0L^2T^{-2}]$

⇒ <u>Latent heat of fusion</u>

The amount of heat required to change the unit mass of solid into liquid at its melting point is called latent heat of fusion.

⁎ latent heat of fusion of ice = 80 cal./g = 336000 J/kg.

Latent heat of vaporization:-

The amount of heat required to change the unit mass of liquid into gas at its boiling point is called latent heat of vaporization.

⁎ Latent heat of vaporization of water = 540 cal./g = 2268000 J/kg.

Problem-1:-

Calculate the power of a child if he can chew 20g of ice in 1 minute.

Ans.

Given, m = 20g, t = 1 min. = 60 sec.

$$H = ml = 20 \times 80 = 1600 \text{ cal.} = 1600 \times 4.2 = 6720 \text{ J}$$

$$\therefore \text{ Power} = w/t = \frac{6720}{60} = 112 \text{ watt.}$$

Problem-2:-

Determine the latent heat of a 10 kg substance if the amount of heat required for a phase change is 200 kcal.

Ans.

Given, m = 10 kg , H = 200 kcal.

We know that $L = H/m = \frac{200}{10} = 20$ kcal./kg.

7.5 Thermal expansion:-

⇒ Most of substances expand on heating and contract on cooling. A change in the temperature of a body causes change in its dimension.

⇒ The increase in dimensions of a body due to the increase in temperature is called thermal expansion.

7.6 Expansion of solid:-

When a solid is heated, it expands due to increase in interatomic distance with rise in temperature. According to increase in length, surface area and volume, there are three types of expansion , such as linear, superficial and cubical expansion.

7.7 Coefficient of linear, superficial and cubical expansion of solids:-

1. Linear expansion:-

The expansion in one dimension is known as linear expansion.

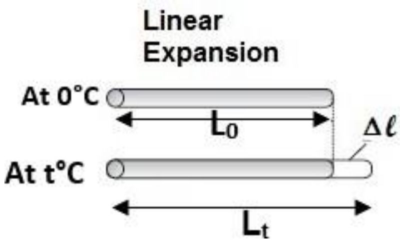


Fig. 7.3

Let, L_0 = length of the conductor at 0 ℃.

L_t = length of the conductor at t ℃.

t = rise in temperature

ΔL = increase in length = $L_t - L_0$

Now $\Delta L \propto L_0$

$\propto t$

$\Rightarrow \Delta L = \alpha L_0 t$, α = proportionality constant

= Coefficient of linear expansion

$\Rightarrow \alpha = \frac{\Delta L}{L_0 t}$ $\Rightarrow \alpha = \frac{L_t - L_0}{L_0 t}$

$\therefore$ $L_t = L_0 (1 + \alpha t)$

⁕ unit of α:- $℃^{-1}$ or K^{-1}

⁕ value of α:- $0 < \alpha < 1$

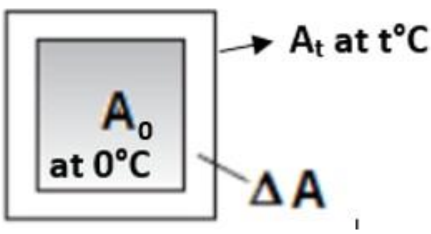
⁕ Dimension of α:- $[\alpha] = [M^0 L^0 T^0 K^{-1}]$

⁕ Def^n of α :-

Coefficient of linear expansion is defined as increase in length per unit original length per unit rise in temperature.

2. Superficial expansion:-

The expansion of length and breadth is known as superficial expansion.



Let, A_0 = surface area of the conductor at 0°C.

A_t = surface area of the conductor at t°C.

t = rise in temperature.

ΔA = increase in surface area = $A_t - A_0$.

NOW, $\Delta A \propto A_0$

$\propto t$

$\Rightarrow \Delta A = \beta A_0 t$, where β = proportionality constant

= Coefficient of superficial expansion

$\Rightarrow \beta = \frac{\Delta A}{A_0 t}$

$\Rightarrow \beta = \frac{A_t - A_0}{A_0 t}$

$\therefore A_t = A_0(1+\boldsymbol{\beta}t)$

⁕ unit of β:- $°C^{-1}$ or K^{-1}

⁕ Range of $\boldsymbol{\beta}$:- $0 < \beta < 1$

⁕ Dimension of $\boldsymbol{\beta}$:- $[\beta] = [M^0L^0T^0K^{-1}]$

⁕ Def^n of β :- Coefficient of superficial expansion is defined as increase in surface area per unit original surface area per unit rise in temperature.

3. cubical expansion:-

The expansion of length, breadth and height is known as cubical expansion.

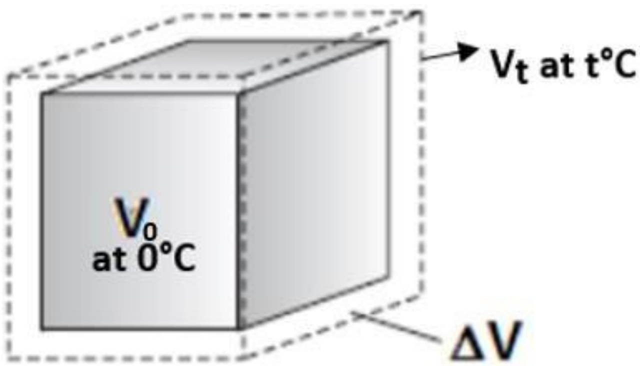


Fig. 7.5

Let, V_0 = volume of the conductor at 0 °C.

V_t = volume of the conductor at t °C.

t = rise in temperature

Δv = change in volume = $V_t - V_0$

Now $\Delta v \propto V_0$

$\propto t$

$\Rightarrow \Delta v = \boldsymbol{\gamma} V_0 t$

$\Rightarrow \boldsymbol{\gamma} = \frac{\Delta v}{V0\ t} \quad \Rightarrow \boldsymbol{\gamma} = \frac{Vt - V0}{V0\ t}$

$\therefore V_t = V_0 \ (1 + \boldsymbol{\gamma t})$

⁕ <u>unit of $\boldsymbol{\gamma}$</u> :- °C^{-1} or K^{-1}

⁕ <u>Range of</u> :- $0 < \boldsymbol{\gamma} < 1$

⁕ <u>Dimension</u> :- $[\gamma] = [M^0 L^0 T^0 K^{-1}]$

⁕ <u>$\mathrm{De}f^n$ of</u> :- Coefficient of cubical expansion is defined as increase in volume per unit original volume per unit rise in temperature.

7.8 <u>Relation between α, $\boldsymbol{\beta}$ and y:</u>

1. Relation between **α** and $\boldsymbol{\beta}$:-

We know that , $A_t = A_0 (1+\boldsymbol{\beta}t)$

$\Rightarrow \ Lt^2 = Lo^2 \ (1+\boldsymbol{\beta t})$, $\quad (\mathbf{A}=\boldsymbol{L^2})$

$\Rightarrow \ Lo^2 \ (1+\alpha t)^2 = \ Lo^2 \ (1+\boldsymbol{\beta t})$, $\quad [L_t = L_0 (1+ \alpha\, t)]$

$\Rightarrow \ 1+ 2\alpha\, t + \alpha^2 t^2 = 1+\boldsymbol{\beta t}$

$\Rightarrow \ \boldsymbol{\beta} = 2\alpha + \alpha^2 t$

Assuming α is very small then $\boldsymbol{\alpha^2}$ **term** is neglected.

$\Rightarrow \ = 2\alpha$ …………….(1)

2. Relation between $\boldsymbol{\alpha}$ and $\boldsymbol{\gamma}$:-

We know that, $V_t = V_0 \ (1 + \boldsymbol{\gamma t})$

$\Rightarrow Lt^3 = Lo^3(1+\boldsymbol{\gamma}t)$, $[\, v = l^3]$,

$\Rightarrow Lo^3(1 + \alpha t)^3 = Lo^3(1+\boldsymbol{\gamma}t)$, $[L_t = L_0 \ (1+ \alpha\, t)]$

$\Rightarrow 1+3\alpha t+3\boldsymbol{\alpha^2 t^2 + \alpha^3 t^3} = 1+\boldsymbol{\gamma}t$

$\Rightarrow \ = 3\alpha + 3\alpha^2 t + \boldsymbol{\alpha^3 t^2}$

Assuming α is very small then higher order α term is neglected.

$\therefore \quad \boldsymbol{\gamma} = 3\,\alpha$ …………………(2)

Now comparing (1) and (2) we get

$\alpha = \frac{\beta}{2} = \frac{\gamma}{3}$ or $\boldsymbol{\alpha} : \boldsymbol{\beta} : \boldsymbol{\gamma} = 1:2:3$

7.9 Work and Heat – concept and Relation:-

Work and Heat are two different ways of transferring energy from one system to another.The distinction between heat and work is important in the field of thermodynamics. Heat is the transfer of thermal energy between systems, while work is the transfer of mechanical energy between two systems so work and heat are interconvertiable.It is a matter of common experience that the two palms become hot if we rub them against each other. In this case work done gets converted into heat. Also due to heat supply, the steam engine works with mechanical motion.

7.10 Joules Mechanical Equivalent of Heat (Definition and Unit)

Work and heat are interconvertiable.

Let W = Amount of work done

H = Amount of heat produced

$\therefore$ W ∝ H

$\Rightarrow$ W = JH , Where J = proportionality constant.

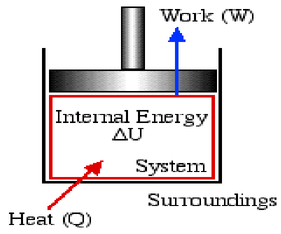
= joules mechanical equivalent of heat.

$= 4.2$ j/cal. $= 4.2 \times 10^7$ erg/cal.

⁎ Def^n :- Joules mechanical equivalent of heat is defined as the amount of work required to produced unit amount of heat.

7.11 First law of Thermodynamics:-

Considering certain amount of gas is taken in a cylinder of non-conducting wall and conducting base with frictionless movable piston. Let U_1 is the initial internal energy of the system and Q amount of heat be added to the system,



Then total energy of the system = $U_1 + Q$.

After gaining heat the gas tends to expand ,pushing the piston upward. As a result Some work(W) is done by the gas and internal energy increases U_1 to U_2.

Then total energy of the system at the end = U_2+ W

Change in internal energy = ΔU = $U_2 - U_1$

According to the law of conservation of energy

$$U_1 + Q = U_2 + W$$

$$\Rightarrow Q = U_2 - U_1 + W$$

$$\Rightarrow Q = \Delta U + W$$

Statement " If the amount of heat supplied to a system is capable of doing some work, then the amount of heat absorbed by the system is equal to the sum of increase in internal energy of the system and external work done by the system".

Possible short Questions with answer

1. Define specific heat of a substance. [2020-W]

Ans. Specific heat of substance is defined as the amount of heat required to rise the temperature of unit mass of substance through 1^o c.

$$\therefore \quad S = \frac{H}{m\Delta\theta}$$

2. Write down the S.I unit and Dimension of specific heat. [2019 – W]

Ans. We know that,

$$S = \frac{H}{m\Delta\theta}$$

unit - J/ kg k (S.I)

Dimension- $[M^0L^2T^{-2}K^{-1}]$

3. Define joule's mechanical equivalent of heat. [17, 18 –W, 18, 19 – S]

Ans. Work and heat are interconvertiable.

Let W = Amount of work done

H = Amount of heat produced

$\therefore$ W $\propto$ H

$\Rightarrow$ W = JH, Where J = proportionality constant.

= joules mechanical equivalent of heat.

Def^n :- Joules mechanical equivalent of heat is defined as the amount of work required to produce unit amount of heat.

4. Define latent heat of vaporization. [W-18, S -19]

Ans. The amount of heat required to change the unit mass of liquid into gas at its boiling point is called latent heat of vaporization.

Latent heat of vaporization of water = 540 cal./g .

5. State first law of thermodynamic. [W- 18,19 , S-19]

Ans. "If the amount of heat supplied to a system is capable of doing some work, then the amount of heat absorbed by the system is equal to the sum of increase in internal energy of the system and external work done by the system".

Possible long Question

1. Define the coefficient of linear, superficial and cubical expansion of solid, and establish the relation between α, β, γ. [W- 19, 20, S – 19]

UNIT-8

OPTICS

LEARNING OBJECTIVE

8.1 ***Reflection & Refraction – Definition.***

8.2 ***Laws Reflection & Refraction (statement only)***

8.3 ***Refractive index- Definition, Formula and simple numerical.***

8.4 ***Critical angle and Total Internal Reflection-Concept, Definition & Explanation.***

8.5 ***Refraction through prism (Ray Diagram & Formula only- No derivation).***

8.6 Fiber ***Optics – Definition*** properties ***& application.***

Optics:-

Optics is a branch of physics that deals with the determination of behaviour and the properties of light. You rely on optics everyday. Your digital camera, wireless mouse, and even your Blu-ray disc of your favourite movie are all technologies enabled by the science of optics.

As light presents a dual behaviour, which can be considered as a wave or particle, basically there are two types of optics.

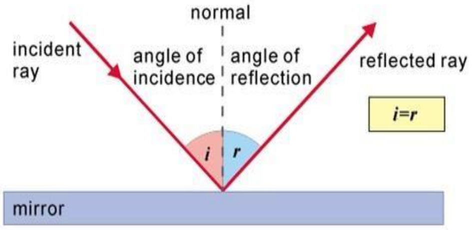
⁕ **Physical optics**– when considering the wave nature of light.

⁕ **Geometric optics** – when light is considered a particle.

8.1 Reflection and Refraction:-

Reflection:-

The phenomenon of light by virtue of which a ray of light moving from a medium to another medium is sent back to the same medium from the interface between the two media is called as reflection.



Incident ray: The ray of light falling on the surface of a mirror is called incident ray.

Reflected ray: The ray of light which is sent back by the mirror from the point of incidence is called reflected ray.

Normal: A line perpendicular or at the right angle to the mirror Surface at the point of incidence is called normal.

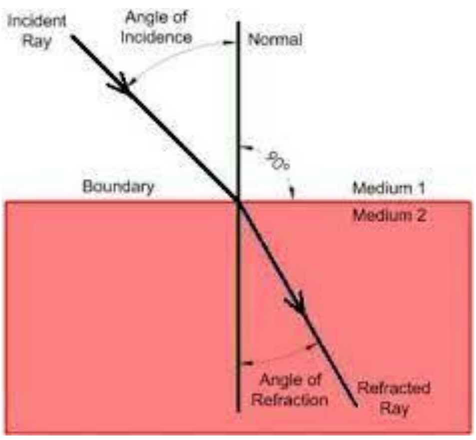
Point of incidence-The point at which the incident ray falls on mirror surfaceis called point of incidence.

Angle of incidence:- The angle made by the incident ray and normal is called angle of incidence.

Angle of reflection:- The angle made by the reflected ray and normal is called angle of reflection.

<u>Refraction</u>:-

The phenomenon of light by virtue of which a ray of light moving from one medium to another medium undergoes a change in its velocity is called as refraction.



※ ※

Refracted ray: The ray of light which travels to the second from thepoint of incidence is called reflected ray.

Angle of refraction: The angle made by the refracted ray with the normal at point of incidence is called angle of refraction.

8.2 Laws of Reflection and Refraction:-

Laws of reflection:-

1. 1st law: The incident ray, reflected ray and normal at the point of incidence are coplaner and the plane is perpendicular to the reflecting surface.
2. 2nd law:-

   Angle of incidence is equal to angle of reflection.

   $\therefore$ i = r

Laws of refraction:-

1. 1st law:-

   The incident ray, refracted ray and normal at the point of incidence are coplaner and the plane is perpendicular to the refracting surface.
2. 2nd law:-

   The ratio of angle of sine of incidence to the angle of sine of refraction is a constant quantity.

   $\therefore \frac{\sin i}{\sin r}$ = constant = μ , where μ = refractive index

   This law is also known as Snell's law.

8.3 Refractive index:-

Refractive index is the property of a medium/material that measure the optical density of that medium and it describes how fast light travels through that medium.

Definition:-

Absolute refractive index is defined as the speed of light in vacuum to the speed of light in given medium.

$\therefore$ $\mu = \frac{C}{V}$ where, C = speed of light in vacuum

V = speed of light in given medium

⁎⁎ It has no unit and no dimension.

Problem 1

Refractive index of water w.r.t air is 4/3, while that of glass is 3/2 . What will be the Refractive index of glass w.r.t water?

Ans.

We know that , $1_{\mu_2 = \mu_2/\mu_1 =} \frac{\mu_g}{\mu_w} = \frac{3}{2} \times \frac{3}{4} = \frac{9}{8}$

Problem 2

A ray of light of light travelling in water is incident at an angle of 30^o on water glass surface.

Calculate the angle of refraction in glass, if Refractive index of water is 4/3 and that of glass is 3/2.

Ans. According to Snell's law ,

$$\mu_1 \text{Sin}\ \theta_1 = \mu_2 \sin \theta_2$$

$$\Rightarrow \frac{4}{3} \times \sin 30 = \frac{3}{2} \sin \theta_2$$

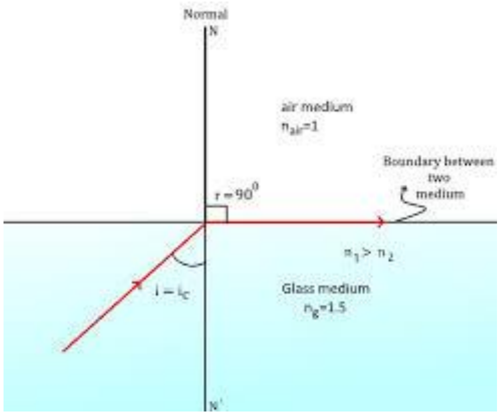
$$\Rightarrow \text{Sin}\ \theta_2 = \frac{4}{9} = 0.444$$

$$\Rightarrow \theta_2 = sin^{-} \frac{4}{9} = 26.4^o$$

8.4 Critical angle and Total Internal Reflection

Critical angle:-

When light ray travels from denser medium to rarer medium then critical angle is defined as the angle of incidence in denser medium for which angle of refraction in rarer medium is 90^o.



Here, i = c and r = 90^o

According to Snell's law,

μ_1Sin θ_1 = μ_2 sin θ_2

$\Rightarrow$ μ_1 Sin c = μ_2 Sin 90^o

$\Rightarrow$ Sin c = $\frac{\mu_2}{\mu_1}$, (Sin $90^o = 1$)

$\Rightarrow$ c $= sin^{-} \frac{\mu_2}{\mu_1}$

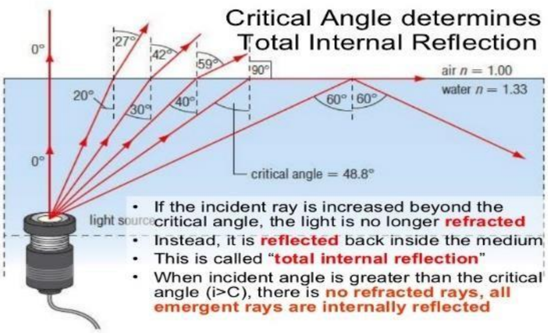
⁎ If both are same medium, then μ_1= μ_2 =1

$\boxed{C = 90^o}$

<u>Total internal reflection (TIR)</u> :-

When light ray travels from denser medium to rarer medium the angle of incidence is greater than critical and it comes back to the original medium. This phenomenon is known as total internal reflection (T.I.R).

It is so named because 100 % light comes back to the original medium.



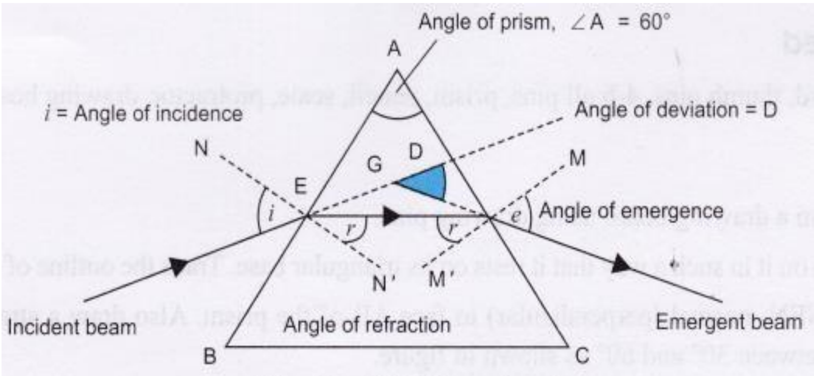
Condition for TIR:-

- Light ray should travels from denser medium to rarer medium.
- Angle of incidence must be greater than critical angle.

8.5 Refraction through prism:-

Prism is triangular base made up glass.

Ray Diagram:-



Refraction of light through a prism

i = angle of incidence

r = angle of refraction

e = angle of emergence

D = Angle of Deviation

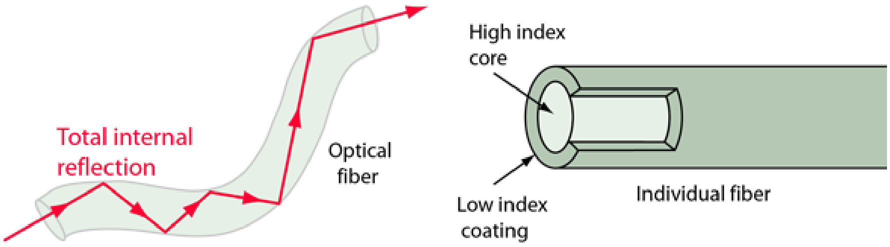
A = Angle of prism

D_m = angle of minimum deviation

$$\mu = \frac{\sin(\frac{A+D_m}{2})}{\sin\frac{A}{2}}$$

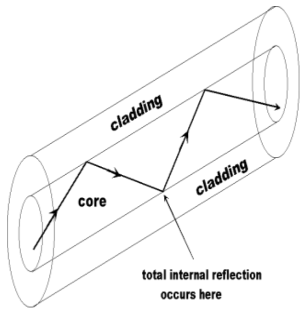
8.6 Fibre Optics:-

Optical fibre is the technology associated with data transmission using light pulses travelling along with a long fibre which is usually made of plastic or glass.Metal wires are preferred for transmission in optical fibre communication as signals travel with fewer damages. Optical fibres are also unaffected by electromagnetic interference. The fibre optical cable uses the application of total internal reflection of light. The fibres are designed such that they facilitate the propagation of light along with the optical fibre depending on the requirement of power and distance of transmission.



<u>Definition</u>

An **optical fiber** is a dielectric cylindrical wave guide consisting oftwo layers, i.e. Core and a surrounding cladding. The refractive index of the material of the core is higher than that of the cladding. Both are made up of thin, flexible, high quality, transparent **fiber** of glass or plastic, where light undergoes successive total internal reflections along the length of the fibre.



Properties

- Optical fibers are small in size and have lightweights as compared to electrical cables. They are flexible and have very high tensile strength. Thus, they can be twisted and bent easily.
- Optical fiber provides a high degree of signal securities as it is confined to the inside of fiber and cannot be tapped and tempered easily. Thus, it satisfies the need for security which is required in banking and defense.
- Optical fiber communication is free from electromagnetic interference.
- Optical fiber material does not carry high voltage or current. Hence, they are safer than electrical cable.

Application

- Communications- for transmitting audio and video signals through long distances. Voice, data, and video transmission are the most common uses of fiber optics, and these include, telecommunications, local area networks (LANs), industrial control system.
- Sensing – Fiber optics can be used to deliver light from a remote source to a detector to obtain pressure, temperature, or spectral information. The fiber also can be used directly as a transducer to measure a number of environmental effects, such as strain, pressure, electrical resistance etc. Environmental changes affect the light intensity, phase and/or polarization in ways that can be detected at the other end of the fiber.
- Power Delivery – Optical fibers can deliver remarkably high levels of power for tasks such as lasercutting, welding, marking, and drilling.

- Illumination – A bundle of fibers gathered together with a light source at one end can illuminate areas that are difficult to reach, for example in medical field, inside the human body, in conjunction with an endoscope.
- Optical fibers are used instead of metal wires because signals travel The fibers in such decorative lamps are optical fibers.

Possible Short Questions with Answer

1. State the laws of reflection [W-19]

Ans. Laws of reflection:-

1st law: The incident ray, reflected ray and normal at the point of incidence are coplaner and the plane is perpendicular to the reflecting surface.

2nd law:-

Angle of incidence is equal to angle of reflection.

$\therefore$ i = r

2. State the laws of refraction. [W-18]

Ans. Laws of refraction:-

1st law:-

The incident ray, refracted ray and normal at the point of incidence are coplaner and the plane is perpendicular to the refracting surface.

2nd law:-

The ratio of angle of sine of incidence to the angle of sine of refraction is a constant quantity.

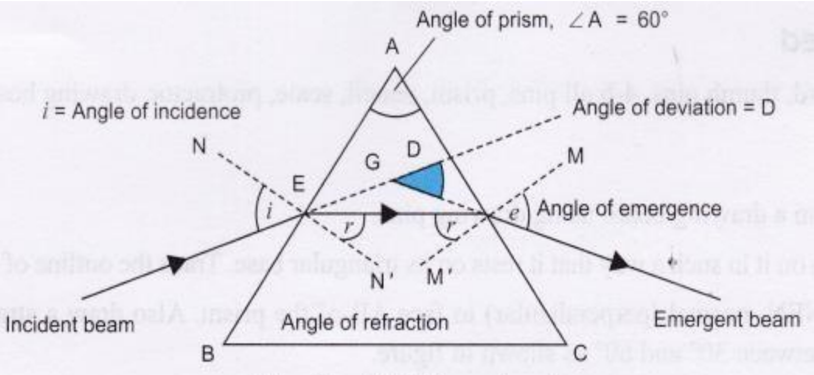
$\therefore \frac{\sin i}{\sin r}$ = constant = μ , where μ = refractive index

3. Write the formula for refractive index of prism. [S -19]

Ans. $\mu = \frac{\sin(\frac{A+D_m}{2})}{sin\frac{A}{2}}$

4. Draw the ray diagram of refraction through prism. [W-19]

Ans.



Refraction of light through a prism

5. State two application of optical fiber. [w-16,17,18,19,S-19]

Ans.

- These are used for study of tissues and blood vessels far below the skin.
- These are used in the field of communications in sending video signals from One place to another.

POSSIBLE LONG QUESTIONS

1. Define critical angel and total internal reflection.[w-16,17,18,19,S-19]

2. Define optical fiber and write its properties and applications.[w-19]

UNIT-9

ELECTROSTATICS AND MAGNETOSTATICS

LEARNING OBJECTIVE

9.1 *Electrostatic – Definition & Concept.*

9.2 *Statement and Explanation Coulomb's law Definition of Unit charge.*

9.3 *Absolute & Relative Permittivity – Definition, Relation and Unit.*

9.4 *Electric potential and Electric potential Difference (Definition, Formula & S.I Unit).*

9.5 *Electric field, Electric field intensity - Definition, Formula & S.I Unit.*

9.6 *Capacitance - Definition, Formula & Unit.*

9.7 *Series and parallel combination of Capacitors (No derivation, Formula for effective / combined / total capacitance & simple numericals).*

9.8 *Magnet, properties of magnet.*

9.9 *Coulomb's law in magnetism – statement & explanation, Unit pole –Definition.*

9.10 *Magnetic field & magnetic field intensity – Definition, Formula and unit.*

9.11 *Magnetic lines of force – Definition and properties.*

9.12 *Magnetic Flux & Magnetic Flux Density- Definition, Formula and unit.*

9.1 Electrostatic:-All of us have the experience of seeing a spark or hearing a crackle when we take off our synthetic clothes or sweater, particularly in dry weather. Have you ever tried to find any explanation for this phenomenon? You might have heard that this is due to generation of static electricity. This is precisely the topic we are going to discuss in this chapter. Static means anything that does not move or change with time.

Electrostatics is the study of properties of stationary or slow-moving electric charges. Electrostatic phenomena arise from the forces that electric charges exerton each other. It deals with the study of forces, fields and potentials arising from static charges.

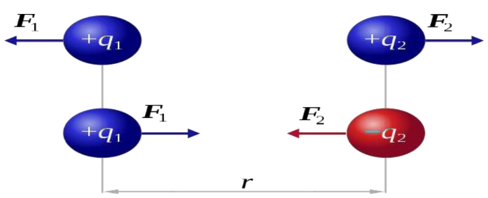
Coulomb's law in Electrostatics

Coulombs law is a quantitative statement about the force between two-point charges. When the linear size of charged bodies are much smaller than the distance separating them, the size may be ignored, and the charged bodies aretreated as point charges.

Statement- It states that "The force between two-point charges is directly proportional to the product of the magnitude of the two charges and inversely proportional to the square of the distance between the charges and acts alongthe line joining the two charges".

Explanation:

The force is along the straight line joining them. If the two charges have thesame sign, the electrostatic force between them is repulsive; if they have different signs, the force between them is attractive.



Consider two-point charges ‑q1‖, ‑q2‖which are separated by a distance ‑r‖, then the magnitude of the force (F) between them is given by

$$F \propto q_1 q_2$$

$$F \propto \frac{1}{r^2}$$

$$F = \beta \quad \frac{q_1 q_2}{r^2}$$

Where β is the constant of proportionality and its value depends on the nature ofthe medium in which two charges are situated.

$$\beta = \frac{1}{4\pi\epsilon_0} = 9 \times 10^9\ N\, m^2/c^2$$

9.3 Absolute & Relative Permittivity

Absolute permittivity is denoted by the Greek letter ε_0 (epsilon) and the relative permittivity is denoted by Greek letter ε_r.Relative permittivity is same as dielectric constant.

Definition- The relative permittivity of a medium is defined as the ratio of the absolute permittivity of the medium and the permittivity of free space.

$$\varepsilon_r = \frac{\varepsilon}{\varepsilon_o}$$

9.4 Electric potential

All of us know that the like charges repel each other and unlike charges attract eachother. Some work is always involved in moving a charge in the area of another charge. What makes the charge to flow? This basically happens because of the electric potential.

If two charged bodies are in contact, the charge starts flowing from one conductor toother. The condition, that determines the flow of charge from one conductor to other in contact, is the **electric potential**. Earth is a conductor that can hold an infinite charge and can give infinite charge without changing its potential. Its potential is taken as zero potential.

Definition: The electrical potential is defined as the capability of the charged body todo work. When the body is charged, either electrons are supplied to it, or they are removed from it. In both the cases, the work is done. This work is stored in the body in the form of electric potential.

$$Electric\ potential = \frac{work\ done}{charge}$$

Electric Potential Difference

When the current flows between two points A and B of an electric circuit as shown in the fig 9.3 below. We only consider the charge between the points A and B. This means it is not necessary to know the exact potential at each pointA and B. It is sufficient to know the potential difference between the two points A and B which is defined as follows.

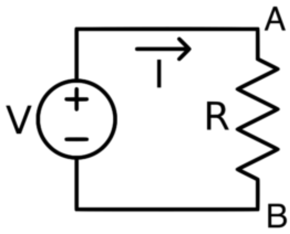


Fig 9.3

Definition: The electrical potential difference is defined as the amount of work done to carry a unit positive charge from one point to another in an electric field.In other words, the potential difference is defined as the difference in the electric potential of the two charged bodies.

When a body is charged to a different electric potential as compared to the othercharged body, the two bodies are said to have a potential difference. The potential difference between two points is said to be 1 volt if the work is done in moving 1-coulomb of charge from one point to other is 1 joule.

S.I unit for measuring the potential difference is volt and instrument used for measuring potential difference is a **voltmeter**. While connecting voltmeter in the circuit, positive terminal of the voltmeter should be in connection with the positiveterminal of the cell and negative with the negative of the cell.

9.4 Electric field and electric field intensity(E):

An electric field is the physical field that surrounds each electric charge andexerts force on all other charges in the field, either attracting or repelling them. Electric fields originate from electric charges, or from time-varying magnetic fields.

Electric field Intensity(Electric field strength): -

The electric field intensity at any point inside an electric field is defined as theforce experienced by the unit positive charge (test charge) placed at that point.

The S.I unit of electric field intensity is Newton/Coulomb or N/C.

9.5 Capacitance

Capacitance is the property of an electric conductor, or set of conductors, that is measured by the amount of separated electric charge that can be stored on it perunit change in electrical potential.

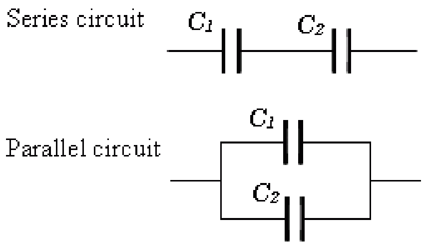
It is denoted as C and is the ratio of the amount of electric charge stored on the conductor to the difference in electric potential.

$$\therefore\ C = \frac{Q}{V}$$

Hence capacity or capacitance of a conductor is defined as the amount of charge required to raise the potential through one unit.

9.6 series and parallel combination of capacitors

We can combine several capacitors of capacitance C1, C2…… Cn to obtain a system with some effective capacitance C. The effective capacitance depends on the way the individual capacitors are combined. Two simple possibilities are discussed below.



In series combination

If positive terminal of first capacitor is connected with –ve terminal of 2nd capacitor is known as series combination.

Effective capacitance

If n number of capacitor connected in series combination then effective capacitance is given by

$$\frac{1}{C_s} = \frac{1}{c_1} + \frac{1}{c_2} + \cdots \frac{1}{c_n}$$

In parallel combination

If +ve terminal of first capacitor is connected with +ve terminal of 2nd capacitor is known as parallel combination.

Effective capacitance

If n number of capacitor connected in parallel combination then effective capacitance is given by

$$c_p = c_1 + c_2 + \cdots c_n$$

9.7 Magnet

The word magnet is derived from the name of an island of Greece called magnesia where magnetic ore deposits were found. A magnet is a material orobject which is capable of producing magnetic field and attracting unlike poles and repelling like poles.

There are three types of magnets, and they are as follows:

- Permanent magnet
- Temporary magnet
- Electromagnets

Properties of magnet

- When a magnet is dipped in iron filings, we can observe that the iron filingscling to the end of the magnet as the attraction is maximum at the ends of the magnet. These ends are known as poles of the magnets.
- Magnetic poles always exist in pairs.
- Whenever a magnet is suspended freely in mid-air, it always points towards north-south direction. Pole pointing towards geographic north is known as theNorth Pole and the pole pointing towards geographic south is known as the South Pole.

9.8 coulomb's law in magnetostatic

Statement-The force of attraction or repulsion between two magnetic poles is directly proportional to product of magnitude of their pole strength and inversely proportional to square of distance between them.

Explanation

$$F \propto m_1 m_2$$

$$F \propto \frac{1}{r^2}$$

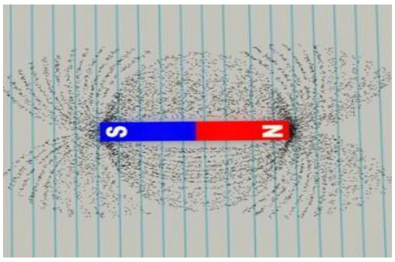
$$\Rightarrow F = \beta \frac{m_1 m_2}{r^2} \; ,\beta = \frac{\mu_0}{4\pi}$$

Unit pole-

Unit pole is the pole which when placed in air at a distance of 1 metreapart from a similar pole repels it with a force of 10^{-7}Newton.

Magnetic field:

Magnetic Field is the region around a magnetic material or a moving electric charge within which the force of magnetism acts. We can say *magnetic field* isthe area around a magnet, magnetic object, or a moving electric charge in whichmagnetic force is exerted.



Magnetic field intensity (H):

***Magnetic field strength**, also called* **magnetic field intensity. Magnetic fieldintensity at any point inside the magnetic field is defined as the force experienced by a unit north pole at that point.The direction of field is thedirection in which the unit pole would move if it is free to do so.**

Magnetic lines of force:

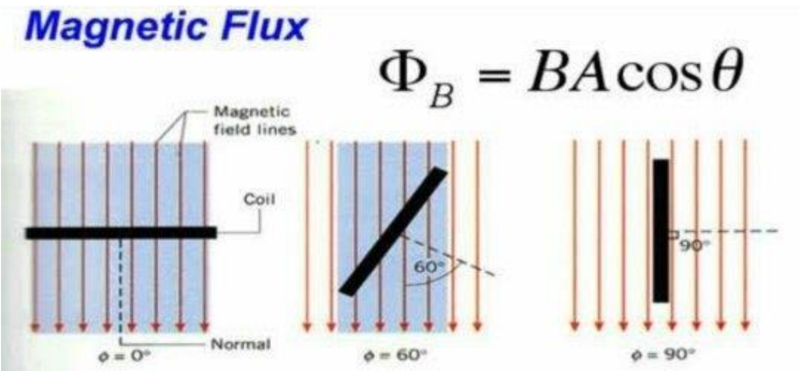
Magnetic lines of force are the imaginary curves along whichthe unit north pole would move if it were free to do so.

Properties of magnetic lines of force:

- Outside the magnet, lines of forces start from north pole and ends at south pole and inside the magnet these are from south to north pole.
- Tangent drawn at any point on the lines of force gives the direction of the magnetic field at that point.
- Magnetic lines of force never intersect with each other because if they do so at the point of intersection there will be two directions of the magnetic field at that point which is impossible.
- The number of lines of force per unit area (area being perpendicular to lines) is proportional to the magnitude of strength of the magnetic field (magnetic field intensity) at that point. Thus, more concentration of lines of force represents stronger magnetic field.
- The lines of force tend to contract longitudinally or length-wise i.e. they possess longitudinal strain. Due to this property two unlike poles attract each other.
- The lines of force tend to exert lateral (sideways) pressure i.e. they repel each other laterally. This explain the repulsion between two similar poles.
- Lines of forces are imaginary, but the field obtained is real.

9.12 Magnetic flux(Φ):

Magnetic flux is defined as the number of magnetic field lines passing through a certain area.



It is denoted by "Φ" and is given as

$$\Phi = \vec{B} \cdot \vec{A} = B\ A\ \text{Cos}\,\theta$$

Where, B = Magnetic

FieldA= SurfaceArea

θ = Angle between the magnetic field and normal to the surface.

Unit: -

Its unit in S.I is Weber and in C.G.S is maxwell

$$1 \text{ Weber} = 10^8 \text{ maxwell}$$

Magnetic Flux Density(B): -

Magnetic flux density is the amount of magnetic flux per unit area of a sectionthat is perpendicular to the direction of flux.

Mathematically, it is represented as

$$B = \frac{\Phi}{A}$$

i.e. $\text{Magnetic flux density} = \frac{\text{Magnetic flux}}{\text{Area}}$

Unit: -

Its unit in S.I is tesla

$$1 \text{ Gauss} = 1 \text{ Maxwell}/(1\text{cm})^2$$

$$1 \text{ Tesla} = 10^4 \text{ Gauss}$$

POSSIBLE SHORT QUESTIONS WITH ANSWER

1. Define unit pole.[W-17,19,S-19]

Ans-

Unit pole is defined as a pole which place in vacuum at a distance of 1 m from an identical pole exert on it a force equal to 10^{-7} N.

2. Define Magnetic flux.[W-18]

Ans-

Magnetic flux is a measurement of the total magnetic field which passes a given area.

It is use ful tool for helping the describe the effect of magnetic force occupying a given area.

3. Define unit charge [W-17,18,19,20]

Ans-

Unit charge is defined as the amount of charge which when placed in air at a distance of 1m from a similar charge repels with a force of 1 N .

POSSIBLE LONG QUESTIONS

1. State and explain coulomb's law in electrostatics[W-19]

2. State and explain coulomb's law in magnetism.[W-20]

3. State the properties of magnetic lines of force.[W-17,19]

UNIT-10

CURRENT ELECTRICITY

LEARNING OBJECTIVE

10.1 *Electric current – Definition, Formula and S.I Unit.*

10.2 *Ohm's law and its application*

10.3 *Series and parallel combination of resistors (No derivation ,Formula for Effective / Combined / Total / Resistance and simple numericals)*

10.4 *Kirchhoff's laws (Statement and Explanation with Diagram)*

10.5 *Application of Kirchhoff's laws to Wheatstone 's bridge – Balanced Condition of Wheatstone's bridge.*

10.1 Electric current:-

The current through a given cross-sectional area in a conductor is defined as thetime rate of flow of charge through that area.

$$\therefore\ I = \frac{Q}{t}$$

- Electric current is a scalar quantity
- S.I unit is c/s or ampere(A)
- Dimension-$[I] = [A] = [M^0L^0T^0A^1]$

Ohm's Law:

It states that at constant temperature current flowing through a conductor is directly proportional to the potential difference between the two ends of the conductor.

Mathematically,

$$I \propto V$$

$\Rightarrow V = IR,$ R = proportionality constant = Resistance

Resistance is a material property which depends on the temperature and geometryof the conductor.

Application of Ohm's Law:

- Ohm's law is used for calculating the current if the resistance and potentialdifference are known.
- The resistance of a material can be estimated by supplying a known amountof voltage and measuring the current flowing through it.
- Ohm's law is used to maintain the desired voltage drop across the electriccomponents.

Limitation: Ohm's law is not applicable in diodes and transistor.

Combination of Resistors

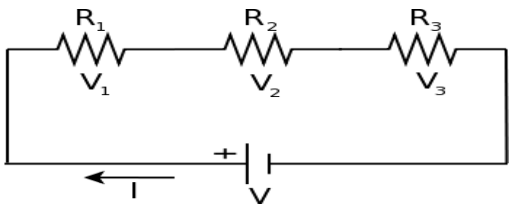
(a) In series-

If +ve terminal of first resistor is connected with –ve terminal of second resistor is called series combination.

Effective resistance

If n number of resistor of resistance is connected in series then effective resistance is given by

$$R_s = R_1 + R_2 + \cdots + R_n$$



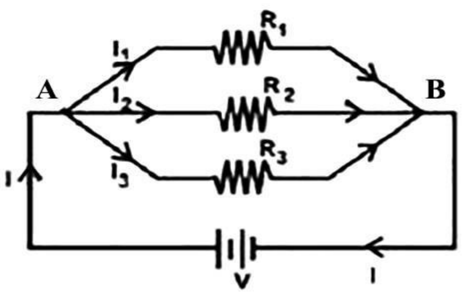
(b)In parallel

If +ve terminal of first resistor is connected with +ve terminal of second resistor is called parallel combination.

Effective resistance

If n number of resistances are connected in parallel combination then effective resistance is given by

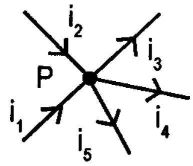
$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots + \frac{1}{R_n}$$



10.4 Kirchhoff's' law

First law (kcl)

It states that the algebraic sum of currents meeting at a point in a junction is zero.Explanation:- To explain this law consider a number of wires connected at apoint P.Currents i_1, i_2, i_3, i_4, and i_5 flow through these wires in the directions as shown infigure 10.4.



To determine their algebraic sum of electric currents, we assume thefollowing sign conventions

The currents approaching a given point are taken positive

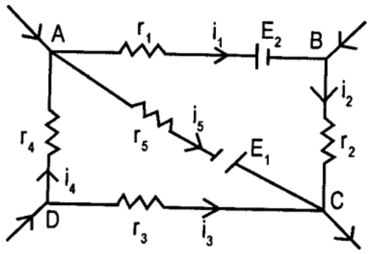
The currents leaving the given point are taken as negative

Second law (Kirchhoff's voltage Law) (KVL)

It states that the algebraic sum of potential difference & emf (electromotive force)across a closed loop is zero.

i.e. $\sum emf + p.d = 0$ where p.d = potential difference

Explanation:



ABCD containing resistance r_1,r_2,r_3,r_4 and r_5 in the parts AB, BC, CD, DA and AC respectively. Also let i_1, i_2, i_3, i_4,i_5 be the respective currents flowing in these parts in the directions shown by arrow heads. Two sources of emf"s E_1, E_2 are also connected in the mesh.

In order to use Kirchhoff's voltage rule, we will assume the following signconventions.

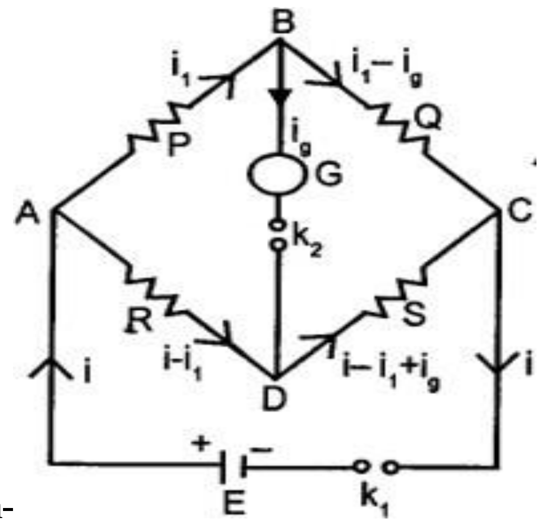
While going along the loop if the current flows in that directionthen ittaken to be +ve otherwise –ve

While going along the loop if we will face first +ve terminal of the emfthen it is taken to be +ve otherwise –ve.

10.5 Wheatstone Bridge

Wheatstone bridge is an electrical arrangement which forms the basis ofmost of the instruments used to determine an unknown resistance.

Construction:- It consists of four resistance P, Q, R & S connected in the four arms of a square ABCD. A cell of emf E is connected between the points A & C throughone way key K_1. A sensitive galvanometer of resistance G is connected between the terminals B & D through another one way key K_2. After closing the keys K_1& K_2,the resistance P, Q, R & S are so adjustable that the galvanometer shows nodeflection. In this position theWheatstone bridge is said to be balanced.



Explanation-

It is an electrical device which is used to measure the

resistance of un known resistor.

It consist of four resistors of resistances (P,Q,R,S). Out of these resistance R is unknown. Across the terminal A and C an ideal cell is connected which supplies the current to the circuit. Across the terminal B and D a galvanometer is connected which is used to detected the current through the arm BD.

When bridge is balanced condition there is no current through the galvanometer that means potential difference between B and D is zero.

Applying kcl at the junction point B

$$I_1P = (I_1 - I_g)Q + I_gG$$

Applying kvl in the mesh ABDA

$I_1P + I_gG = (I - I_1)R$......i

Applying kvl in the mess BCDB

$(I_1 - I_g)Q - (I - I_1 + I_g)S - I_gG = o$.........ii

The values of P, Q and R are so adjusted that the galvanometer shows no deflection i.e., the current through galvanometer is zero.

In this condition B and Dare at same potential which is called as the balanced condition of the bridge.

By putting $i_g = 0$, equations (i) & (ii) becomes

$P/Q = R/S$

Conclusion

- Putting the value of P,S,Q then we can find the unknown resistance R.
- This instrument is named as post office box as it was used in post office to determine the resistance of a wire for telegram purposes.

POSSIBLE SHORT QUESTION WITH ANSWERS

1. State Ohm's law.[W-18,S-19]

Ans-

At constant temperature for a given conductor the amount of current is

Directly proportional to the potential difference between two ends of the conductor.

Mathematically $I \propto V$

$\Rightarrow V = IR,$

POSSIBLE LONG QUESTIONS

1.State and explain Kirchhoff's law of electricity.[W-16,17,19]

2.State Kirchhoff's law and obtained balanced condition of whetstones bridge. [W-18,19,20,S-19]

UNIT- 11

ELECTROMAGNETISM

&

ELECTRO MAGNETIC INDUCTION

LEARNING OBJECTIVE

11.1 *Electromagnetism- Definition & concept*

11.2 *Force acting on a current carrying conductor placed in a uniform Magnetic field, Flemings Left Hand Rule.*

11.3 *Faradays laws of Electromagnetic Induction (statement only)*

11.4 *Lenz's law (statement)*

11.5 *Flemings Right Hand Rule*

11.6 *Comparison between Flemings Left Hand Rule and Flemings Right Hand Rule.*

11.1 ELECTROMAGNETISM:

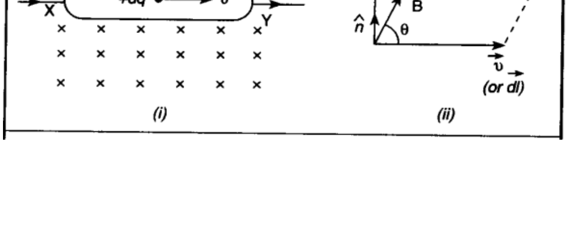
Ampere and a few other scientists established the fact that electricity and magnetism are inter-related. They found that moving electric charges produce magnetic fields. For example, an electric current deflects a magnetic compass needle placed in its vicinity. This naturally raises the question like: Is the converse effect possible? Can a moving magnet produce electric current ? Does the nature permit such a relation between electricity and magnetism ? The answer is a resounding yes ! The experiments of Michael Faraday in England demonstrated conclusively that electric currents were induced in closed coils when subjected to changing magnetic fields.

ELECTROMAGNETIC INDUCTION

A charged body is capable of producing electric charge in a neighbouring conductor. The phenomenon of induction of electricity due to electricity is called electric induction. A magnet is capable of producing magnetism in a neighbouring magnetic substance. This phenomenon of production of magnetism due to magnetism is called magnetic induction. A current flowing through a wire produces a magnetic field around itself. This phenomenon of production of magnetism due to electricity is called magnetic effect of currents. The phenomenon of production of electricity due to magnetism is called electro-magnetic induction.

11.2 Force acting on a current carrying conductor placed in a uniform magnetic field.

A conductor has free electrons in it. When a potential difference is maintained across the two ends of the conductor, the electrons drift from lower potential tohigher potential with a small velocity. These electrons constitute a current throughthe conductor. When the electrons (charged particles) move in a magnetic field, they experience a force $\vec{F}$.



Let, L= length of the conductor

I = Amount of current flowing through the conductor = q/t.

$\vec{B}$ = Magnetic field intensity

Θ = Angle between L and B.

$\vec{F}$= Force acting on current carrying conductor on the given magnetic field.

We know $F = qBv \sin\theta$

$= qB\,(l/t)\sin\theta.$

$F = (q/t)\, l\, B \sin\theta$

$F = I\, l\, B \sin\theta$

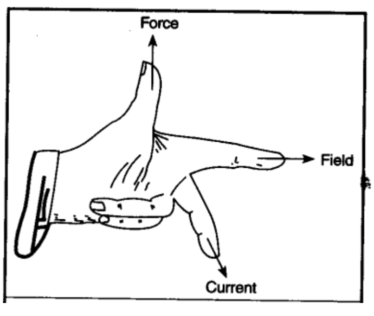
$\vec{F} = I\,(\vec{L} \times \vec{B})$,Vector form

⁕ Direction of $\vec{F}$ is always perpendicular to the plane of $\vec{L}$ *and* $\vec{B}$ obeying Right Hand Rule.

Flemings Left Hand Rule:-

⇒ This principle is used to determine the direction of force acting on the current carrying conductor in the given magnetic field.

⇒ Stretch the forefinger, middle finger and thumb of left hand in which they are kept mutually perpendicular. If the forefinger points the direction of magnetic field, the middle finger is the direction of current then thumb will point the direction of force or motion of the conductor.



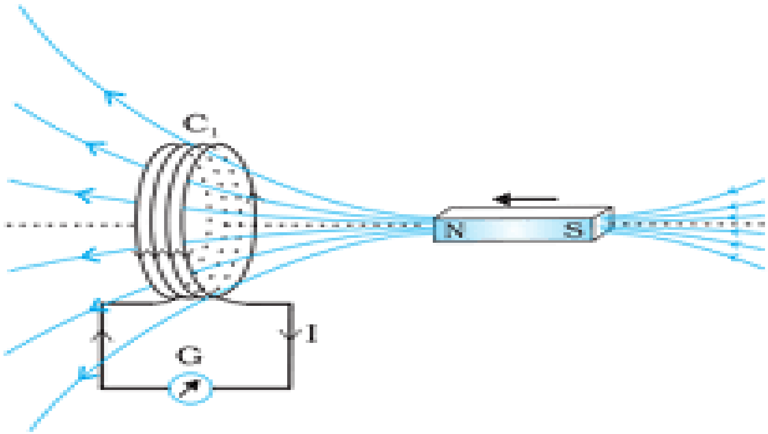
⇒ This rule is widely use in case of electric motor.

11.3 Faradays laws of Electromagnetic Induction:-

Faraday's laws deal with the induction of an electromotive force (e.m.f) in an electriccircuit when magnetic flux linked with the circuit changes. They are stated as follows.

⇒ 1st law (qualitative):-

Whenever magnetic flux linked with a circuit changes, an e.m.f is induced in it.The induced e.m.f exists in the circuit so long as the change in magnetic flux linked with it continues.



⇒ 2nd law (quantitative):-

The induced e.m.f. is directly proportional to the negative rate of change ofmagnetic flux linked with the circuit.

If „$d\phi$" is the change in magnetic flux linked with a circuit, that takes place in a timedt.

Rate of change of magnetic flux = $\frac{d\Phi}{dt}$

If „E" is e.m.f induced in the circuit as a result of this change,

$$E \ \alpha \ \frac{d\Phi}{dt} \qquad \text{or} \qquad E = -k\frac{d\Phi}{dt}$$

By selecting the units of „E", „ϕ " and „t" in a proper way, we can have

$$K = 1 \qquad \therefore\ E = -\frac{d\Phi}{dt}$$

If N = no. of turns in the coil then, $E = -N\frac{d\Phi}{dt}$

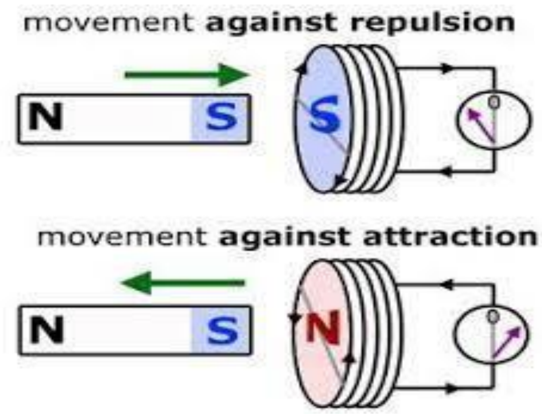
⁕ Negative sign is due to direction of induced e.m.f, opposes the change inmagnetic flux.

11.4 LENZ‟S LAW

The direction of e.m.f induced in the circuit due to a change in magnetic flux linked with it.

" It states that direction of induced e.m.f or induced current is such that it tends to oppose the verycause which produces it."

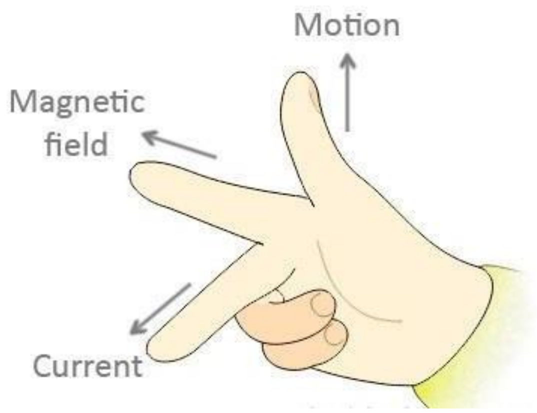
$$\therefore \quad E = -\frac{d\Phi}{dt}$$



11.5 FLEMING‟S RIGHT HAND RULE

⇒ This rule is used to determine the direction of induced current.

⇒ "Stretch the forefinger, middle finger and thumb of Right hand in which they are kept mutually perpendicular to each other. If the forefinger represents the direction of magnetic field thumb represents motion of the conductor then middle finger represents the direction of induced current".



⇒ This principle is widely used in case of electric generator.

11.6Comparison between Flemings Left Hand Rule and Flemings Right Hand Rule

Flemings Left Hand Rule	Flemings Right Hand Rule
⇒ This principle is used to determine the direction of force acting on the current carrying conductor in the given magnetic field.	⇒ This principle is used to determine the direction of induced current.
⇒ Stretch the forefinger, middle finger and thumb of left hand in which they are kept mutually perpendicular. If the forefinger points the direction of magnetic field, the middle finger is the direction of current then thumb will point the direction of force or motion of the conductor.	⇒ Stretch the forefinger, middle finger and thumb of right hand in which they are kept mutually perpendicular to each other. If forefinger represents the direction of magnetic field and thumb represents direction of motion of the conductor then middle finger represents direction of induced current.
⇒ This rule is widely used in electric motor.	⇒ This rule is widely used in electric generator.

Possible Short Questions

Q-1. State Lenz's law. [16, 17, 18 - W, 19 – S & W]

Ans. "The direction of induced emf or induced current is such that it tends to oppose the Very cause which produces it".

$$\therefore \quad E = -\frac{d\Phi}{dt}$$

Q-2. State Fleming's Right Hand Rule. [19-W (old)]

Ans. "Stretch the forefinger, middle finger and thumb of Right hand in which they are kept mutually perpendicular to each other. If the forefinger represents the direction of magnetic field thumb represents motion of the conductor then middle finger represents the direction of induced current".

Q-3. State Fleming's Left Hand Rule. [19 – W (New)]

Ans. Stretch the forefinger, middle finger and thumb of left hand in which they are kept mutually perpendicular. If the forefinger points the direction of magnetic field, the middle finger is the direction of current then thumb will point the direction of force or motion of the conductor".

Q-4. State Faradays qualitative law of electromagnetic induction.

Whenever magnetic flux linked with a circuit changes, an emf is induced in it.The induced emf exists in the circuit so long as the change in magnetic flux linked with it continues.

Q-5. State faradays quantitative law of electro magnetic induction.

The induced emf is directly proportional to the negative rate of change ofmagnetic flux linked with the circuit.

Possible long Question

Q-1. State and Explain Faradays laws of Electromagnetic Induction.[17,18,19-W]

Q-2. Comparison between Flemings Left Hand Rule and Right Hand Rule.

[16, 17, 18, 19-W and 19,20-S]

Q-3. Find an expression for force acting on a current carrying conductor placed In a uniform magnetic field. [18-W, 18 , 19 – S]

UNIT-12

MODERN PHYSICS

LEARNING OBJECTIVE

12.1 *LASER & Laser beam (concept and Definition).*

12.2 *Principle of LASER (population inversion & Optical pumping).*

12.3 *Properties and Application of LASER.*

12.4 *Wireless Transmission – Ground wave, sky wave, space waves*

(Concept and Definition).

12.1 LASER & Laser beam:-

⇒ The term LASER is an acronym for Light Amplification by Stimulated Emission of Radiation.

⇒ LASER is an optical device which produces light through a process of optical amplification based on the principle of stimulated emission of electromagnetic radiation.

12.2 Principle of LASER:-

population inversion:-

The two photons interact with two more atoms in the metastable state E 2 and soon, as a result the number of photons keeps on increasing. All the photons have same phase, same energy and same direction, thus amplification of light will beachieved.However,higher energy metastable state „E 2 ‟ must have larger numbers of atoms than the number in the lower energy state „E 1 ‟ for all the time to achieve the amplification and to obtain a stablelasing action. When the higher energy state has more number atoms than the lower energy state, this condition is called as population.

(i) Or

⇒ The redistribution of atomic energy levels that takes place in a system so that laser action occurs is called population inversion.

⇒ Population inversion occurs when more electrons are in a higher energy state than in a lower energy state.

(b). Optical pumping :-

⇒ The use of light energy to raise the atoms of a system from one energy level to another.

⇒ The process in which light is used to raise electrons from a lower energy level in an atom or molecule to a higher energy level is called optical pumping.

⇒ Optical pumping is also used to cyclically pump electrons bound within an atom or molecule to a well-defined quantum state.

Properties and Application of LASER:-

Properties of Laser Beam:

(i) **Directionality:** Light emitted from conventional sources spread in all directions. Laser beam is highly parallel and directional. A narrow beam of light can be obtained from it.

(ii) **Intensity:** As the laser beam has the ability of focusing over an area as small as 10^{-6} cm^2, therefore, it is highly intense beam. Also, the constructive interference between the coherent photons lead to a high amplitude and hence a high intensity.

(iii) **Mono-chromaticity:** Light emitted from a laser is vastly more monochromatic than that emitted from a conventional mono-chromatic sources of light.

(iv) **Coherence:** The laser light is highly coherent in space and time. This property enables us to realize a tremendous spatial concentration of light power.

PRINCIPLE BASED APPLICATIONS OF LASERS

(i) **Laser in surgery:** Laser beam can be carried from source using optical fibers from one place to another and can be focused over an extremely small area. The beam travels through optical fibers suffering total internal reflections. As the beam is very powerful, it can cut the flesh and seal the blood oozing cells instantly allowing the surgery to be carried out without wasting blood. In laser surgery the cut is so fine that the patient does not feel the pain. Laser is used in eye surgery to attach a detached retina.

(ii) **Laser in industry:** As laser beam is very high power beam, it is employed in melting, cutting, drilling and welding metals. A powerful laser beam can cut a few cm thick iron sheet like a hot knife cutting butter.

(III) **Laser in other branches of science:** One of the most important branch in chemistry is the study of the nature of chemicals bonds. A suitable laser can be employed to break the bond in a molecule by resonating it with the bond,helps to determine the structure of the molecule.

In astronomy radio-astronomers are frequently using it to determine the distances of planets and sub-planets.

(IV) **Laser in warfare:**Laser beams are capable of destroying enemy war planes. America is employing laser beam in their star war programme in which they will operate from artificial satellites to destroy enemy‟s inter-continental missiles etc. A laser gun can kill human-beings without any shot sound.

12.4: WIRELESS TRANSMISSION

In electronic communication, radio waves propagate between a transmitter and a receiver. The signal must reach the receiver without any distortion or noise. Depending on the frequency of the signal and the distance over which it is to be transmitted, different methods are used. A wide range of research is going on to shape and improve the quality and speed of transmission. Also, the electronic components are being improved. Here, we will discuss the basic methods in a brief manner.

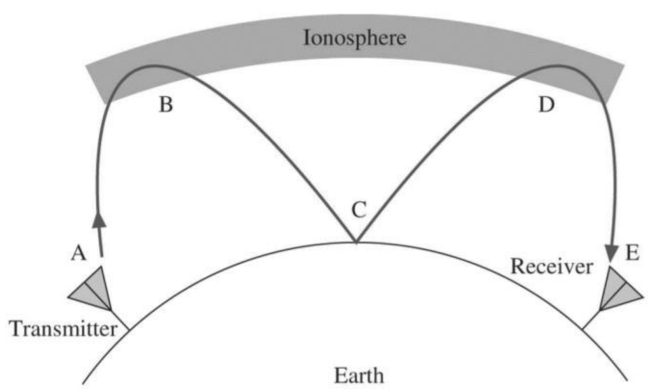
a. Ground Waves:

- A ground wave is a radio wave that travels along earth‟s surface. This is also known as surface wave.
- The nature of surface influences the propagation. The ground wave travels better over a conducting surface for example, saline water.
- For an optimum propagation with surface wave, vertical polarization is used . That is why self- radiating, vertical transmitters are used as antennas in long and medium wave radio stations in amplitude modulated broadcast.

- The maximum range of coverage depends on the transmitted power and frequency (few megahertz).
- The attenuation of ground waves increases rapidly with increase in frequency.
- Ground waves have the tendency to bend around the corners of the surface of earth or obstructions during propagation which makes them more efficient and also these are not affected by the changein atmospheric conditions.
- In submarine, propagation of very low frequency (30 Hz to 300 Hz) is needed. Hence, ground waveis the only efficient method.
- As discussed above, the disadvantage of ground wave is high-frequency waves cannot be transmitted as the energy losses are more because of the absorption of energy in the earth‟s atmosphere.
- The transmission of ground wave is effective for few MHz and is not suitable above 30 MHz

b. Sky Waves:

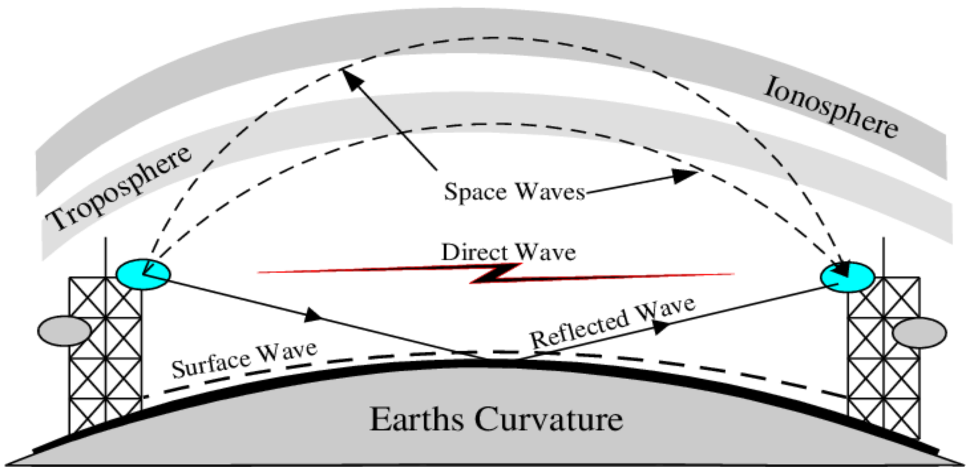
- For the frequency range of few MHz to 30 MHz, radio wave is reflected back to earth from the ionosphere of atmosphere and is utilized for long range communication. This mode of propagationis known as sky wave propagation.
- The ionosphere extends from a height of about 70 km to 400 km above the earth‟s surface. It contains a large number of charged particles which result from the absorption of sun‟s radiation by the air molecule.
- The high frequency above 30 MHz can penetrate ionosphere due to high energy.
- However, as in the case of total internal reflection, the ionospheric layer can reflect the wave with frequency about 3 MHz to 30 MHz towards the Earth‟s surface.
- The sky wave from the transmitter is directed towards the ionosphere. It bounces between the ionosphere and earth to reach the receiver.



- For sky wave propagation, gaseous medium is required. Hence, communication with sky wave isnot possible in space where atmosphere is not present.

c. Space Wave:

- High frequency electromagnetic waves (>40 MHz) cannot be propagated as ground wave as they get attenuated and also cannot be propagated as sky wave as they penetrate the ionosphere and escape.
- Such high frequency waves are propagated as space wave. In space wave propagation, the wave emitted from the transmitter travels in a straight line towards the receiver antenna.
- Space wave method is used for satellite communication, line of sight (LOS) communication, microwave linking and radar communication.
- TV signals having frequency above 50 MHz can propagate only via space wave.



POSSIBLE SHORT QUESTION WITH ANSWERS

1. Write down the properties of LASER. [W-18, S-19]

Ans- The properties of LASER are

- LASER beam is highly parallel and directional.
- It is highly intense beam.
- It is highly monochromatic.
- It is highly coherent in space and time
-

2. State the principle of LASER [2018-w new]

Ans-

- To explain the process of light amplification in a laser requires an understanding of energy transition phenomenon in the atoms its active medium.
- They include spontaneous emission, stimulated emission and non-radiative decay.

3. Write down the important application of LASER.[2019-S]

Ans-

- For industry-
  For drilling, For cutting, For welding.

- For medical Science-
  For operation, For cancer treatment, For chemo therapy.

4. What does LASER stands for? [w-20]

Ans- LASER stand for
Light amplification by stimulated emission of radiation.

POSSIBLE LONG QUESTIONS

1. Describe the properties and application of LASER. [W-16,18,19,S-19]
2. State the laws of photo electric emission.[W-17,19,S-19]