LEARNING MATERIAL

OF

APPLIED PHYSICS - 1

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& HUMANITIES

C.V RAMAN POLYTECHNIC

BHUBANESWAR

Solution of first order and first degree differential equation by variable separation method (simple problems). MATLAB – Simple Introduction.

References:

1. B.S. Grewal, Higher Engineering Mathematics, Khanna Publishers, New Delhi, 40th Edition, 2007.
2. G. B. Thomas, R. L. Finney, Calculus and Analytic Geometry, Addison Wesley, 9th Edition, 1995.
3. S.S. Sabharwal, Sunita Jain, Eagle Parkashan, Applied Mathematics, Vol. I & II, Jalandhar.
4. Comprehensive Mathematics, Vol. I & II by Laxmi Publications, Delhi.
5. Reena Garg & Chandrika Prasad, Advanced Engineering Mathematics, Khanna Publishing House, New Delhi

Course Outcomes:

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

(i) the students are expected to acquire necessary background in Determinants and Matrices so as to appreciate the importance of the Determinants are the factors that scale different parameterizations so that they all produce same overall integrals, i.e. they are capable of encoding the inherent geometry of the original shape.

(ii) the cumulative effect of the original quantity or equation is the Integration

(iii) the coordinate geometry provides a connection between algebra and geometry through graphs of lines and curves.

(iv) Tell the difference between a resultant and a concurrent force to model simple physical problems in the form of a differential equation, analyze and interpret the solutions.

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Course Code	:	BS104
Course Title	:	Applied Physics -II
Number of Credits	:	3 (L: 2, T: 1, P: 0)
Prerequisites	:	High School Level Physics
Course Category	:	BS

Course Objectives

Applied Physics aims to give an understanding of this world both by observation and by prediction of the way in which objects behave. Concrete use of physical principles and analysis in various fields of engineering and technology are given prominence in the course content. The course will help the diploma engineers to apply the basic concepts and principles to solve broad-based engineering problems and to understand different technology based applications.

Teaching Approach

Teachers should give examples from daily routine as well as, engineering/technology applications on various concepts and principles in each topic so that students are able to understand and grasp these concepts and principles. In all contents, SI units should be followed.

Use of demonstration can make the subject interesting and develop scientific temper in the students. Student activities should be planned on all the topics.

Activity- Theory - Demonstrate/practice approach may be followed throughout the course so that learning may be outcome and employability based.

Course Content

UNIT - 1: Wave motion and its applications

Wave motion, transverse and longitudinal waves with examples, definitions of wave velocity, frequency and wave length and their relationship, Sound and light waves and their properties, wave equation ($y = r \sin\omega t$) amplitude, phase, phase difference, principle of superposition of waves and beat formation.

Simple Harmonic Motion (SHM): definition, expression for displacement, velocity, acceleration, time period, frequency etc. Simple harmonic progressive wave and energy transfer, study of vibration of cantilever and determination of its time period, Free, forced and resonant vibrations with examples.

Acoustics of buildings – reverberation, reverberation time, echo, noise, coefficient of absorption of sound, methods to control reverberation time and their applications, Ultrasonic waves – Introduction and properties, engineering and medical applications of ultrasonic.

UNIT - 2: Optics

Basic optical laws; reflection and refraction, refractive index, Images and image formation by mirrors, lens and thin lenses, lens formula, power of lens, magnification and defects. Total internal reflection, Critical angle and conditions for total internal reflection, applications of total internal reflection in optical fiber.

Optical Instruments; simple and compound microscope, astronomical telescope in normal adjustment, magnifying power, resolving power, uses of microscope and telescope, optical projection systems.

UNIT - 3: Electrostatics

Coulombs law, unit of charge, Electric field, Electric lines of force and their properties, Electric flux, Electric potential and potential difference, Gauss law: Application of Gauss law to find electric field intensity of straight charged conductor, plane charged sheet and charged sphere.

Capacitor and its working, Types of capacitors, Capacitance and its units. Capacitance of a parallel plate capacitor, Series and parallel combination of capacitors (related numerical), dielectric and its effect on capacitance, dielectric break down.

UNIT - 4: Current Electricity

Electric Current and its units, Direct and alternating current, Resistance and its units, Specific resistance, Conductance, Specific conductance, Series and parallel combination of resistances. Factors affecting resistance of a wire, carbon resistances and colour coding.

Ohm's law and its verification, Kirchhoff's laws, Wheatstone bridge and its applications (slide wire bridge only), Concept of terminal potential difference and Electro motive force (EMF)

Heating effect of current, Electric power, Electric energy and its units (related numerical problems), Advantages of Electric Energy over other forms of energy.

UNIT - 5: Electromagnetism

Types of magnetic materials; dia, para and ferromagnetic with their properties, Magnetic field and its units, magnetic intensity, magnetic lines of force, magnetic flux and units, magnetization.

Concept of electromagnetic induction, Faraday's Laws, Lorentz force (force on moving charge in magnetic field). Force on current carrying conductor, force on rectangular coil placed in magnetic field.

Moving coil galvanometer; principle, construction and working, Conversion of a galvanometer into ammeter and voltmeter.

UNIT - 6: Semiconductor Physics

Energy bands in solids, Types of materials (insulator, semi-conductor, conductor), intrinsic and extrinsic semiconductors, p-n junction, junction diode and V-I characteristics, types of junction diodes. Diode as rectifier – half wave and full wave rectifier (centre taped).

Transistor; description and three terminals, Types- pnp and npn, some electronic applications (list only).

Photocells, Solar cells; working principle and engineering applications.

UNIT - 7: Modern Physics

Lasers: Energy levels, ionization and excitation potentials; spontaneous and stimulated emission; population inversion, pumping methods, optical feedback, Types of lasers; Ruby, He-Ne and semiconductor, laser characteristics, engineering and medical applications of lasers.

Fiber Optics: Introduction to optical fibers, light propagation, acceptance angle and numerical aperture, fiber types, applications in; telecommunication, medical and sensors.

Nanoscience and Nanotechnology: Introduction, nanoparticles and nanomaterials, properties at nanoscale, nanotechnology, nanotechnology based devices and applications.

Learning Outcome:

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

a) Describe waves and wave motion, periodic and simple harmonic motions and solve simple problems. Establish wave parameters: frequency, amplitude, wavelength, and velocity and able to explain diffraction, interference, polarization of waves.

b) Explain ultrasonic waves and engineering, medical and industrial applications of Ultrasonics. Apply acoustics principles to various types of buildings for best sound effect.

c) State basic optical laws, establish the location of the images formed by mirrors and thin converging lens, design and assemble microscope using lenses combination.

d) Describe refractive index of a liquid or a solid and will be able to explain conditions for total internal reflection.

e) Define capacitance and its unit, explain the function of capacitors in simple circuits, and solve simple problems.

f) Differentiate between insulators, conductors and semiconductors, and define the terms: potential, potential difference, electromotive force.

g) Express electric current as flow of charge, concept of resistance, measure of the parameters: electric current, potential difference, resistance.

h) List the effects of an electric current and its common applications, State Ohm's law, calculate the equivalent resistance of a variety of resistor combinations, distinguish between AC and DC currents, determine the energy consumed by an appliance,

i) State the laws of electromagnetic induction, describe the effect on a current-carrying conductor when placed in a magnetic field.

j) Explain the operation of appliances like moving coil galvanometer, simple DC motors.

k) Apply the knowledge of diodes in rectifiers, power adapters and various electronic circuits. Use the knowledge of semiconductors in various technical gadgets like mobile phones, computers, LED, photocells, solar lights etc.

l) Illustrate the conditions for light amplification in various LASER and laser based instruments and optical devices.

m) Appreciate the potential of optical fiber in fields of medicine and communication.

n) Express importance of nanoscience and nanotechnology and impact of nanotechnology to the society.

References:

1. Text Book of Physics for Class XI& XII (Part-I, Part-II); N.C.E.R.T., Delhi
2. Applied Physics, Vol. I and Vol. II, TTTI Publications, Tata McGraw Hill, Delhi
3. Concepts in Physics by HC Verma, Vol. I & II, Bharti Bhawan Ltd. New Delhi
4. Engineering Physics by PV Naik, Pearson Education Pvt. Ltd, New Delhi.
5. Modern approach to Applied Physics-I and II, AS Vasudeva, Modern Publishers.
6. A Textbook of Optics, N Subramanyam, Brij Lal, MN Avahanulu, S Chand and Company Ltd.
7. Introduction to Fiber Optics, Ajoy Ghatak and K Thyagarajan, Cambridge University Press India Pvt. Ltd, New Delhi.
8. Nanoscience and Nanotechnology, KK Choudhary, Narosa Publishing House, Pvt. Ltd. New Delhi.
9. Nanotechnology: Importance and Applications, M.H. Fulekar, IK International Publishing House Pvt. Ltd, New Delhi.
10. e-books/e-tools/ learning physics software/websites etc.

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Course Code	:	ES 102
Course Title	:	Introduction to IT Systems
Number of Credits	:	2 (L: 2, T: 0, P: 0)
Prerequisites (Course code)	:	NIL
Course Category	:	ES

Course Objectives::

This course is intended to make new students comfortable with computing environment - Learning basic computer skills, Learning basic application software tools, Understanding Computer Hardware, Cyber security awareness

Course Content:

UNIT 1:

Basic Internet skills: Understanding browser, efficient use of search engines, awareness about Digital India portals (state and national portals) and college portals.

General understanding of various computer hardware components – CPU, Memory, Display, Keyboard, Mouse, HDD and other Peripheral Devices.

UNIT 2:

OS Installation (Linux and MS Windows), Unix Shell and Commands, vi editor.

UNIT 3:

UNIT-1

WAVE MOTION AND ITS APPLICATIONS

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

- *Understand concept of waves and wave motion, define parameters representing a wave motion and their relationship, define simple harmonic motion with examples, understand vibrations and types of vibrations.*
- *Describe concept of acoustics, associated parameters and methods to control acoustics of buildings.*
- *Identify ultrasonic waves and enlist their engineering applications.*

7.1 WAVE MOTION

Motion of an object is the change in its position with time. In different types of motions, some form of energy is transported from one place to another. There are two ways of transportation of energy from its place of origin to the place where it is to be utilized. One is the actual transport of matter. For example when a bullet is fired from a gun it carries kinetic energy which can be utilized at another place. The second method by which energy can be transported is the wave process.

A wave is the disturbance in which energy is transferred from one point to other due to repeated periodic motion of particles of the medium. The waves carry energy but there is no transport of matter.

There are two types of waves;

1. Mechanical or Elastic waves
2. Electromagnetic waves

Mechanical waves

Those waves which are produced due to repeated periodic motion of medium particles are called mechanical or elastic waves. They need a material medium for their generation and propagation.

For example sound waves, water waves are mechanical in nature.

Electromagnetic waves

The wave which travels in form of varying electric and magnetic fields mutually perpendicular to each other and also perpendicular to direction of propagation of wave. They do not need material medium for their propagation.

For example, light waves, heat radiations, radio waves, X-rays are electromagnetic waves.

The characteristics of wave motion are:

1. The wave travels forward but the particles vibrate only about their mean position.
2. The velocity of wave is the rate at which the disturbance travels through the medium.
3. The velocity of the wave depends on the type of wave (light, sound) and type of medium (solid, liquid or gas).
4. The velocity of waves is different from the velocity of particles.
5. There is regular phase difference between particles of wave.

Types of Wave Motion: There are two types of wave motion;

a) Transverse wave motion
b) Longitudinal wave motion

a) **Transverse wave motion**

When the particles of the medium vibrate *perpendicular to the direction of propagation* of wave the wave motion is called transverse wave motion. A transverse wave motion is shown in Fig. 7.1. A transverse wave consists of one crest and one trough that makes one cycle. The distance between two consecutive crests or two consecutive troughs is called wave length.

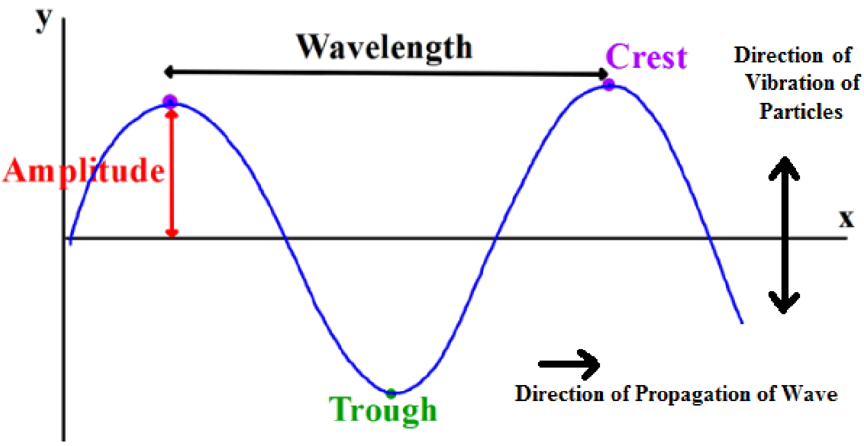


Fig. 7.1

Examples are wave produced by a stretched string, light waves, waves produced on surface of water etc.

b) **Longitudinal Waves**

When the particles of medium vibrate parallel to the direction of propagation of wave the wave motion is called longitudinal wave motion. A longitudinal wave travels in the form of compressions and rarefactions as shown in the Fig. 7.2. The part of medium where distance between medium particles is less than their normal distance is called compression and the portion where distance is more than their normal distance is called rarefaction. One cycle consist of one complete compression and one complete rarefaction. The distance between two consecutive compressions and rarefaction is called wave length.

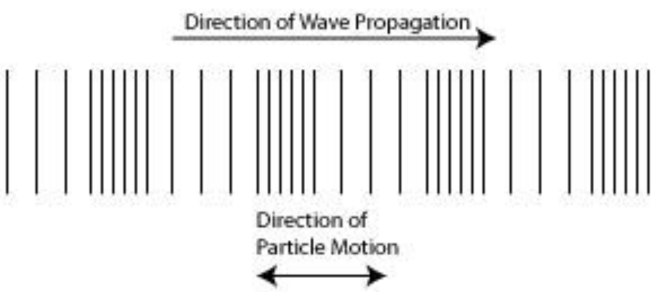


Fig. 7.2

Most familiar example of longitudinal waves is sound waves. Sound waves can travel in different medium such as solids, liquids and gases.

The main points of difference between transverse and longitudinal waves are listed below:

S. No.	Transverse Waves	Longitudinal Waves
1.	The particles of the medium vibrate perpendicular to the direction of propagation of wave	The particles of medium vibrate parallel to the direction of propagation of wave
2.	The wave travels in form of crests and troughs	The wave travels in form of compressions and rarefactions.
3.	There is no change in density of the medium.	These waves produce change in density of the medium.
4.	These waves can be polarised.	These waves cannot be polarised.
5.	Velocity of wave decreases with density of medium	Velocity of wave increases with density of medium
6.	Electromagnetic waves, wave travelling on stretched string, light waves are the examples.	Sound waves, pressure waves, musical waves are its examples.

Terms Characterizing Wave Motion:
Various parameters used to characterize a wave motion are defined below.

Displacement*: The distance of a particle from its mean position, at any instant is called displacement.*

Amplitude*: It is the maximum displacement of the particle from its mean position of rest.*

Wavelength*: It is the distance travelled by the wave in the time in which the particle of the medium completes one vibration.*
Or the distance between two consecutive crests or troughs is called as wavelength.
It is denoted by λ and measured in metres. The distance AB or DE in figure 7.3 is equal to one wave length.

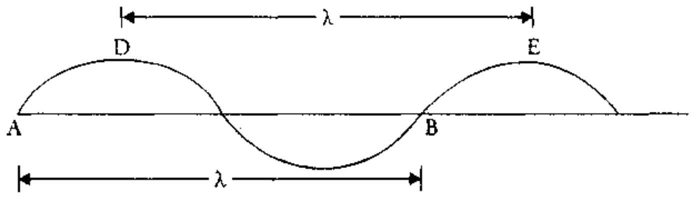


Fig. 7.3

Time period*: It is defined as the time taken by a wave to complete one vibration or one cycle. It is denoted by* T *and SI unit is second.*

Frequency*: The number of vibrations made by a wave in one second is called frequency. It can also be written as reciprocal of time period* ($\nu = 1/T$).
It is represented by n or ν (nu) and units are hertz (Hz), kilohertz (kHz), Megahertz (MHz) ... etc.

Wave Velocity: *The distance travelled by the wave per unit time is defined as wave velocity.* It is denoted as (v) and measured in m/s.
Or it may be defined as the velocity by which a wave propagates is called as wave velocity.

Phase: *Phase of a vibrating particle tells the position of a particle at that instant*. It is measured by the fraction of angle or time elapsed by wave at any instant since the particle has crossed its mean position in positive direction. It is denoted by θ and unit is radian.

Phase difference: *The difference in angle or time elapsed between two particles at any instant*. It is calculated by the formula

$$\text{Phase difference } (\phi) = \frac{2\pi}{\lambda} \times \text{path difference}$$

Relation between Wave velocity, Wavelength and Frequency

Wave velocity is the distance travelled by a wave in one time period.

$$v = \frac{distanse}{time} = \frac{\lambda}{T}$$

and frequency is reciprocal of time period i.e.

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

Thus $v = \nu\lambda$

The relation holds for both transverse and longitudinal waves.

Numerical 1: A radio station broadcasts at a frequency of 15 MHz. The velocity of transmitted waves is 3×10^8 m/s. What is the wavelength of transmitted waves?

Solution: Given, frequency (ν) = 15 MHz = 15×10^6 Hz,

Velocity of waves (v) = 3×10^8 m/s

Using relation; $v = \nu\lambda$

we get wavelength $(\lambda) = \frac{v}{\nu} = \frac{3\times10^8}{15\times10^6} = 20$ m

Numerical 2: A tuning fork of frequency 512 Hz makes 24 vibrations in air. If velocity of sound in air is 340 m/s, how far does sound travel in air?

Solution: Here, frequency (ν) = 512 Hz and velocity = 340 m/s

Using the relation $v = \nu\lambda$, we get

Wavelength $(\lambda) = \frac{V}{\nu} = \frac{340}{512} = 0.664$ m

Therefore, distance in 24 vibrations = $24 \times\lambda = 24 \times 0.664$ m = 15.94 m

7.2 FREE, FORCED AND RESONANT VIBRATIONS

Vibrations

A motion in which the object moves to and fro about a fixed mean position is called oscillatory motion (vibration). All oscillatory motion needs to be periodic. The motion in which the object repeats its path after a fixed or regular interval of time is called periodic motion. For example, motion of hands of clock, motion of spring mass system, simple pendulum, cantilever, rim of cycle wheel etc.

Types of Vibrations: There are three types of vibrations: free, forced and resonant.

1) **Free Vibrations:** A force can set a resting object into motion. But when the force is a short-lived or momentary, it only begins the motion. The object moves back and forth, repeating the motion over and again.

   When a body is set into vibrations and is allowed to vibrate freely under the influence of its own elastic forces, such vibrations are called free vibrations.

   The frequency of free vibration is called natural frequency. Examples are vibrations of simple pendulum, cantilever, loaded beam etc.

Free vibrations can also be divided in two classes; damped and undamped vibrations.

a) **Damped Vibrations**:

   In case of free vibrations, the extent of displacement from the equilibrium position reduces with time. This is because the force that started the motion is a momentary force and the vibrations ultimately cease. The object is said to experience damping. Thus *when the amplitude of vibrations goes on decreasing with time and finally the vibrations stop after some time then such vibrations are called damped vibrations* as shown in Fig.7.4. For example vibrations of cantilever, loaded beam, spring mass system etc. Damping is the tendency of a vibrating object to lose or to dissipate its energy over time.

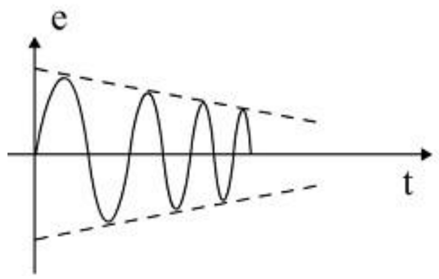


Fig. 7.4. Damped vibrations

b) **Undamped Vibrations**:

   If the amplitude of vibrations remains constant and the vibrations continue for infinite time then such vibrations are called undamped vibrations as shown in Fig. 7.5. For example vibrations of simple pendulum in vacuum.

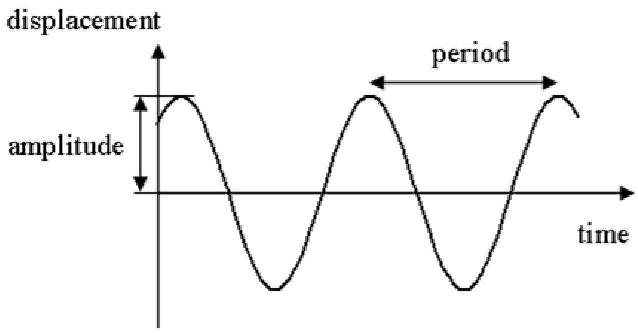


Fig. 7.5. Undamped vibrations

2) **Forced Vibrations**: A vibrating object naturally loses energy with time. It must continuously be put back into the vibrations through a force in order to sustain the vibration. A sustained input of energy would be required to keep the back and forth motion going. Thus *when a periodic force is used to maintain the vibrations of an object then such vibrations are called forced vibrations*. For example swing of a child.

3) **Resonant Vibrations**: *It is a special type of forced vibration in which the frequency of applied force matches with natural frequency of an object.* In this situation resonance occurs and the amplitude of vibrations increases largely. For example tuning of radio set, swing of a child.
   (a) Tuning of a radio set: There are many stations sending radio waves of various frequencies causing forced oscillations in the circuit of receiver. When the frequency of tuner equals that of waves from particular broadcasting station, the resonance takes place and hence we can hear only that station, whose amplitude is increased.
   (b) During earthquake certain building whose natural frequency are same as the frequency of earthquake collapse due to resonant vibration.

Resonance occurs widely in nature. Some sounds we hear, like when hard objects of metal, glass, or wood are struck, are caused by brief resonant vibrations in the object. Electromagnetic waves are produced by resonance on an atomic scale. Other examples are the balance wheel in a mechanical watch, tidal resonance, acoustic resonances of musical instruments, production of coherent light by optical resonance in a laser etc.

7.3 SIMPLE HARMONIC MOTION (SHM)

It is a special type of motion in which the restoring force is directly proportional to displacement from the mean position and opposes its increase. Applying Newton's second law of motion (force = mass × acceleration), it can be stated as *a periodic motion in which the acceleration is directly proportional to displacement and is always directed towards mean position*.

In other words, if F is the restoring force and 'y' is the displacement from the mean position, then

$$F = -K\,y \qquad \text{or} \qquad a = -\frac{K}{m}\,y$$

The negative sign indicates that F opposes increase in y and K is constant of proportionality, called force constant. In such motion displacement varies harmonically with time and can be represented in terms of harmonic functions i.e. $\sin\theta$, $\cos\theta$ such as

$$y(t) = A \sin \omega t \text{ or } A \cos \omega t \qquad (\theta = \omega t)$$

Here A is the amplitude of SHM and ω is angular frequency.

Examples of SHM are; motion of simple pendulum, cantilever, mass-spring system, swing etc.

Characteristics of SHM:

- The motion should be periodic.
- Force causing the motion is directed toward the equilibrium point (minus sign).
- Acceleration produced is directly proportional to the displacement from equilibrium.

7.4 CANTILEVER

A metallic beam fixed at one end and free to vibrate at other end is called cantilever. The normal configuration of a cantilever is shown in Fig. 7.6.

When it is loaded at free end it vibrates and its edge performs simple harmonic motion. The time taken to complete one vibration is called time period.

The time period is given by

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

Where p is the depression of beam (displacement of beam from its unloaded position) and g is acceleration due to gravity.

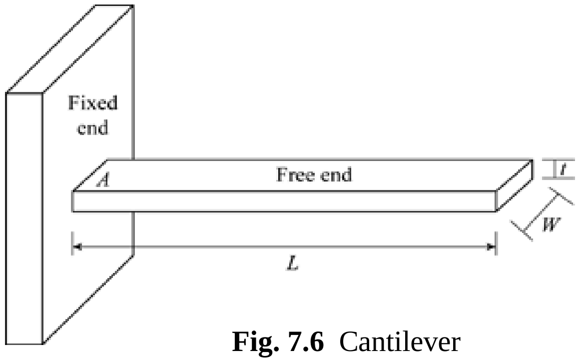


Fig. 7.6 Cantilever

7.5 SOUND WAVES

These are mechanical waves and need medium for their propagation. Sound waves also called pressure waves can be transmitted through solid, liquid or gas. There are three frequency ranges in which sound is categorised:

a) **Audible:** The sound waves between frequencies 20 Hz to 20 kHz is called audible range and audible to human. It is also called sonic sound.
b) **Infrasonic:** Sound waves below frequency 20Hz are called infrasonic and are inaudible to human ears. A number of animals produce and use sounds in the infrasonic range. For example elephant, whales, rhinos etc.
c) **Ultrasonic:** The sound waves with frequency above 20 kHz are called ultrasonic. Bats communicate through ultrasonic waves. These waves also inaudible to human ears.

Properties of sound waves are:-

1. Sound waves are longitudinal mechanical waves.
2. They need material medium for their generation and propagation.
3. They cannot traverse through vacuum so their velocity in vacuum is zero.
4. Their velocity in air at NTP is 332 m/s and it increases with rise in temperature.
5. Sound waves travel faster in solids than in liquids than in gasses.
6. They show the phenomena of reflection, transmission, diffraction etc.

7.6 ACOUSTICS OF BUILDINGS

The branch of physics that deals with study of audible sound including their generation, propagation and properties is called acoustics.

Acoustics of buildings: It deals with construction of public halls, auditoriums, cinema halls etc. for best sound effects.

Generation of Audible Sound: Any object that can produce longitudinal mechanical waves of frequency between 20 Hz to 20 kHz generates audible sound. For example, musical instruments, vibrating fork, human throat (vocal chord) etc.

Propagation of Audible Sound: Audible sound propagates in material medium only. Its velocity is lowest in air and increases with increase in density of the medium. It travels fastest in metals. While travelling in one medium if it meets another medium it gets divided into three parts; reflected part, absorbed part and transmitted part.

Coefficient of Absorption of Sound:

The ratio of sound energy absorbed by a surface to the total sound incident on a surface is called coefficient of absorption or simply absorption coefficient of sound. It is denoted by 'a' and its SI unit is OWU (open window unit). Its value is maximum (=1) for an open window.

$$a = \frac{\text{absorbed sound energy by a surface}}{\text{Total sound energy incident on the surface}}$$

Types of Audible Sound: Two types of audible sound are musical sound and noise.

Musical Sound: The sound that produces pleasant effect on our ears is called musical sound. It is a single sound or multiple sounds having same frequency, wavelength and meeting in same phase.

e.g. Sound of music, crisping of birds etc.

Noise: The sounds that produce unpleasant effect on our ears are called noise. It has irregular amplitude with time. It is generally a combination of multiple sounds of different frequency, wavelength and meeting in different phases.

e.g. sound of horn, thunder etc.

Reverberation:

It is the persistence of sound after the source has stopped emitting sound due to reflection from multiple surfaces.

Reverberation Time:

The time up to which a sound persists in a hall or room after the source has stopped emitting it is called reverberation time.

Standard reverberation time (Sabine's formula): Reverberation time is the time taken by the sound intensity to drop by 60 dB or reduce to its one millionth parts. An American scientist W. C. Sabine developed an equation for calculating the reverberation time as:

$$T = \frac{0.16\,V}{\sum aS}$$

where V is the volume of the hall in m^3, *a* is the average absorption coefficient of room surfaces and S is total surface area of room in m^2.

Here $\sum a\,S = a_1 s_1 + a_2 s_2 + a_2 s_3 + ...$

where a_1, a_2, $a_3$etc. are absorption coefficients of different objects in hall and s_1, s_2, $s_3$etc. are their surface areas.

Echo:

The repetition of original sound by reflection from a surface is called echo. The echo is produced if the reflected sound reaches our ears after 1/10 of a second. It is different from reverberation as echo is identified as repeated sound due to a time gap of at least 1/10 of a second.

The distance 'd' of reflector/obstacle causing echo is given by

$$d = \frac{v.t}{2}$$

where 'v' is velocity of sound and 't' is time taken by reflected sound to reach our ears.

The minimum distance of obstacle to produce echo thus is given as

$$s = \{332\times (1/10)\}/2 = 16.6 \text{ m/s}$$

Thus, the obstacle must be placed at a minimum distance of 16.6 m from the source to produce echo.

Methods to Control Reverberation time:

To control reverberation time the simplest way is to increase absorption in the hall. The methods to control reverberation are:

1. *Provide few open windows in hall*- Open windows are good absorbers of sound and the reverberation time can be controlled by adjusting the number of open windows in the hall.
2. *Cover the floor with carpets*- The carpets are also good absorbers of sound which help in reducing the reverberation time in the hall.
3. *Curtains*- The use of heavy folded curtains on doors and windows allows to control the reverberation time.
4. *Cover the walls*-Covering the walls with absorbing materials like fibre or asbestos sheets etc help in reducing reverberation time.
5. *Using false ceiling*- False ceiling is made of sound absorbing materials which reduces the reverberation in a hall.
6. *Using upholstered cushioned seats in hall*- the seats in the empty hall would also absorb the sound if they are made of good absorbing cushioned material and turn up when no one is sitting on them.
7. *A good number of audience* increases the absorption of hall.

7.7 ULTRASONICS

The sound waves having frequency more than 20 kHz are called ultrasonics. Their characteristics are:

i. They are high frequency and high energy waves.
ii. If they are passed through a liquid it is shaken violently.
iii. They work as catalyst for chemical reactions.
iv. They can be sent in the form of narrow beam to long distances without loss of energy.
v. Travelling in one medium if they meet another, they return back in same medium at 180 degree.
vi. Just like ordinary sound waves, ultrasonic waves get reflected, refracted and absorbed.
vii. They produce intense heating effect when passed through a substance.

Production of Ultrasonic: The natural producer of ultrasonics is 'Bat'. Another simple method to produce low frequency ultrasonics is 'Galton's whistle'. Two types of oscillators are used to produce ultrasonic sounds: Magnetostriction oscillator, Piezoelectric oscillator.

Applications of Ultrasonic: Ultrasonic waves are used in various fields like; medical for ultrasound, navigation for various purposes, engineering for drilling, cleaning, flaw detection etc. Some important applications of ultrasonic are described below:

1) **Drilling:** Ultrasonic is high frequency and high energy wave, so they can be used in applications involving high amount of energy. They can be used to make a drill even in hardest material of world i.e. Diamond. For this a tool bit is attached at lower end of magnetostriction oscillator. The sheet to be drilled is kept below the tool bit. It is driven by a magneto-striction oscillator that creates the vibrations. When oscillator is switched on the tool bit moves up and down that produces enough strain to make a drill in the sheet. The setup of drilling is shown in figure 7.7.

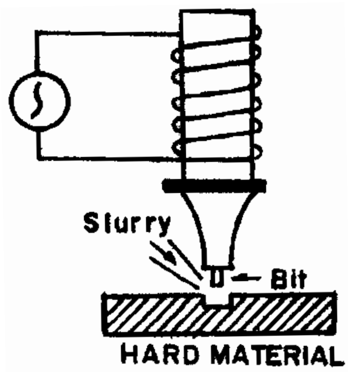


Fig. 7.7 Ultrasonic drilling

2) **Ultrasonic welding (cold welding):** The setup is shown in figure 7.8. Cold welding means welding without involvement of heat which is possible only with ultrasonics. A hammer is attached at lower end of magnetostriction oscillator. The sheets to be welded are kept below hammer. When oscillator is switched on hammer strikes the sheets frequently. In case of resonance the molecules of both sheets enter in each other due to high amplitude and welding is performed without involvement of heat. The interface of the two parts is specially designed to concentrate the energy for maximum weld strength.

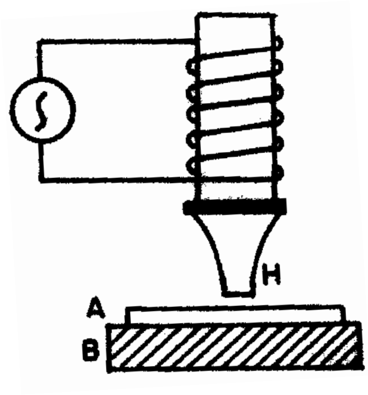


Fig. 7.8 Cold welding

3) **SONAR**: is a technique which stands for **SOund Navigation and Ranging**. It uses ultrasonic for the detection and identification of underwater objects. A powerful beam of ultrasonic is sent in the suspected direction in water. By noting the time interval between the emission and receipt of beam after reflection, the distance of the object can be easily calculated. Measuring the time interval (t) between the transmitted pulses and the received pulse, the distance (d) between the transmitter and the remote object is determined using the formula

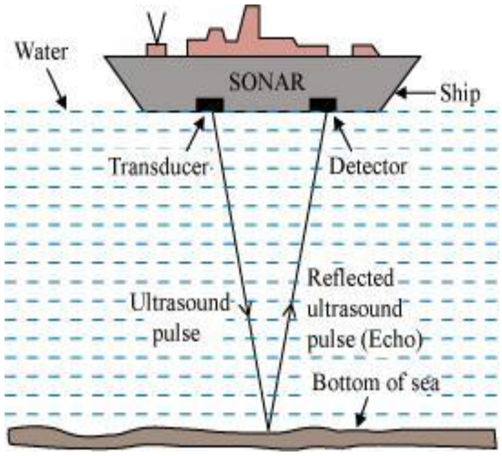


Fig. 7.9 Sound navigation and ranging

$$d = v \times \frac{t}{2}$$

where v is the velocity of sound in sea water. The same principle is used to find the depth of the sea as shown in figure 7.9.

Numerical 3. An ultrasonic scanner travelling with a speed of 1.5 km/s in a tissue operating under a frequency of 4.1 MHz. What is the wavelength of sound in the tissue?

Solution:

Given, Velocity (v) = 1.5 km/s = 1.5×1000 = 1500 m/s

Frequency (ν) = 4.1 MHz = 4.1×10^6 Hz

Using the relation; $v = \nu\lambda$ we can get

$$\text{Wavelength, } \lambda = \frac{v}{\nu} = \frac{1500}{4.1\times10^6} = 3.65\times10^{-4} \text{ m} = 36.5 \text{ mm}$$

Numerical 4. A man hears his sound again after reflection from a cliff after 1 second. If the velocity of sound is 330 m/s, find the distance of cliff from the man.

Solution: Given

Velocity of sound, v = 330 m/s

Time after which sound is heard, t = 1.0 s

Let d be the distance of cliff from man.

Total distance travelled by sound in going and coming back from cliff = 2 d

Thus, $2d = v \times t = 330 \times 1 = 330$ m

$$d = \frac{330}{2} = 165 \text{ m}$$

* * * * * *

UNIT-2

OPTICS

Learning Objectives: After studying this chapter the student should be able to;

- *Understand light properties, reflection and refraction of light, lens parameters, lens formula and power of a lens.*
- *Explain total internal reflection, conditions for TIR and its applications.*
- *Describe microscope, telescope and their uses.*

Introduction

Optics is the branch of physics which deals with the study of behavior and properties of light. Light is an electromagnetic wave having transverse nature. Although light has dual nature; particle as well as wave, classical approach considers only wave nature. The wave nature is further simplified in geometric optics, where light is treated as a ray which travels in straight line. Ray optics model includes wave effects like diffraction, interference etc. Quantum optics deals with application of light considered as particles (called photons) to the optical systems. The phenomena of photoelectric effect, X-rays and lasers are explained in the quantum optics (particle nature of light).

Ray Optics (Geometric optics)

Geometrical optics describes the propagation of light in terms of rays. The assumptions of geometrical optics are:

- Light travels in straight-line paths.
- It bends, or split into part, at the interface between two different media.
- It follows curved paths in a medium where refractive index changes.
- It may be reflected, absorbed or transmitted.

8.1 REFLECTIONAND REFRACTION OF LIGHT

Reflection of Light

The phenomena of bouncing back of light after striking at a polished surface is called as reflection

Glassy surfaces such as mirrors exhibit reflection. This allows for production of reflected images that can be associated with real or virtual location in space. Figure 8.1 depicts the phenomenon of reflection from a glass-air interface. The light ray incident on a glass mirror at an angle θ_i (angle of incident) and the light ray reflected from the surface at an angle θ_r (angle of reflection).

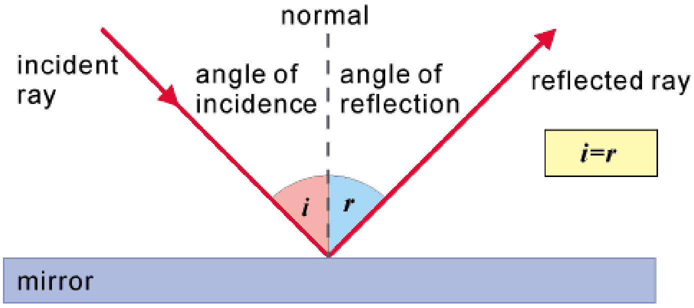


Fig. 8.1 Reflection of light

Laws of reflection:

1) The incident ray, reflected ray and the normal, all lie in same plane, and
2) The angle of incidence is always equal to angle of refraction i.e. $\theta_i = \theta_r$

Refraction of light

When a light ray passes from one transparent medium to another, it gets deviated from its original path while crossing the interface of two media. *The phenomena of bending of light rays from their original path while passing from one medium to another is called refraction.*

- When light travels from a rarer medium to denser medium, it bends towards the normal.
- When light travels from a denser medium to rarer medium, it bends away from the normal.

It happens when light travels through medium that has a changing index of refraction. Refraction occurs due to change in speed of light as it enters a different media. Figure 8.2 describe the occurrence of refraction at an interface.

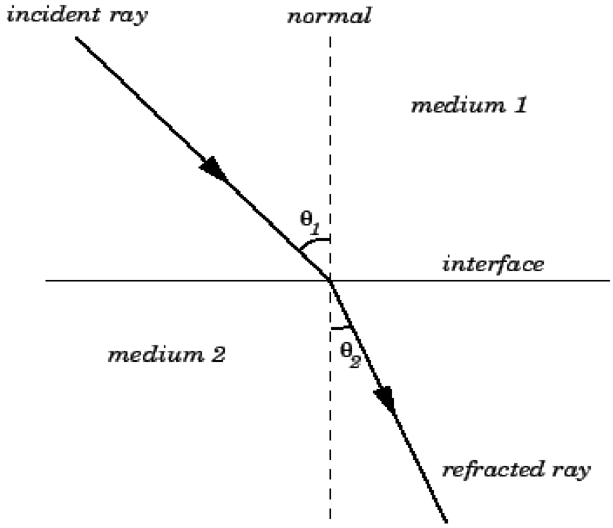


Fig. 8.2 Refraction of light

Laws of refraction:

1) The incident ray, the refracted ray and the normal all lie in the same plane.
2) The ratio of sine of incidence angle (θ_1) to the sine of refracted angle (θ_2) is a constant for that pair of media and is equal to the **refractive index** of that media. This is also known as **Snell's law**

$$^1\mu_2 = \frac{\sin\theta_1}{\sin\theta_2} = \frac{\sin i}{\sin r}$$

Where '*i*' is the angle of incidence and '*r*' is the angle of refraction and $^1\mu_2$ is the refractive index of medium 2 w.r.t. medium 1.If medium 1 is vacuum then,

$$\mu = \frac{\sin\theta_1}{\sin\theta_2}$$

When light travels from air (vacuum) to a medium then refractive index of the medium can be written as

$$\mu = \frac{c}{v}$$

where c is the velocity of light in air (vacuum) and v is the velocity of light in the medium. For example, the refractive index of water is 1.333, meaning that light travels 1.333 times slower in the water than in vacuum. Thus, the refractive index of a material is a dimensionless number that describes how light propagates through that medium.

The Snell's law is used to find the deflection of light rays when they pass through different media. It is used to produce dispersion spectra through a prism since light ray having different frequencies have slightly different refractive index in most materials.

Lens and lens formula

Lens is an optical device based on phenomenon of refraction. A lens is a transparent medium bounded by two refracting surfaces. It can produce two types of rays- converging and diverging rays. Convex lens is converging while concave lens is diverging.

Terms related in study of lenses:

1. **Centre of curvature**: The center of curvature of a lens is the centre of sphere which forms a part of the spherical surface of the lens.
2. **Radius of curvature**: The radius of the sphere of the spherical surface of lens is called radius of curvature. It is the distance of the vertex of the lens from the center of curvature.
3. **Principal axis**: The principal axis of a lens is an imaginary line that is perpendicular to the vertical axis of the lens. Principal focus of the lens lies on this axis. All rays parallel to the principal axis that are incident on the lens, would either converge (if lens is converging) to, or diverge (if the lens is diverging) from, the principal focus.
4. **Optical centre**: Optical centre is the centre of the lens lying on the principal axis. If a light ray passes through optical centre, it goes undeviated.
5. **Principal focus**: When the parallel rays are incident on a lens, they either meet or appear to meet at a point on the principal axis, that point is called principal focus.
6. **Focal length (f)**: The distance of principal focus from the optical centre is called focal length. In other words, focal length is equal to the image distance when the object is at infinity.
7. **Image**: If two or more rays passing from a point gets refracted through a lens and converges or appears to diverge to a point then that point is called the image of first point. The image can be real or virtual. In real image, rays actually meet at the second point, while in virtual image; the rays appear to diverge from the second point.

Lens formula

The formula which gives relation between focal length (f), object distance (u) and image distance (v) as

$$\frac{1}{f}=\frac{1}{v}-\frac{1}{u} \qquad \Rightarrow \text{This is called lens formula.}$$

Linear magnification: the ratio of size of image to the size of object is called as linear magnification of a lens. It is given by; m **=** $\frac{I}{O}$ **or** $\frac{v}{u}$ and holds for both convex and concave lenses and for real as well as virtual images.

Power of lens

The ability of a lens to converge or diverge the light rays is called as power of lens. Mathematically, power of a lens is defined as *the reciprocal of the focal length.*

$$P = \frac{1}{f} \qquad \text{(f is taken in metre)}$$

The unit of power of lens is m^{-1} which is called ***dioptre*** and indicated by symbol 'D'. In other words, one dioptre is the power of a lens of one metre focal length.

The power of a convex lens is positive and that of concave lens is negative. If two lenses are combined (placed in contact), the focal length of the combination is given by

$$\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2}$$

Thus the power of combination becomes sum of power of individual lenses. i.e.

$$P = P_1 + P_2$$

$$\text{In general, } P = P_1 + P_2 + P_3 + \dots\dots\dots$$

8.2 TOTAL INTERNAL REFLECTION (TIR)

When light is goes from denser medium to rare medium and the angle of incidence is greater than critical angle, the light get completely reflection in the same medium. This phenomenon is known as total internal reflection.

There are two essential conditions for TIR:

1. The light should travel from a denser medium to a rarer medium.
2. The angle of incidence in the denser medium should be greater than the critical angle.

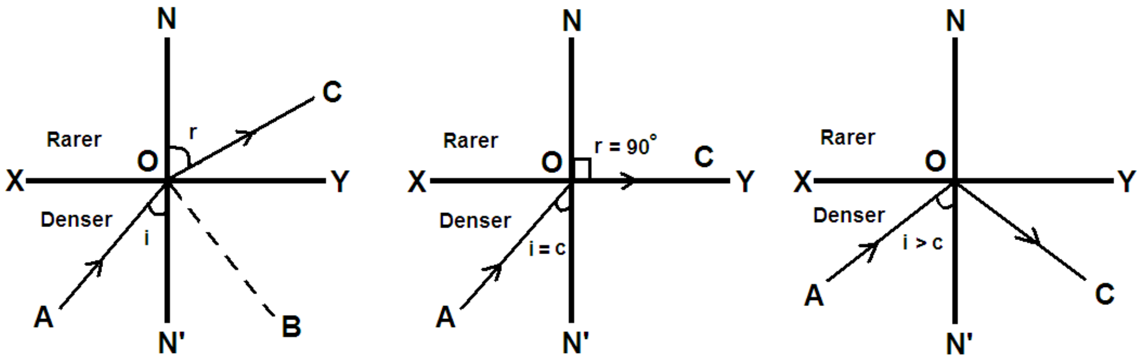


Fig. 8.3 Total internal reflection

The angle of incidence for which the angle of refraction becomes 90^o is called as *critical angle* (θ_c). At the critical angle of incidence, the refracted ray travels along the boundary between the two media i.e. the angle of refraction becomes 90^0. For angle of incidence greater than critical angle light is totally reflected as shown in Fig. 8.3.

The critical angle for a material depends upon the refractive index. Higher the refractive index, the lower the critical angle. It can be calculated using the following formula:

$$\text{Sin } \theta_c = \frac{1}{\mu}$$

Where θ_c is the critical angle and μ is the refractive index.

Applications of TIR

1. TIR is the basic principle of optical fibers which are used as transmission media in sending telecommunication signals and images in endoscopes.
2. Automotive rain sensors work on the principle of TIR, which control automatic windscreen wipers.
3. Prisms in binoculars also form erect images based on total internal reflection.
4. Some multi-touch screens also use TIR to pick up multiple targets.
5. Optical fingerprinting devices used to record fingerprints without the use of ink are also based on TIR.
6. The bright shining of diamonds is also a result of total internal reflection.
7. Formation of mirage.

8.3 OPTICAL INSTRUMENTS

An optical instrument is a device which is used to view the objects. The eye is natural optical system. In addition to it, other instruments are devised to increase the range a human's viewing ability. The optical instruments are an aid to the eye. They consist of an arrangement of lenses, prisms or mirrors which enables to see better than what we can see with the naked eye. These can be of two types:

1. When the real image is formed on screen as in case of photographic camera, overhead projector etc.
2. When a virtual image is formed and can be seen directly with eye as in telescopes, microscopes, binoculars etc.

a) Microscope: *A microscope is an optical instrument which enables us to see magnified image of very small objects*. A microscopic object is invisible to the eye unless aided by a microscope. Fig.8.4 shows the view of a microscope.

There are two types of microscope:

1. **Simple microscope**. It is also known as magnifying glass. It is made of only one convex lens and the object is so adjusted before the focal point that the image is formed at least distance of distinct vision.
2. **Compound microscope**. The magnification produced by a simple microscope is small and is only governed by the focal length of lens. To produce large magnification, a compound microscope is used in which magnification is obtained in two stages by the use of two convex lenses.

Fig. 8.4 A microscope

Fig. 8.5 A Telescope

Telescope: A telescope is an optical instrument which is used to see distant objects clearly. There are three types of telescopes:

1. **Astronomical**: It is used to see astronomical heavenly objects like stars and planets. The image formed in an astronomical telescope is inverted.
2. **Terrestrial**: Astronomical telescope forms an inverted image which is not suitable to see the terrestrial objects like buildings, trees etc. For seeing the distant objects lying on earth, the final image should be erect. A terrestrial telescope (Fig. 8.5) forms an erect image and makes use of three convex lenses.
3. **Galilean** (modification of terrestrial telescope): It is a modified version of terrestrial telescope which also forms erect image but with the use of only two lenses.

8.4 USES OF MICROSCOPE AND TELESCOPE

a) Uses of Microscope

1. Biological scientists use microscope to see microorganisms and their behavior.
2. Doctors use microscope to see and examine blood cells and bacteria.
3. Forensic science experts use microscope to analyze the evidences of crimes.
4. Jewelers and watch makers use it to see the details of parts they are working with.
5. Environmentalist uses it to test the soil and water samples for presence of pollutants.
6. Geologist uses it to test the composition of different types of rocks.
7. These are used in various laboratories.

b) Uses of Telescope

1. Astronomical objects are seen by using telescope by astronomers.
2. They found use in terrestrial applications also. They are used in laboratories to perform different experiments and finding values of different quantities.
3. Spectrometry uses telescopes to find wavelength of light and spectral lines etc.
4. It is used in spy glasses and long focus camera lenses.

Solved Numericals

Numerical 1. A lens is having power of +4 D. What is its focal length?

Solution: Given, Power (P) = +4 D

We know that $P = \frac{1}{f}$

Therefore, $4 = \frac{1}{f}$ or $f = \frac{1}{4}$ m = 0.25 m = 25 cm

Thus, focal length of lens is 25 cm.

Numerical 2. An object is kept at distance of 30 cm from a convex lens of focal length 0.2 m. Find the position of the image formed.

Solution: Given, distance of object, u = - 30 cm = - 0.3 m, and f = 0.2 m

The lens formula is $\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$

or

$$\frac{1}{v} = \frac{1}{f} + \frac{1}{u} = \frac{1}{0.2} + \frac{1}{(-0.3)} = 5\text{-}3.33 = 1.67$$

$$v = \frac{1}{1.67} = 0.598 = 0.6 \text{ m} = 60 \text{ cm}$$

Numerical 3. A light wave has wavelength of 600 nm in vacuum. What is the wavelength of the light as it travels through water (index of refraction = 1.33)?

Solution:

Given, wavelength (λ) = 600 nm = 600 $\times 10^{-9}$ m (1 nm = 10^{-9} m).

The wavelength of light that travels through a medium of refractive index n changes by expression

$$\lambda_n = \frac{\lambda}{n} = \frac{600 \times 10^{-9}}{1.33} = 451 \times 10^{-9} \text{ m} = 451 \text{ nm}$$

* * * * * *

UNIT-3
ELECTROSTATICS

Learning Objectives: After studying this chapter, the student should be able to;

- *Understand fundamental of charges at rest, properties of point charges;*
- *Explain conservation and quantization of charges;*
- *Relate the properties leading charge storage capacity of the electronic devices using static charges.*

Electrostatics is the branch of physics which deals with the study of charges at rest.

9.1. ELECTRIC CHARGE

Electric Charge: it is the physical property of matter that causes it to experience force when placed in an electromagnetic field. There are two types of charges.

(1) **Positive charge**: e.g. proton, alpha particle

(2) **Negative charge**: e.g. electron, etc.

Charge on electron is smallest unit of charge.
SI unit of charge is coulomb (C).

> Charge on electron (e) = -1.6×10^{-19} C
>
> Charge on proton (P) = $+1.6 \times 10^{-19}$ C

Like charges repel each other and unlike charges attract each other. i.e.

+ ve	+ve	Repel
-ve	-ve	Repel
+ve	-ve	Attract
-ve	+ve	Attract

Conservation of Charge

Charge conservation is the principle that *total electric charge in an isolated system always remains constant*. This also means that no net charge can be created or destroyed. When an atom is ionized, equal amounts of positive and negative charges are produced. Hence the algebraic sum of charges before and after remains the same.

Quantization of Charges

Charge quantization is the principle that the total charge on any object is an integral multiple of the elementary charge (e). Thus, an object's charge can be exactly $\pm ne$ (i.e. 1 e, −1 e, 2 e, etc.).

Or $\boxed{Q = \pm ne}$

9.2. COULOMB LAW OF ELECTROSTATICS

It states that force of interaction between two point charges is

(i) Directly proportional to magnitude of charges and

(ii) Inversely proportional to the square of the distance between them.

Let F is force between two charges q_1 and q_2. Then

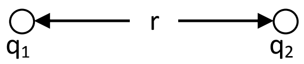


Figure 9.1

$$F \alpha q_1 q_2$$

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

$$\Rightarrow F \alpha \frac{q_1 q_2}{r^2} \qquad \text{.........(1)}$$

$$F = K \frac{q_1 q_2}{r^2} \qquad \text{.........(2)}$$

where K is constant of proportionality and its value is given as

$$K = \frac{1}{4\pi \in_0} = 9 \times 10^9 \text{ Nm}^2/\text{C}^2 \text{ (in SI units system)}$$

Now from equation (2)

$$F = \frac{q_1 q_2}{4\pi \in_0 r^2} \qquad \text{..........(3)}$$

Here $\in_0$ is electrical permittivity of vacuum. Its value is 8.854×10^{-12} $N^{-1}m^{-2}C^2$.

Let $q_1 = q_2 = q$ (say)

and $r = 1$ m

then from equation (3), $F = 9 \times 10^9$ N

Thus *one coulomb is that much charge which produces a force of* 9×10^9 *N at a unit charge placed at a distance of 1 m.*

Smaller units of charge;

milli coulomb (mC) = 10^{-3} C.

micro coulomb (μC) = 10^{-6} C.

9.3. ELECTRIC FIELD

It is the space around the charge in which force of attraction or repulsion can be experienced by another charge.

Electric field intensity

At point is defined as the force acting on a unit positive charge at that point.

$$\vec{E} = \frac{\vec{F}}{q_0}$$

- *A unit positive charge is also called as test charge*

The value of q_0 should be very small. Its SI unit is N /C (newton per coulomb)

Electric Lines of Force:

It is *the path along which the isolated charge moves in electric field if it is free to do so*. These are imaginary continuous line in an electric field such that tangent to it at any point gives the direction of electric force at that point (Fig. 9.2).

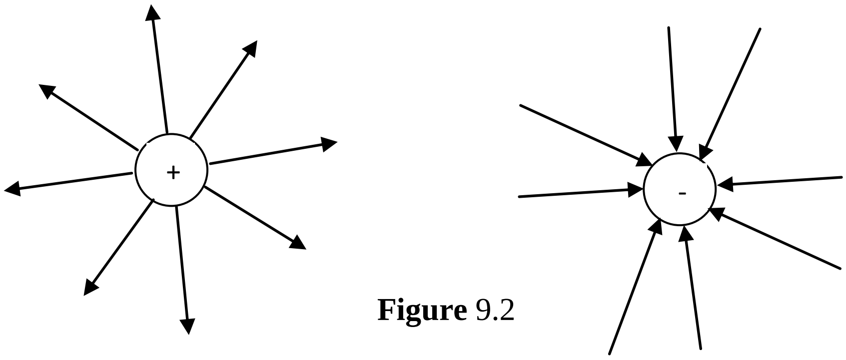


Figure 9.2

Properties of electric lines of force

- Electric lines of force originate from a +ve charge and terminate to a -ve charge.
- The tangent to the line of force indicates the direction of the electric field and electric force.
- Electric lines of force are always normal to the surface of charged body.
- Electric lines of force contract longitudinally and expand laterally.
- Two electric lines of force cannot intersect each other.
- Two electric lines of force proceeding in the same direction repel each other.
- Two electric lines of force proceeding in the opposite direction attract each other.
- There are no lines of force inside the conductor, so electric field inside conductor is zero.

9.4. ELECTRIC FLUX

It is the measure of distribution of electric field through a given surface. Electric flux is defined as *total number of electric lines of force passing per unit area normal to the surface*. It is denoted by ϕ (phi).

Consider small elementary area $\overrightarrow{ds}$ on a closed surface S. Electric field $\vec{E}$ exit in the space. If θ is the angle between $\vec{E}$ and area vector $\overrightarrow{ds}$ as then

$\phi = \oint \vec{E}d\vec{S}$ is called electric flux.

GAUSS'S LAW

It s*tates that net electric flux of an electric field over a closed surface is equal to the net charge enclosed by the surface divided by* $\in_0$ *i.e.*

$$\phi = \oint \vec{E}.\overrightarrow{ds}$$

$$\phi = \oint_S E ds \cos\theta = \frac{q}{\varepsilon_0}$$

Proof: Consider a closed surface S having a charge q placed at a point O inside a closed surface as shown in Fig. 9.3. Take a point P on the surface and consider a small area ds around P.

Let $OP = r$

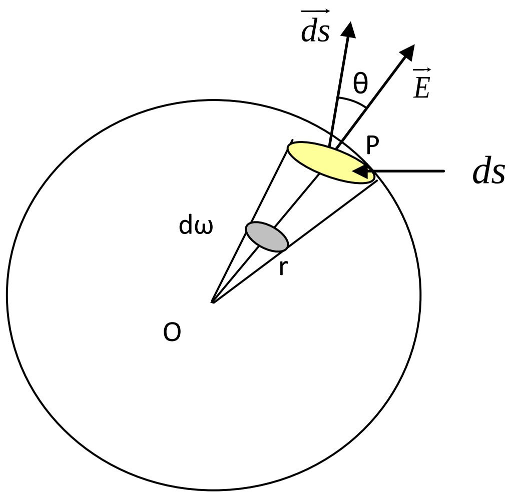


Figure 9.3

Then Electric field at P is

$$E = \frac{q}{4\pi \in_0 r^2} \qquad \ldots\ldots\ldots\ldots(1)$$

Now electric flux

$$\phi = \oint_S E ds \cos\theta$$

Putting value of E we get

$$\phi = \oint_S \frac{q}{4\pi\varepsilon_0 r^2} ds \cos\theta$$

$$\phi = \frac{q}{4\pi\varepsilon_0} \oint_S \frac{ds\cos\theta}{r^2}$$

$$\phi = \frac{q}{4\pi\varepsilon_0} \oint_S d\omega \qquad \because \frac{ds\cos\theta}{r^2} = d\omega$$

$$\phi = \frac{q}{4\pi\varepsilon_0} .4\pi \qquad \because Total \quad Solid \quad angle = 4\pi$$

$$\phi = \frac{q}{\in_0}$$

$$Hence, \phi = \oint_S E ds \cos\theta = \frac{q}{\varepsilon_0}$$

Applications of Gauss's Law:

Electric field due to a point charge:

Consider a point charge q. We want to find electric field at point P at a distance of r from it. Construct a spherical surface of radius r. This is called as Gaussian surface. Consider small area dS on the surface. Let θ is angle between $\vec{E}$ and Area vector as shown in Fig. 9.4.

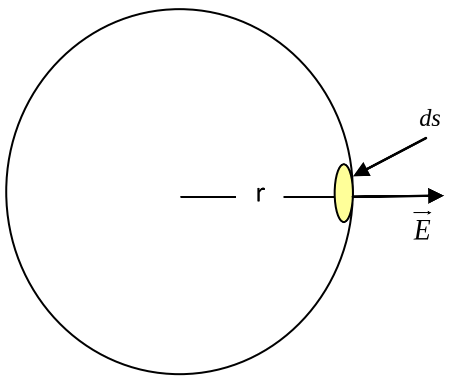


Figure 9.4

Now flux $\phi = \oint_S E ds \cos\theta = \frac{q}{\varepsilon_0}$ $\quad (\because \ \theta = 0)$

$$E \oint_S ds = \frac{q}{\varepsilon_0}$$

$$\Rightarrow E.4\pi r^2 = \frac{q}{\in_0} \qquad (\because \text{ Area of Sphere} = 4\pi r^2)$$

$$\Rightarrow \boxed{E = \frac{q}{4\pi \in_0 r^2}}$$

Thus the electric intensity decreases with increase in distance.

9.5. CAPACITOR

Capacitor is an electronic component that stores electric charge.

Capacitance

Of a capacitor is defined as the ability of a capacitor to store the electric charge.
As potential is proportional to charge

$$V \propto q$$

or $$q \propto V$$

$$q = CV$$

$$C = \frac{q}{V}$$

Unit of capacitance: farad (F), microfarad

<u>Grouping of Capacitors</u>

Series Grouping:

A number of capacitors are said be connected in series if -ve plate of one capacitor is connected to the +ve plate of other capacitor and so on. In this grouping, current is same on each capacitor.
Consider three capacitors of capacitances C_1, C_2, C_3 in series. Let V is total applied voltage. If V_1, V_2, V_3 → voltage drops across C_1, C_2, C_3 as shown in fig. 9.5.

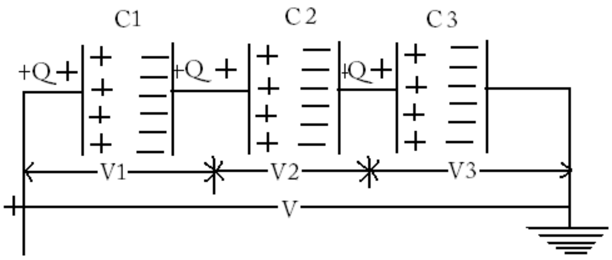


Figure 9.5

Then $V = V_1+V_2+V_3$ ----------------- (1)

Now $C = \frac{q}{V} \Rightarrow V = \frac{q}{C}$

So, $V_1 = \frac{q}{C_1}$, $V_2 = \frac{q}{C_2}$, $V_3 = \frac{q}{C_3}$

Putting in Equation (1)

$$\frac{q}{C} = \frac{q}{C_1} + \frac{q}{C_2} + \frac{q}{C_3}$$

$$\frac{q}{C} = q\left(\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}\right)$$

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

So the total capacitance decreases in series grouping.

The reciprocal of the equivalent capacitance of two capacitors connected in series is the sum of the reciprocals of the individual capacitances.

Parallel Grouping:

A number of capacitors are said to be connected in parallel if +ve plate of each capacitor is connected to the +ve terminal of battery and –ve plate of each capacitor is connected to the –ve terminal of battery. In this grouping voltage across each capacitor in same.

Consider three capacitors of capacitances C_1, C_2, C_3 connected in parallel and V is applied voltage.

$q_1, q_2, q_3 \rightarrow$ charges on capacitors C_1, C_2, C_3 as shown in fig. 9.6

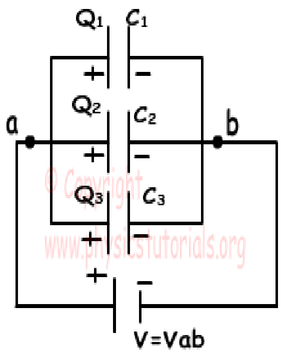


Figure 9.6

So

$$q = q_1 + q_2 + q_3 \text{ ------------------- } (1)$$

Now $C = \frac{q}{V}$ or $q = CV$

$\therefore$ $q_1 = C_1 V$, $q_2 = C_2 V$, $q_3 = C_3 V$

Put in equation (1)

$$CV = C_1V + C_2V + C_3V$$

$$CV = (C_1 + C_2 + C_3)\, V$$

$$C = C_1 + C_2 + C_3$$

So the total capacitance increases in parallel grouping.

The equivalent capacitance of capacitors connected in parallel is sum of the individual capacitance.

Solved Numerical

Example 1. Calculate the Coulomb force between two protons separated by a distance of 1.6×10^{-15} m.

Solution: Given, 2 protons**;**

Charge on Proton $= 1.6 \times 10^{-19}$ C

Thus, $q_1 = q_2 = 1.6 \times 10^{-19}$ C

Distance, $r = 1.6 \times 10^{-15}$ m

Also $\frac{1}{4\pi\varepsilon_0} = 9\times10^9\ \text{Nm}^2/\text{C}^2$

Now $F = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}$

$$F = \frac{9\times10^9 \times1.6\times10^{-19}\times1.6\times10^{-19}}{\left(1.6\times10^{-15}\right)^2}$$

F = 90 N

Example 2. Calculate the force between an alpha particle and a proton separated by distance of 5.12×10^{-15} m.

Solution: Given, q_1 = Charge on alpha particle = $2 \times 1.6 \times 10^{-19}$ C

q_2 = Charge on proton = 1.6×10^{-19} C

distance, $r = 5.12 \times 10^{-15}$ m

$\frac{1}{4\pi\varepsilon_o} = 9\times10^9\ \text{Nm}^2/\text{C}^2$

Now

$$F = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}$$

$$F = \frac{9\times10^9\times\ 3.2\times10^{-19}\times\ 1.6\times10^{-19}}{\left(5.12\times10^{-15}\right)^2}$$

F = 17.58 N

Example 3. Three capacitors of capacitances 3 μF, 2 μF and 4 μF are connected with each other. Calculate total capacitance (a) in Series grouping (b) in Parallel grouping.

Solution: Given,

$C_1 = 3\ \mu$F, $C_2 = 2\ \mu$F and $C_3 = 9\ \mu$F

In Series grouping

$$\frac{1}{C_{tot}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

$$\frac{1}{C_{tot}} = \frac{1}{3} + \frac{1}{2} + \frac{1}{9}$$

$$= \frac{17}{18} \mu F$$

$$\therefore \quad C_{tot} = \frac{18}{17} = 1.06\ \mu F$$

In Parallel grouping

$$C_{tot} = C_1 + C_2 + C_3$$

$$C_{tot} = 3 + 2 + 9$$

$$C_{tot} = 14\ \mu F$$

Example 4.Three capacitors 1 F, 2 F, and 3 F are joined in series first and then in parallel. Calculate the ratio of equivalent capacitance in two cases.

Solution: Given,

$C_1 = 1$ F, $C_2 = 2$ F, $C_3 = 3$ F

In series grouping

$$\frac{1}{C_S} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

$$\frac{1}{C_S} = \frac{1}{1} + \frac{1}{2} + \frac{1}{3}$$

$$\frac{1}{C_S} = \frac{11}{6}$$

$$\therefore C = \frac{6}{11} F$$

In Parallel grouping

$$C_p = C_1 + C_2 + C_3$$

$$C_p = 1 + 2 + 3$$

$$C_p = 6F$$

$$\therefore \quad \text{Ratio} \quad \frac{Cp}{C_S} = \frac{6}{\frac{6}{11}}$$

or

$$\frac{Cp}{C_S} = 11$$

UNIT-4
Current Electricity

Learning Objectives: After studying this chapter, the learner should be able to;

- *Describe electric current and types of current; AC and DC.*
- *Define resistance, combination of resistances; series and parallel.*
- *State Ohm's law, Kirchhoff's law and their applications*

10.1 ELECTRIC CURRENT AND ITS UNITS

In a conductor, there are many free electrons. These electrons are in random motion but there is no net motion along the conductor. But if the two ends of a conductor are at different potentials, the charge will start flowing from one end of conductor to the other end. Therefore, the free electrons (charge) which were moving randomly will now move towards positive terminal of the battery and constitute a current. Hence a potential difference is always needed to make charge move from one end of the conductor to the other end of the conductor.

In a conductor the motion of the free electrons give rise to the electric current as shown in Fig. 10.1.

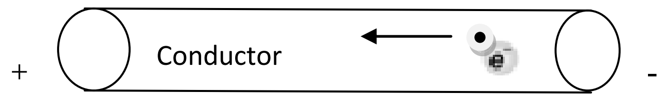


Figure 10.1

Electric current passing through a conductor is *the rate of flow of charge passing through it.* If a charge of *q* units passes through any cross section of the conductor in *t* seconds. The current (*I*) flowing through the wire is given by the formula

$$I = \frac{Charge}{time} = \frac{q}{t}$$

The direction of current is the direction of flow of positive charge i.e. opposite to the direction of flow of electron.

Unit: ampere (A)

In the relation

$$I = \frac{q}{t}$$

If the charge is measured in coulombs and time is measured in seconds then the unit of current will be ampere.

Where 1 ampere (A) = $\frac{1\ coulomb}{1\ \sec}$

One Ampere: *The current flowing through the conductor is said to be of one ampere if one coulomb of charge flows through the conductor in one second.*

Electric Potential difference (V)

Electric potential between two points is defined as the work done in moving a unit positive charge from one point to other against the electric field.

SI unit: volt (V)

One Volt:

$$1\ V = \frac{1\ joule}{1\ coulomb}$$

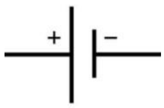
So, electric potential difference is said to be 1 V, if 1 J work is done in moving 1 C charge from one point to another point. It is defined as energy consumption of one joule per electric charge of one coulomb.

Direct Current (DC)

Direct current in an electric wire is that which flow in only one direction. It is the unidirectional flow of current. The electric current flowing through a semi-conductor diode is an example of direct current. Direct current (DC) is produced by sources such as batteries, fuel cells and solar cells and cannot travel over long distances since it has more loss of energy.

The frequency of DC is zero and it has a single polarity. In direct current the electron flows from negative end of the battery to the positive end of the battery.

Symbol of DC voltage source



It can be shown as Fig. 10.2.

DC form is used in low voltage apparatus like charging batteries, cell phones, automotive apparatus, aircraft apparatus and other low voltage low current apparatus.

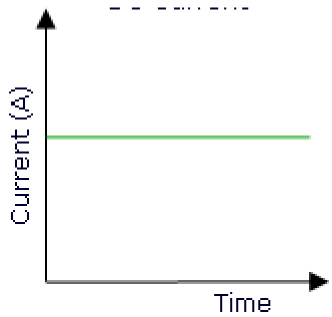


Figure 10.2

Alternating current (AC)

AC is current that reverses the direction periodically and also has a magnitude that varies continuously with time.

AC is used in our homes. Power stations generate AC because it is easy to low and raise the voltage with the help of transformers. In North America the frequency of AC is 60 Hz and in India it is 50 Hz. The AC in our home is sinusoidal in nature.

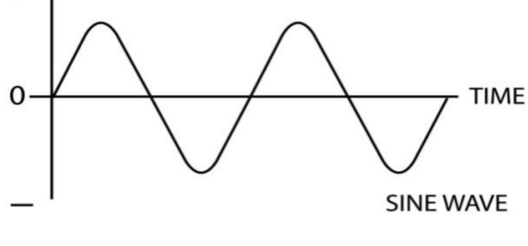


Figure 10.3

The radio frequency current in antennas and transmission lines are the examples of AC.

Symbol of AC 

It is produced by an alternator and has more power and can be easily transferred from one place to another.

10.2 OHM'S LAW

According to Ohm's law "*The current flowing through a conductor is always directly proportional to the potential difference between the two ends* if the physical condition (temperature, pressure etc.) of the conductor remains the same".

If I is the current passing through a conductor and V is the potential difference between the ends of the conductor having resistance R, then

$$V \propto I$$

$$V = R\,I$$

$$\frac{V}{I} = R$$

Therefore, $R = \frac{V}{I} = \frac{\text{potential differnce}}{\text{electric current}}$

where R is a constant and is called electric resistance.

The value of R depends upon nature, dimension and temperature of the conductor.

$$V = I\,R$$

Therefore $I = \frac{V}{R}$

If a graph is drawn between current (I) and the potential difference (V) it will be a straight line for a conductor (Fig. 10.5).

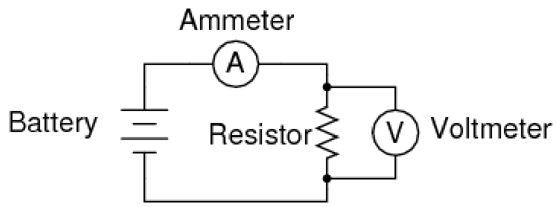


Figure 10.4

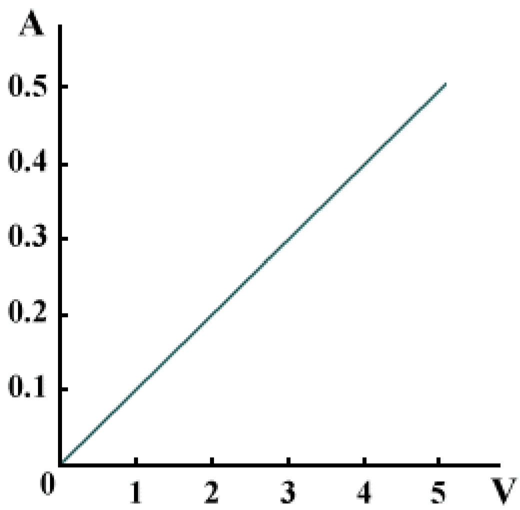


Figure 10.5

10.3 RESISTANCE (R)

The *opposition to the flow of electric current in an electric circuit is called resistance*. Therefore, it is the measure of the difficulty to pass an electric current through the circuit.

$$R = \frac{V}{I} = \frac{\textit{potential difference}}{\textit{electric current}}$$

If V is measured in volts and I is measured in amperes then the resistance R is measured in ohms.

Symbol: 

Unit: ohms (Ω)

One ohm:

$$1\ ohm = \frac{1\ volt}{1 ampere}$$

Therefore, one ohm is the resistance of conductor in which a current of one ampere flows through it when the potential difference of one volt is maintained between its two ends.

Specific Resistance (Definition and Units)

The resistance of a conductor depends on following factors;

(i) The resistance of a given conductor is directly proportional to its length i.e.

$$R \propto l \qquad \text{............ (1)}$$

ii) The resistance of a given conductor is inversely proportional to its area of cross-section.

$$R \propto \frac{1}{A} \qquad \text{........... (2)}$$

By combining equation (1) and (2), we get

$$R \propto \frac{l}{A}$$

or

$$R = \rho \frac{l}{A}$$

where ρ (rho) is a constant and known as specific resistance or resistivity of the material. The resistivity of a material does not depend on its length or thickness. It depends on the nature of the material.

If l = 1 m and A = 1 m^2 then from above equation

$$\rho = R$$

Thus *resistivity of the material is the resistance of a conductor having unit length and unit area of cross- section*.

Units: ohm-m (Ωm)

Conductivity: *It is the degree to which an object conducts electricity.* This is the reciprocal of the resistivity,

$$\sigma = \frac{1}{\rho}$$

Where, σ is the conductivity and ρ is the resistivity of the conductor.

Unit: siemens per metre or mho per metre

Conductance (G): It is the reciprocal of the resistance and it is a measure of ease with which the current flows through an object.

$$G = \frac{1}{R}$$

where G = Conductance

R = Resistance

Unit: mho

10.4 COMBINATION OF RESISTANCES

1. Series combination

The resistance are said to be connected in series if the same current passes through all the resistances and the potential difference is different across each resistance.

Let three resistances R_1, R_2, R_3 be connected in series as shown in the Fig. 10.6

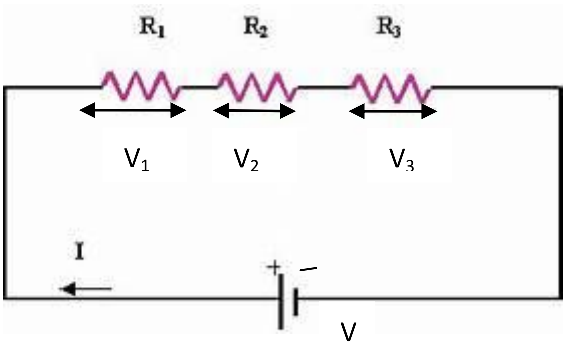


Figure 10.6

Let

V = Voltage applied across the series combination

I = Current passing through the circuit

Clearly current I is same throughout the circuit

Let V_1, V_2, V_3 be the potential difference across R_1, R_2, R_3 respectively. Then, according to Ohm's law

$$V = I R$$

where R is the total resistance in series

Now

$$V = V_1 + V_2 + V_3 \qquad \text{---------------} \ (1)$$

Then by Ohm's law

$$V_1 = I R_1$$
$$V_2 = I R_2$$
$$V_3 = I R_3$$

Putting the values of V_1, V_2 and V_3 in equation (1) we get

$$IR = I R_1 + I R_2 + I R_3$$
$$IR = I (R_1 + R_2 + R_3)$$
$$R = (R_1 + R_2 + R_3)$$

Thus the combined resistances when they are connected in series is the sum total of the individual resistances.

2. Parallel Combination

The resistances are said to be connected in parallel if the potential difference across each resistance is the same but the current passing through each resistance is different.

Let there be three resistances R_1, R_2, R_3 connected in parallel as shown in Fig. 10.7. One end of each resistance is connected to point A and the other end of each resistance is connected to the point B.

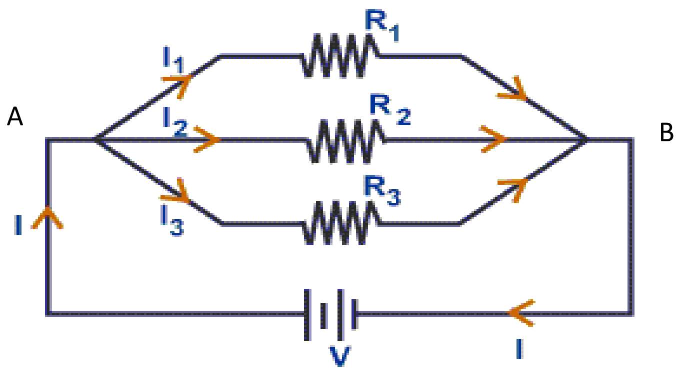


Figure 10.7

Let

V = potential difference applied across A and B (same across each resistance)

I = total current flowing in the circuit.

R = total resistance of the circuit

Let I_1, I_2, I_3 be the current passing through the resistances R_1, R_2, R_3 respectively.

From Ohm's law applied to the whole circuit

$$I_1 = \frac{V}{R_1}$$

$$I_2 = \frac{V}{R_2}$$

$$I_3 = \frac{V}{R_3}$$

Now we have,

$$I = I_1 + I_2 + I_3 \quad \text{-----------------------} (2)$$

Putting the values of I, I_1, I_2, I_3 in the equation (2)

$$\frac{V}{R} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

$$V\frac{1}{R} = V\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right)$$

Or
$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

Thus we can say that if the resistances are connected in parallel, then the reciprocal of the equivalent resistance is equal to the sum of reciprocals of individual resistances in the circuit.

10.5 HEATING EFFECT OF ELECTRIC CURRENT

When an electric current is passed through a conductor, the conductor becomes hot after some time and produces heat. This effect of electric current is called heating effect of current. This happens due to the conversion of some electric energy passing through the conductor into heat energy.

The heating effect of current was studied experimentally by Joule in 1941. After doing this experiments, Joule came to the conclusion that the heat produced in a conductor is directly proportional to the product of square of current (I^2), resistance of the conductor (R) and the time (t) for which current is passed. Thus,

$$H = I^2Rt$$

Derivation of Formula

To calculate the heat produced in a conductor, consider current I is flowing through a conductor of resistance R for time t. Also consider that the potential difference applied across its two ends is V.

Now, total amount of work done in moving a charge q from point A to point B is given by:

$$W = q \times V \qquad \text{------------------ (1)}$$

Now, we know that charge = current x time

or $q = I \times t$

and $V = I \times R$ (Ohm's law)

Putting the values of q and V in equation (1), we get

$$W = (I \times t) \times (I \times R)$$

or $W = I^2Rt$

Now, assuming that all the work done is converted into heat energy we can replace symbol of 'work done' with that of 'heat produced'. So,

$$H = I^2 Rt$$

Applications of Heating Effect of Current

The heating effect of current is used in various electrical heating appliances such as electric bulb, electric iron, room heaters, geysers, electric fuse etc.

10.6 ELECTRIC POWER

Electric power is the rate per unit time at which electric energy is transferred or consumed by an electric circuit.

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

Or $P = V I$

Where, V is the applied voltage and I is the current flowing through the circuit. SI unit of power is watt (W).

Now $P = V I$

If, V = 1 volt (1 V) and I = 1 ampere (1 A), then,

$P = 1$ watt

Thus, power is said to be 1 watt, if a potential difference of 1 volt causes 1 ampere of current to flow through the circuit.

Bigger units of electric power are kilowatt (kW) and megawatt (MW)

10.7 KIRCHHOFF'S LAWS

These two rules are commonly known as: Kirchhoff's circuit laws with one of Kirchhoff's laws dealing with the current flowing in a closed circuit, Kirchhoff's current law (KCL); while the other law deals with the voltage sources present in a closed circuit, Kirchhoff's voltage law, (KVL).

(i) Kirchhoff's First Law (Kirchhoff's Current Law) KCL

The law states that "The *algebraic sum of all the currents meeting at any junction point in an electric circuit is zero*"

$$\Sigma I = 0$$

Let us suppose the currents I_1, I_2, I_3 entering the junction are all positives in value and the two currents I_4, I_5 are leaving the junction are negative in values (Fig. 10.8), then according to KCL

$$I_1 + I_2 + I_3 - I_4 - I_5 = 0$$

Or $I_1 + I_2 + I_3 = I_4 + I_5$

or Sum of incoming currents = sum of outgoing currents

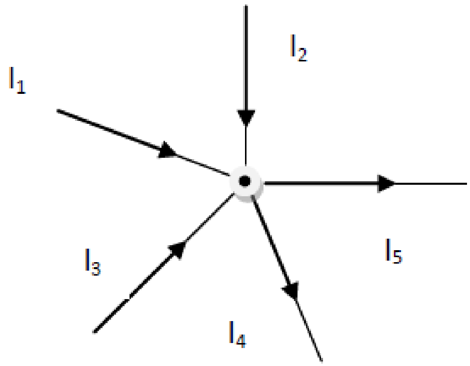


Figure 10.8

(ii) Kirchhoff's Second Law (Kirchhoff's Voltage Law) KVL

The law states that "*In any closed loop of a circuit, the algebraic sum of products of the resistances and currents plus the algebraic sum of all the e.m.f. in that circuit is zero*".

In any closed circuit; $\Sigma E + \Sigma IR = 0$

Here we use two sign conventions (Fig. 10.9).

1. If we go from negative terminal of the battery to the positive terminal then there is rise in potential and it is considered positive. And if we go from positive terminal to negative terminal, there is fall of potential and it is considered as negative.

2. If we go with the current, voltage drop is negative and if we go against the current, the voltage drop is positive.

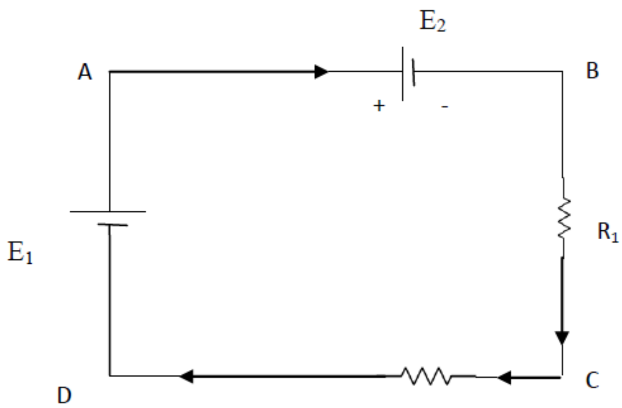


Figure 10.9

In the closed loop ABCD using KVL we get

$$- E_2 - IR_1 - IR_2 + E_1 = 0$$

Solved Numerical

Example 1. An source of emf 6 V is connected to a resistive lamp and a current of 2 ampere flows. What is the resistance of lamp?

Solution. Given, V = 6 V and I = 2 A

From Ohm's law, we know, $V = I R$ or $R = V/I$

$$R = 6/2 = 3\Omega$$

Example 2. An electric fan has a resistance of 100 ohms. It is plugged into potential difference of 220 V. How much current passes through the fan?

Solution. Given, R = 100 ohm and V = 220 V

We know, I =V/R = 220/100

Therefore I =2.2 A

Example 3. Calculate the total resistance, if three resistances of 1 ohm, 2 ohm and 3 ohm are connected in series.

Solution. Given, R_1 = 1 ohm,

R_2 = 2 ohm

R_3 = 3 ohm

We know that in series combination; $R = R_1 + R_2 + R_3$

Therefore R = 1 + 2 + 3 = 6 ohm

Example 4. Calculate the total resistance if three resistances of 4 ohm, 1 ohm and 6 ohm are connected in parallel.

Solution. Given, R_1 = 4 ohm

R_2 = 1 ohm

R_3 = 6 ohm

Form formula we know in parallel combination

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

Hence $$\frac{1}{R} = \frac{1}{4} + \frac{1}{1} + \frac{1}{6}$$

Therefore, total resistance, $R = \frac{12}{17}$ ohm

* * * * * *

UNIT-5

ELECTROMAGNETISM

Learning Objectives: After studying this chapter, students will be able to;

- *Understand the magnetic field associated with flow of current and related parameters*
- *Classify materials on basis of magnetic properties*
- *Describe magnetic flux and magnetic lines of force*

11.1 ELECTROMAGNETISM

Electromagnetism or magnetism in general is the study of production of magnetic field when current is passed through a conductor. Various terms associated with magnetism are;

Magnetization (I)

It represents the extent to which a material is magnetized when placed in a magnetic field. It is given by magnetic moment per unit volume of material.

$$I = \frac{M}{V}$$

where, M is magnetic moment and V is volume of the material.

Unit: ampere/metre

Magnetic Intensity (H):

It is the capability of magnetic field to magnetize a magnetic material.

Magnetic Permeability (μ):

It is property of material and defined as the degree to which magnetic lines of force can penetrate the medium.

Magnetic susceptibility (χ):

It is a property which determines how easily a specimen can be magnetised. It is given by ratio of magnetization and magnetic Intensity.

$$\chi = \frac{I}{H}$$

Types of Magnetic Materials:

On the basis of behaviour of magnetic material in magnetic field, the materials are divided in to three categories:

1. **Diamagnetic materials:**

The materials when placed in magnetic field, acquire magnetism opposite to the direction of magnetic field (Fig. 11.1). The magnetic dipoles in these substances tend to align opposite to the applied field and tend to repel the external field around it.

- Diamagnetic substances have tendency to move from stronger to the weaker magnetic field.

- When rod of diamagnetic material is placed in magnetic field, it aligns perpendicular to the magnetic field.
- Permeability of diamagnetic material is < 1.

Examples; gold, water, mercury, graphite, lead etc

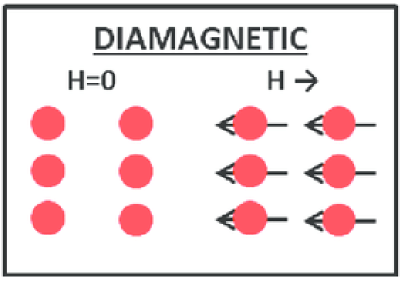


Fig 11.1

2. Paramagnetic materials:

Paramagnetic substances are those which get weakly magnetized when placed in an external magnetic field (Fig. 11.2). These materials show weak attraction in magnetic field. The magnetic dipoles in the magnetic materials tend to align along the applied magnetic field. Such materials show weak feeble magnetization and the magnetization disappears as soon as the external field is removed.

- Permeability of paramagnetic material is > 1.
- The magnetization (**I**) of such materials dependent on the external magnetic field (**B**) and temperature (T) as:

$$I = C\frac{B}{T}$$

Where C is the Curie constant.

Examples: sodium, platinum, liquid oxygen, salts of iron and nickel.

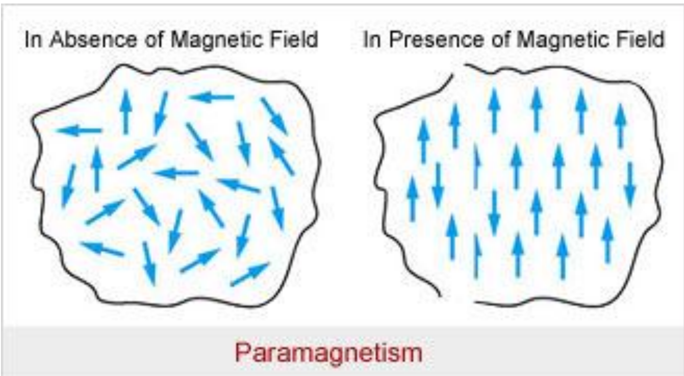
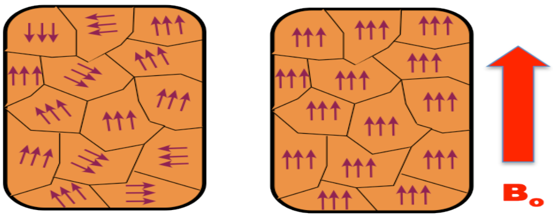


Fig 11.2

Ferromagnetic materials:

Ferromagnetic substances are those which get strongly magnetized when placed in an external magnetic field. They exhibit the strongest attraction in magnetic field. Magnetic dipoles in these materials are arranged into domains.



(a) (b)

Figure 11.3

These domains are usually randomly oriented as shown in Fig. 11.3 (a) and net magnetism is zero in the absence of magnetic field. When an external field is applied, the domains reorient themselves to reinforce the external field as shown in Fig. 11.3 (b) and produce a strong internal magnetic field that is along the external field. These materials show magnetism on removal of magnetic field.

Examples are iron, cobalt, nickel, neodymium and their alloys. These are usually highly ferromagnetic and are used to make permanent magnets.

11.2 MAGNETIC FIELD

The space around a magnetic material or a moving electric charge within which the force of magnetism can be experienced. The direction of a magnetic field within a magnet is from south to north and outside the magnet is north to south.

Unit: tesla (Wb/m^2)

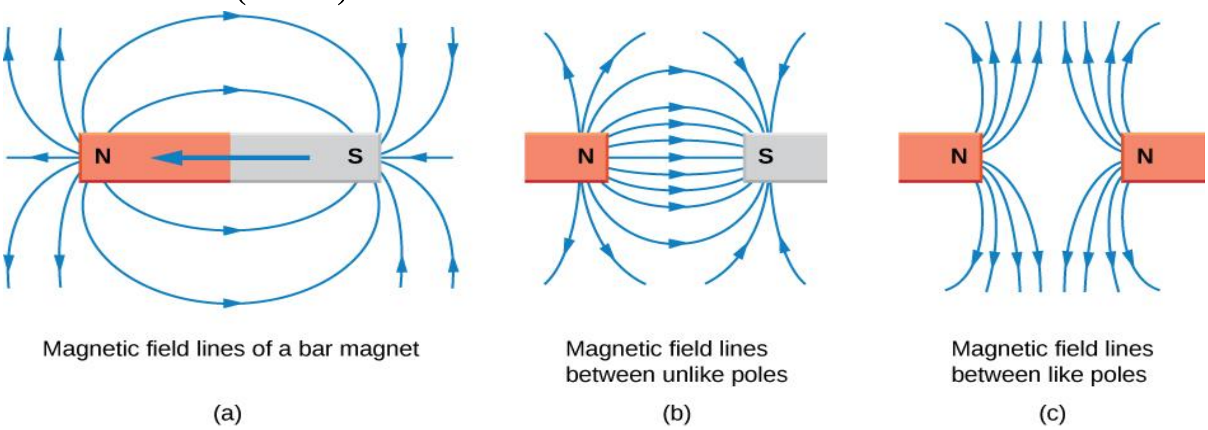


Figure 11.4

Magnetic lines of force:

Curved lines used to represent a magnetic field, drawn such that the number of lines relates to the magnetic field's strength at a given point (Fig. 11.4).

Properties of magnetic lines of force

(i) The magnetic field lines of a magnet forms continuous closed loops.

(ii) The tangent to the field line at a given point represents the direction of the net magnetic field (B) at that point.

(iii) Larger the number of field lines crossing per unit area, the stronger is the magnitude of the magnetic field (B).

(iv) Their density decreases with increasing distance from the poles.

(v) The magnetic field lines do not intersect with each other.

(vi) They flow from the South pole to the North pole within a material and North pole to South pole in air.

Magnetic flux:

The total number of magnetic field lines crossing through given surface area (S) held perpendicular to direction of magnetic field (B).

$$\phi = B\ S\ \cos\theta$$

Unit: The SI unit of magnetic flux is the weber (Wb)

Magnetic Intensity:

It is the amount of magnetic flux in a unit area perpendicular to the direction of magnetic flow.

11.3 ELECTROMAGNETIC INDUCTION

The phenomenon of producing an induced e.m.f. in a conductor by changing magnetic flux linked with it is **electromagnetic induction**.

When the speed at which a conductor is moved through a magnetic field is increased, the induced voltage increases and vice versa.

Electromagnetic Induction is used in

- Electrical motor
- Generator to produce AC electricity.
- Induction cooker
- Metal detector
- Inductors and transformers
- Induction welding
- Inductive charging

* * * * * *

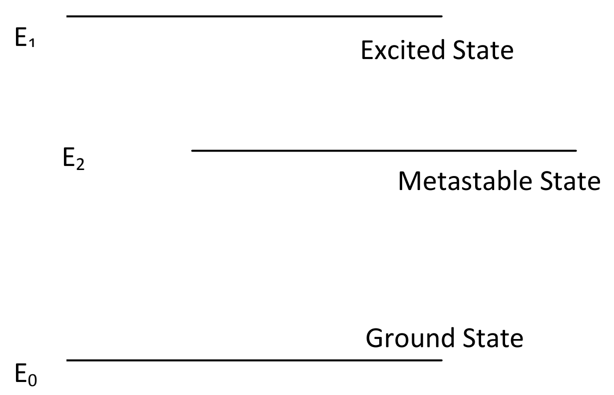
UNIT -6
SEMICONDUCTOR PHYSICS

Learning Objectives: After studying this chapter, students should be able to;
- *Understand concept of energy levels and energy bands in solids,*
- *Describe semiconductor materials, their types and doping,*
- *Explain semiconductor junctions, junction diodes, and transistors,*

12.1 ENERGY LEVEL AND ENERGY BANDS
Energy Levels:

In an atom, electrons cannot revolve in any direction, but are confined to well defined energy states. These states are called ***energy levels***.

There are three types of energy levels:
1. **Ground level:** This refers to the lowest energy state in the system (E_0). Thus the completely de-excited atoms would occupy this level.



2. **Excited level:** any level above the ground state is excited state (E_1). The atom can stay in excited state only for 10^{-8} s. After this time the atom will lose its energy in the form of radiation and come back to ground state.

3. **Metastable level:** This level (E_2) lies in between the excited (E_1) and ground levels (E_0). Its lifetime is 100 times more than excited state.

Energy bands:

If two atoms are brought closer to form a solid, the energy levels get modified due to mutual interactions. Each energy level split into two levels, one having energy higher than the original level and another having lower energy.

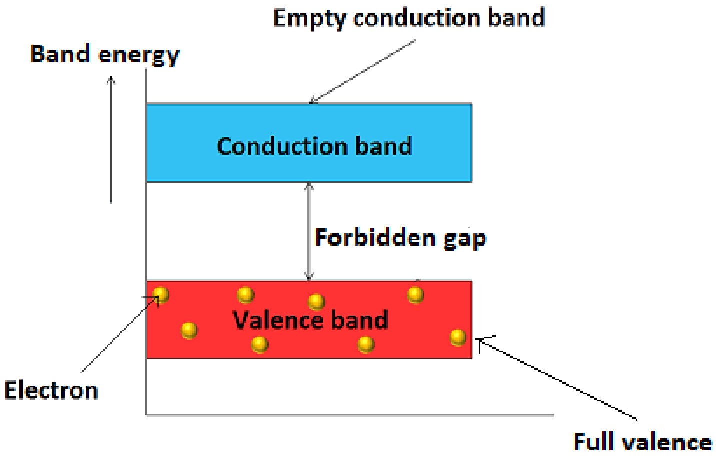


Figure 12.1

Now when a large number of atoms (*n*) come closer to each other, each energy level splits into a large number of levels. As a result a large number of discrete but closely spaced energy levels are formed. These are called energy bands. The inner shells however remain unaffected by neighbouring atoms, because, they are shielded by the outer electrons of their own atoms.

The highest energy band occupied by the valence electrons is called the **valence band**. Above this band there lies an empty band called the **conduction band.** These bands are separated by an energy gap known as **forbidden gap (E_g)** as shown in Fig. 12.1.

12.2 TYPES OF MATERIALS

On the basis of the forbidden gap (E_g), the material can be divided into following categories (Fig.12.2).

Insulators: These are poor conductors of electricity. Forbidden gap for these materials is E_g = 5 - 9 eV. The *energy gap between valence band and conduction band is very large*. Hence valence electrons will not be freed and no current will flow. Examples are paper, wood, plastics etc.

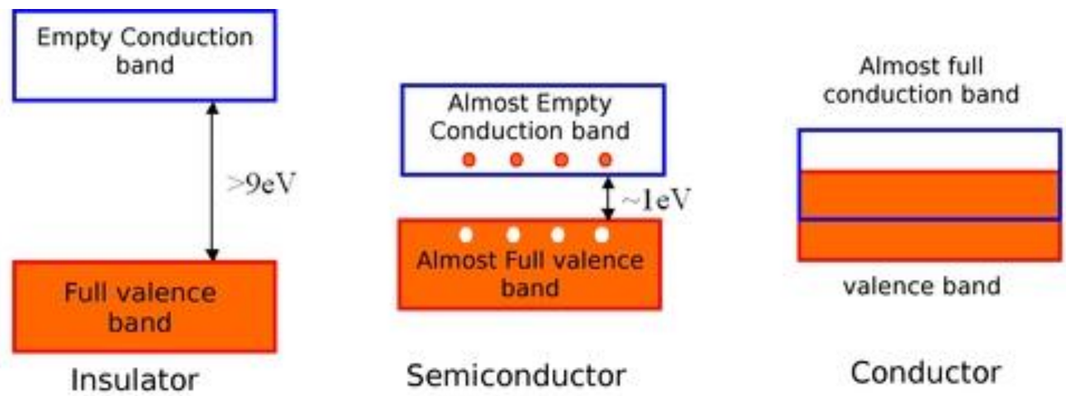


Figure 12.2

Conductors: Metals or good conductors are those substances which can conduct heat and electricity through them easily as there are many free electrons. In case of conductors $E_g = 0$ i.e. *valence band and the conduction band overlap each other*. Examples are Copper, Aluminium, Gold etc.

Semiconductors: The *conductivity of a semiconductor lies between that of conductors and insulators*. In case of semiconductors, E_g is of the order of 1 -2 eV.

At absolute zero temperature, the conduction band is totally empty and there is no flow of current. So these materials act as insulators at room temperature. But at the higher temperature, some valence electrons acquire sufficient energy to go in the conduction band. So at higher temperatures these materials start working as conductors. Even a small electric field can cause a flow of current in such materials. Examples are Silicon (Si), Germanium (Ge).

12.3 INTRINSIC AND EXTRINSIC SEMICONDUCTORS

Intrinsic Semiconductors: A semiconductor, which is quite pure and completely free from any impurity, is called an intrinsic semiconductor. E.g. Silicon (Si) and Germanium (Ge).

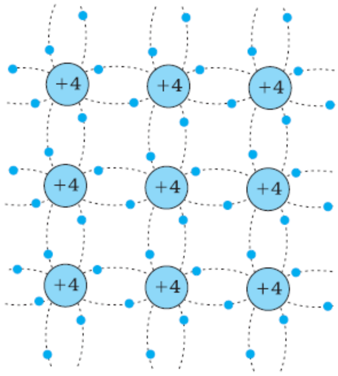


Figure 12.3

They have four valence electrons. Each of the four electrons forms *covalent bond* with neighbouring four atoms. By forming such covalent bonds, there is no free electron at absolute zero temperature. At room temperature some electrons break away from the covalent bond and enter into the conduction band. Each electron leaves behind a vacancy known as hole.

Hence in pure semiconductors both electrons and holes constitute current and the numbers of these two types of charge carriers are equal i.e. $n_e = n_h$

Doping:
The process of adding desirable impurity to a semiconductor is called **doping** and the impurity atoms added are called **dopants**.

Extrinsic Semiconductors

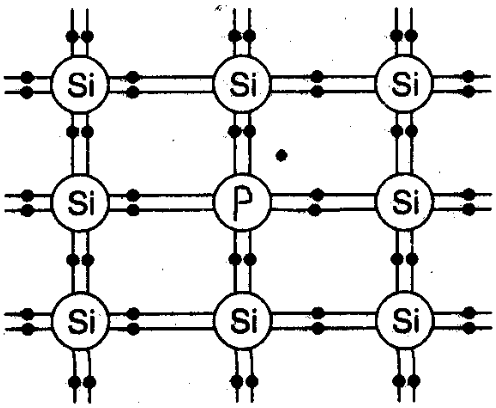
A doped semiconductor is called an extrinsic semiconductor. On the basis of doping, semiconductors are of two types

n-Type Semiconductor:

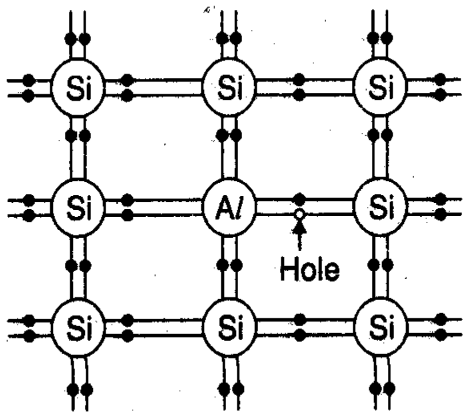
When a small amount of pentavalent impurity (e.g. Phosphorous, Arsenic etc.) is added to an intrinsic semiconductor (Si or Ge), it provides a large numbers of free electrons. The semiconductor is then, called n-type semiconductor.

Because impurity atom has five valence electrons, four of these will form covalent bonds, but one excess electron will be left free. Hence the current carriers are electrons. Therefore majority carriers are negatively charge electrons while the holes are minority carriers.

In an n-type semiconductor, number of electrons is much larger than the number of holes, i.e. $\boldsymbol{n_e} >> \boldsymbol{n_h}$



n-type semiconductor



p-type semiconductor

Figure 12.4

p-Type Semiconductor:

When a small amount of trivalent impurity (e.g. Boron, Aluminium etc.) is added to intrinsic semiconductor, it creates a large number of holes in valence band. The semiconductor is called a p-type semiconductor.

When a trivalent impurity is added to semiconductor, its three valence electrons form covalent bonds with three neighbouring atoms, while the fourth bond has a deficiency of electron. Thus there is a vacancy, which acts as a hole that tends to accept electrons.

The number of holes is greater than the number of electrons, *i.e.* $\boldsymbol{n_h} >> \boldsymbol{n_e}$

Hence, in p-type semiconductors, holes are the majority carriers and electrons are the minority carriers.

p-n junction Diode

A single crystal of silicon or germanium that has been doped in such a way that half of it is a p-type and the other half an n-type semi-conductor is known as a p-n junction diode. The junction is called p-n junction as shown in Fig.12.5.

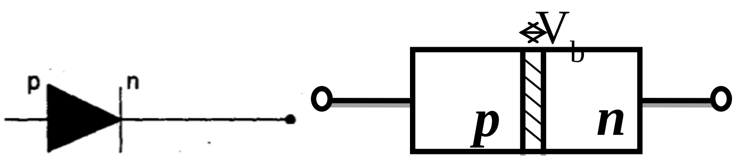


Figure 12.5

Characteristics of p-n Junction Diode

The graph (Fig. 12.7) showing the variation of the current flowing through the junction, when the voltage is applied across the junction diode in forward biased and reverse biased, is known as characteristic curve of a p-n junction diode.

Forward bias characteristic: the p-n junction diode is said to be forward biased if the positive terminal of battery is connected to the p-type and the negative terminal to the n-type of semiconductoras shown in Fig. 12.6.

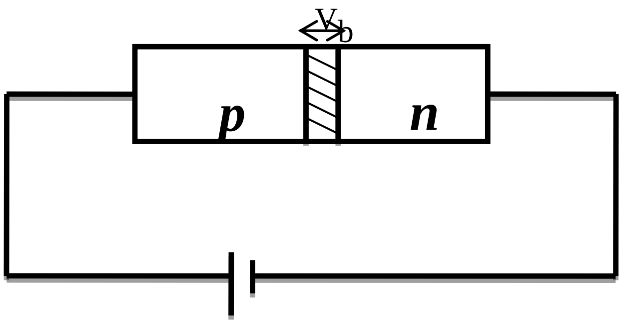


Figure 12.6

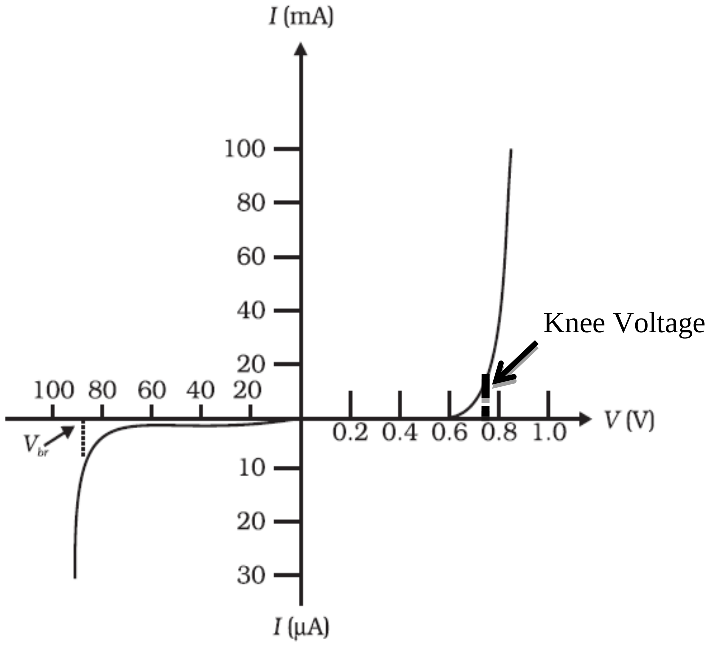


Figure 12.7

Let V is the voltage applied. This pushes the majority carriers, the holes in the p-type and electrons in the n-type towards the p-n junction.

If $V > V_B$, then the majority carriers from both sides are able to diffuse across the junction and a current is set up in the circuit. This process decreases the thickness of the depletion layers. The diode offers a low resistance to the flow of current.

A minimum amount of voltage required so that a current start flowing is known as the knee voltage. The current starts following at point A (knee voltage).

Reverse bias characteristic:

The p-n junction diode is said to be reverse biased if the negative terminal of the external source is connected to the p-type and the positive terminal to the n-type of semiconductor as shown in Fig 12.8.

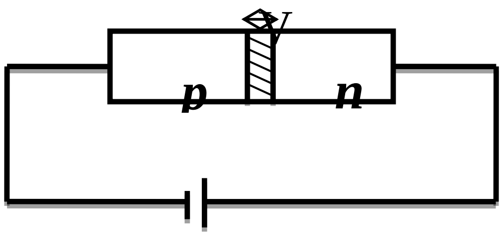


Figure 12.8

The external voltage pulls the majority carriers holes in the p-type crystal and the electrons in the n-type crystal away from the junction. This increases the width of depletion layer. The diode offers very high resistance and no current is set up across the junction due to majority carriers. However, a small current may be there across the junction due to minority carriers. It is called *leakage current* (I_s).

12.4 DIODE AS A RECTIFIER

The rectifier is *an electronic device which converts alternating current (AC) into direct current (DC).*

Half wave rectifier:

Half wave rectifier convert AC in to DC for only half of the input cycle. The circuit diagram for half wave rectifier using the p-n diode is as shown. During the first half cycle of AC the diode operates under a forward bias and current flows through the load R_L. During the other half, the diode becomes reverse bias and no current flows through the load R_L. Thus we get a rectified, unidirectional current across R_L and only half of the AC signal wave is rectified. The half wave rectifier gives output only for half cycle, hence power loss is high.

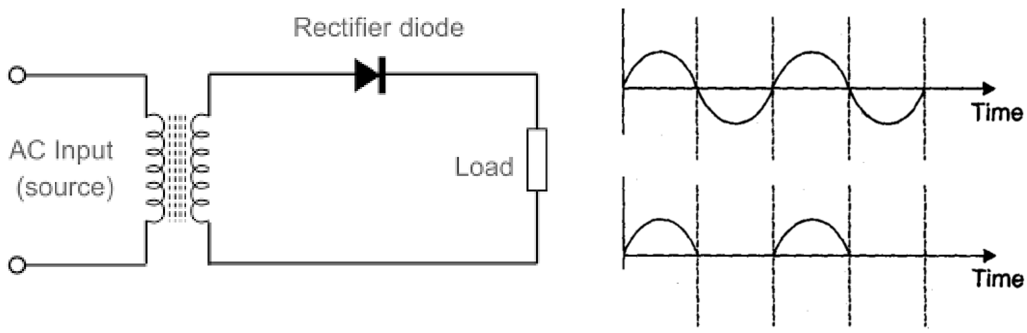


Figure 12.9

Full wave rectifier:

Full wave rectifier converts AC in to DC for complete cycle of input wave. The circuit diagram for full wave rectifier is shown. The center tap transformer is used. Two diodes are connected across the secondary of the transformer, the middle point of which is tapped at T. During the first half of the AC cycle, one end of the secondary say A becomes positive and B becomes negative. Diode D_1 is forward biased and diode D_2 is reverse bias. Thus a current flows through the diode D_1 and output is obtained across R_L.

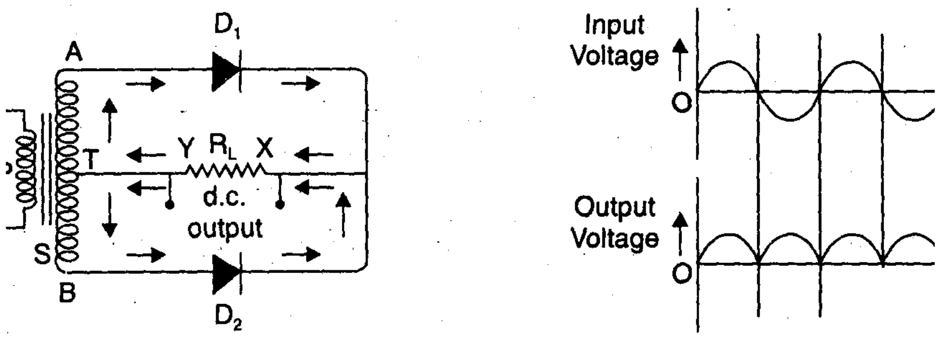


Figure 12.10

Now, during the other half of AC cycle, end B becomes positive and the end A becomes negative and the current flows through the diode D_2. Thus, during both halves, the current through the load R_L is in the same direction and full wave rectification of AC is achieved.

12.5 SEMICONDUCTOR TRANSISTOR

The transistor is composed of three semiconductor elements. One type of semiconductor is sandwiched between two types of semiconductors. So, basically transistor is combination of two pn-junctions joined back to back (Fig. 12.11). If n-type semiconductor is sandwiched between two p-type semiconductors, this is known as p-n-p transistor.

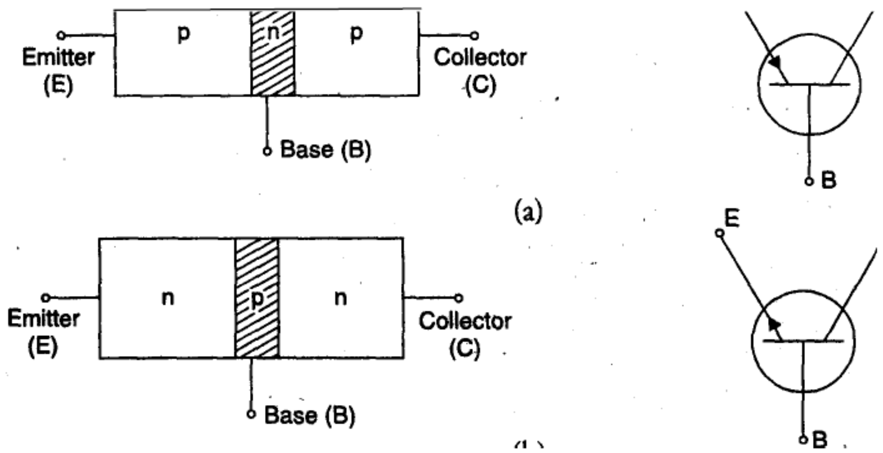


Figure 12.11

If p-type semiconductor is sandwiched between two n-type semiconductors then this is known as n-p-n transistor. In the circuit symbols of a transistor, only emitter has an arrow to indicate that it is the supplier electrode. It also indicates the direction of flow of current.

- The three elements of the transistor are; emitter (E), collector (C) and base (B).
- The emitter supplies the majority carriers for transistor current flow. The collector collects current and the base controls the passage of electrons from the emitter to collector.
- The doping level in the emitter is more than in the collector.
- The base is thin and lightly doped.
- Collector is moderately doped.
- Area of emitter is moderate, for base is minimum and of collector is maximum.
- In normal operation of a transistor, the emitter-base junction is always forward biased whereas the collector-base junction is reverse biased.

* * * * * *

UNIT-7

MODERN PHYSICS

Learning objectives: *After studying this chapter, the student should be able to;*

- *Understand concepts of Laser, emission processes and lasing conditions;*
- *List laser beam characteristics and engineering applications.*
- *Describe Optical Fibre, its structure, working principle and applications.*
- *Acquire some knowledge about Nanotechnology and its long term applications.*

13.1 LASER

LASER is an acronym for **Light Amplification by Stimulated Emission of Radiation**. It is a beam of light which is coherent, monochromatic, highly directional and very intense.

Energy Level: In an atom, the electrons are confined to well defined energy states. These states are called as energy level (Fig. 13.1).

There are three types of energy levels:

1. **Ground level:** This refers to the lowest energy state in the system (E_0). The completely de-excited atoms would occupy this level.

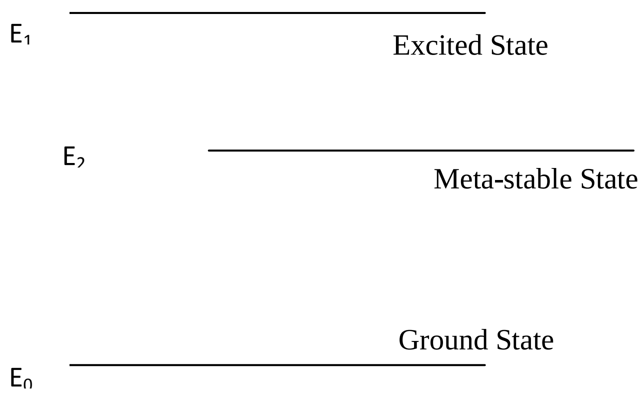


Figure 13.1 Energy levels

2. **Excited level:** Any level above the ground state is excited state (E_1). The atom can stay in excited state only for a very short time varying from 10^{-8} to 10^{-10} second. After this time the atom will lose its energy in the form of radiations and come back to ground state.
3. **Metastable level:** This level lies in-between the excited and ground levels (E_2). Its lifetime is 100 times more than excited state and atom can stay in this state for a longer time.

<u>The Emission Process</u>

When a material is energized by some radiations, the atoms of the material get excited to the higher state from ground state. These excited atoms may lose energy and come back to ground state. The energy loss may be in the form of heat, light or X-rays etc. This process may takes place in two ways:

I. Spontaneous Emission:

Spontaneous emission is the process of light emission in which the atoms in excited state (E_1) comes back to ground state (E_0) after 10^{-8} seconds, without any external radiation(see Fig.13.2).The atoms in excited state, release radiation of energy $h\nu = E_1 - E_0$ in the form of photons. These photons are emitted in random directions.

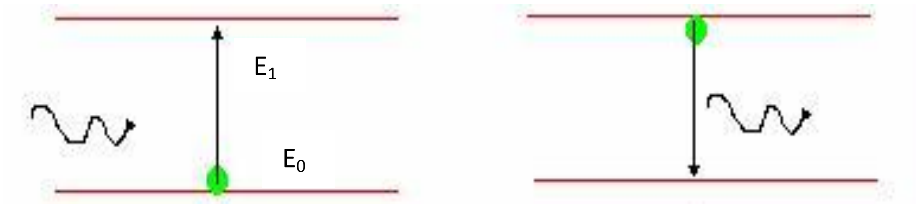


Figure 13.2 Spontaneous emission process

II. Stimulated Emission:

If excited atom is irradiated with a photon having energy $h\nu = E_1 - E_0$ before spontaneous emission process, then the excited atom will lose the energy in the form of two photon as shown in Fig.13.3. This process occurs in such a way that the incident photon and the emitted photon are found to be moving with same momentum and phase. This kind of emission is called stimulated emission.

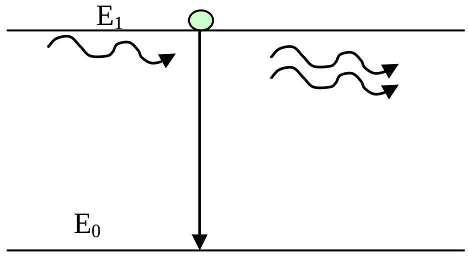


Figure 13.3 Stimulated emission process

Population Inversion:

In a material, when the number of atoms in excited state (N_2) becomes more than the number of atoms in ground state (N_1), this condition is known as population inversion. This condition is must for stimulated emission and hence for Laser emission.

Characteristics of Laser

Laser light has four unique characteristics that differentiate it from ordinary light:

a) Coherence

The photons emitted from ordinary light sources have different phases and hence non-coherent. While in Laser all the emitted photons have same phase or constant phase difference. Thus the laser light is highly coherent in nature. Because of this coherence, a large amount of power can be concentrated in a narrow space.

b) Monochromatic

In laser, all the photons emitted have the same frequency, or wavelength. Hence, the laser light has single wavelength or color. Therefore, laser light covers a very narrow range of frequencies or wavelengths. Hence the light emitted by a laser is highly monochromatic.

c) Directionality

In ordinary light sources (lamp, torch), photons will travel in random direction. Therefore, these light sources emit light in all directions. But, in laser, all photons will travel in same direction. Therefore, laser emits light only in one direction. This is called directionality of laser light. As a result, a laser beam can travel to long distances without spreading.

If an ordinary light travels a distance of 2 km, it spreads to about 2 km in diameter. On the other hand, if a laser light travels a distance of 2 km, it spreads by less than 2 cm.

d) High Intensity

In laser, the light spreads in small region of space and in a small wavelength range. Hence, laser light has greater intensity when compared to the ordinary light. Even 1 mW laser would appear many thousand times more intense than 100 W ordinary lamp.

Applications of Lasers:

- **Laser welding**: Lasers can be used for spot welding, seam welding, inert gas laser welding and welding of non-metals.
- **Laser cutting**: Metals can be cut with output power of atleast 100 W to 500 W. Wide range of materials can be cut e-g. paper, cloth, plywood, glass, ceramics, sheet metal like steel, titanium, aluminium etc.
- **Laser drilling**: Lasers are used for fine drilling
- Lasers are used for accurate measurement of the order of 0.1 m to the extent of distant object.
- Lasers are used to produce thermonuclear fusion.
- These are used to study the chemical process, nature of chemical bonds, structure of molecule and scattering.
- Long distance communication by using optical fibre and laser is very efficient.
- In medicine, lasers are used to study many biological samples, treatment of lever and to remove tumors.
- Laser is used for printing. Laser printers are very fast and efficient. The quality is very high.
- In computers, we use laser disc. In CD writer, a tiny laser beam burns spot on the compact disc.

13.2 OPTICAL FIBRE

An optical fibre consists of a very thin core made of glass or silica having a radius of the order of micrometers (10^{-6} m). The core is covered by a thin layer of cladding material of lower refractive index. Such optical fibres can transmit a light beam from one end to the other without significant energy loss. These are generally made from transparent materials such as glass (silica) or glass like polymers.

*The branch of physics dealing with the propagation of light through optical fibres is known as **fibre optics***

Principle: It is based on the phenomenon of *total internal reflections* at the glass or silica boundary. The light will reach at other end even if the fibre is bend or twisted.

If ray of light travelling from a denser medium into a rarer medium and the angle of incidence is greater than the critical angle, the ray is totally reflected back into the same media. This phenomenon is called as **total internal reflection.**

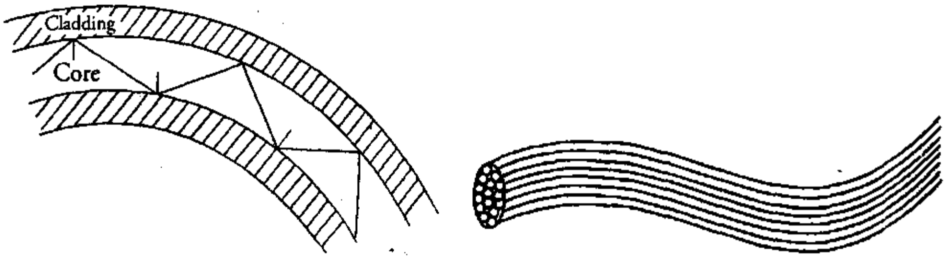


Figure 13.4 Schematic of optical fibre

Fibre Types

On the basis of mode of propagation the fibre can be classified as:

Monomode fibre: It has a very narrow core of diameter about 8-12 μm or less and the cladding is relatively big 125 μm as shown in Fig. 13.5 (a). As the name implies, monomode fibre sustains only one mode of propagation that is why it is also known as single mode fibre,

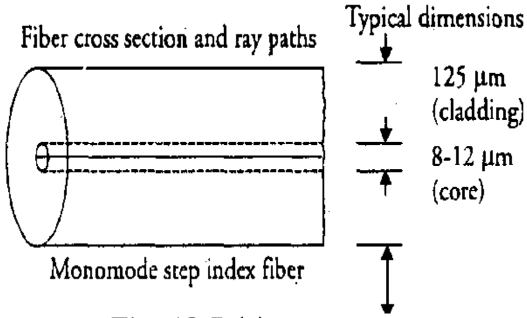


Fig. 13.5 (a)

Multimode fibre: It has a core of relatively large diameter such as 50-200 μm as shown in Fig.13.5 (b). As the name suggests the multimode fibre contain many hundreds of modes of propagation simultaneously. The signals do not intermix with each other. This is most commonly used optical fibre

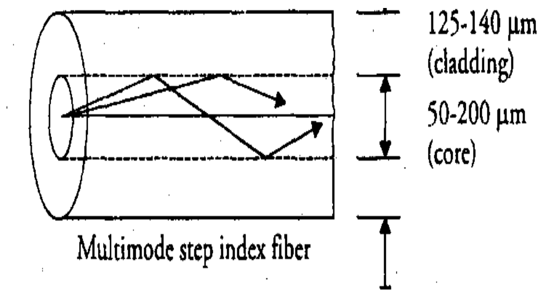


Fig. 13.5 (b)

Numerical Aperture (NA): *It is the light collecting ability of an optical fiber*. It depends on difference in refractive index of core and cladding. Generally, value of NA ranges from 0.1 to 0.5 for most of the commonly used optical fibres.

Applications of Optical Fibres:

- With the help of light pipes made up of flexible optical fibres, it is possible to examine the inaccessible parts of equipment or of the human body. For example in endoscopy, a patient's stomach can be viewed by inserting one end of a light pipe into the stomach through mouth.
- Optical fibres are also used for transmitting and receiving electrical signals that are converted to light by transducers.
- These are used as transmission medium to transmit communication signals at high data rates over long distances. For example, more than 100000 telephone signals at data rate of Gigabits/sec can be simultaneously transmitted through a typical single pair of optical fibre.
- Optical fibres are also being extensively used for cable TV networks and local area networks (LAN) in premises.

The quality of the signals transmitted with optical fibres is much better than other conventional methods.

13.3 NANOTECHNOLOGY

It is the branch of technology that deals with use of nanomaterials with dimensions less than 100 nanometres, especially the manipulation of individual atoms and molecules.

Nanomaterials:

These are materials with any dimension in the nanoscale (1 nm to 100 nm). These materials are very reactive and exhibit unique physical, chemical and biological properties due to high surface-to-volume ratio.

Example: Carbon nanotube, nanoparticle, quantum dots, nanoplymers, nanoshell, nanopores,nanorod, nanowires, nanopowder, fullerene, etc.

Applications of Nanotechnology

Nanomaterials are of interest because of their unique optical, magnetic, electrical, and other properties. These emergent properties have the potential for great impacts in electronics, medicine, and other fields.

- **Medicine**: Nanotechnology based drugs are being used to treat dangerous diseases like cancers and prevent health issues more effectively, as customized nanoparticles can deliver drugs directly to diseased cells in the body. New nanoparticles based chemotherapy drugs that can be delivered directly to cancer cells for better treatment are under development.
- **Electronics:** Electronic devices made with nano-fabrication techniques help in reducing weight and power consumption. This also improves display screens on electronic devices and increasing the density of memory chips. Nanotechnology can help to reduce the size of transistors and other components used in integrated circuits.
- **Food Industry**: Developing new nanomaterials will not only make a difference in the

taste of food, but also in improve the food production, nutrient value and preservation.

- **Fuel Cells:** Nanotechnology is being used to reduce the cost of catalysts, used in fuel cells to produce hydrogen ions from fuel such as methanol. Nanomaterials are also being developed to improve the efficiency of membranes used in fuel cells.
- **Solar Cells:** Nanotechnology based solar cells can be manufactured at significantly lower cost with better efficiency as compared to conventional solar cells.
- **Space:** Advancements in development of nano- composites make lightweight spacecrafts. Carbon nano-tubes based cables have been proposed for the space elevators.
- **Fuels:** Nanotechnology can be used for production of fuels from low grade raw materials which are economical and also increase the efficiency of engines.
- **Catalyst:** Nanoparticles have a greater surface area to interact with the reacting chemicals than catalysts made up of larger particles. This allows more chemicals to interact with the catalyst simultaneously and hence makes the catalyst more effective.
- **Chemical Sensors:** Nanotechnology based sensors can detect very small amounts of chemical vapours. Various types of nanostructures such as carbon nano-tubes, Graphene, Zinc oxide nanowires can be used as detecting elements in nanotechnology based sensors.
- **Fabric:** Making composite fabric with nano-sized particles or fibres allows improvement of fabric properties without a significant increase in weight, thickness, or stiffness.
- **Environment:** Nanotechnology is being used in cleaning water and existing pollution, improving manufacturing methods to reduce the generation of new pollution, and making alternative energy sources more cost effective.

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