

## **CHAPTER-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.

#### **1.1 WAVES**

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 Wave (Light)**

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 propagation of disturbance through a medium due to repeated periodic motion of medium particles is called wave motion.

The characteristics of wave motion are:

1. The wave travels forward but the particles vibrate only about their mean position.
2. The velocity of propagation 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 (air, water, or metal).
4. The velocity of waves is different from the velocity of particles.
5. There is regular phase difference between particles of wave.

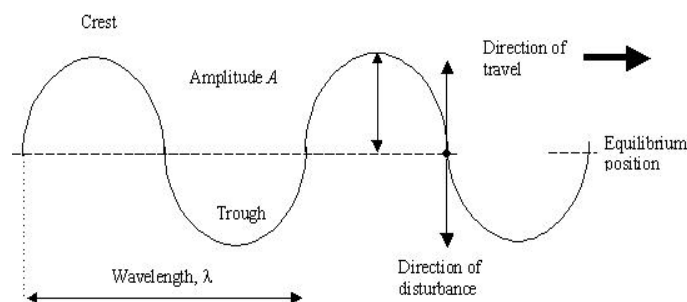
## 1.2 Types of Wave Motion:

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. The farthest point in positive direction is called crest and that in negative direction is called trough.

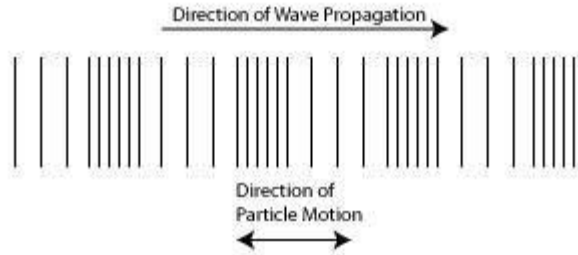


**Fig. 7.1**

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 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.     | 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:

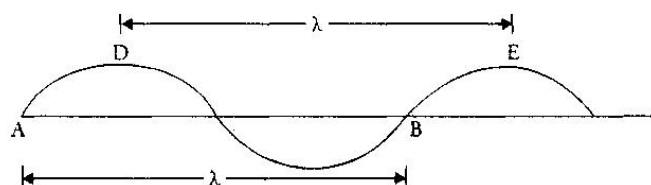
Various parameters used to characterize a wave motion are defined below.

**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.

**It is denoted by  $\lambda$  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 S.I. 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  $\nu$ (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.

**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  $\theta$  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

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

### Relation between Wave velocity, Wavelength and Frequency

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

$$V = \frac{\text{Distance}}{\text{Time}} = \frac{\lambda}{T}$$

and frequency is reciprocal of time period i.e.

$$\nu = T^{-1}$$

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  $3 \times 10^8$  m/s. What is the wavelength of transmitted waves?

**Solution:** Given, frequency ( $\nu$ ) = 15 MHz =  $15 \times 10^6$  Hz,

Velocity of waves (V) =  $3 \times 10^8$  m/s

Using relation;  $V = \nu\lambda$

$$\text{we get wavelength } (\lambda) = \frac{V}{\nu} = \frac{3 \times 10^8}{15 \times 10^6} = 20 \text{ m}$$

**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 ( $\nu$ ) = 512 Hz and velocity = 340 m/s

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

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

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

### 1.3 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  $\times$  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

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

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

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

Here  $A$  is the amplitude of SHM and is the ***maximum value of displacement from the mean position*** and  $\omega$  is angular frequency.

#### 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.

Under the influence of a restoring force ( $F$ ), a body acquires a velocity  $\left(\frac{dy}{dt}\right)$  and hence an

acceleration  $\left(\frac{d^2 y}{dt^2}\right)$ . This can be written as

$$\text{Acceleration} = \frac{K}{m} \times y$$

$$\text{or} \quad \frac{d^2 y}{dt^2} = -\omega^2 y \quad ; \quad \omega = \sqrt{\frac{K}{m}}$$

Term  $\omega$  is called angular frequency which is  $2\pi$  times the frequency ( $\nu$ ). Frequency ( $\nu$ ) is measured in cycles per second (cps) or Hertz (Hz) and  $\omega$  in radians/sec.

$$\omega = 2\pi\nu = \frac{2\pi}{T}$$

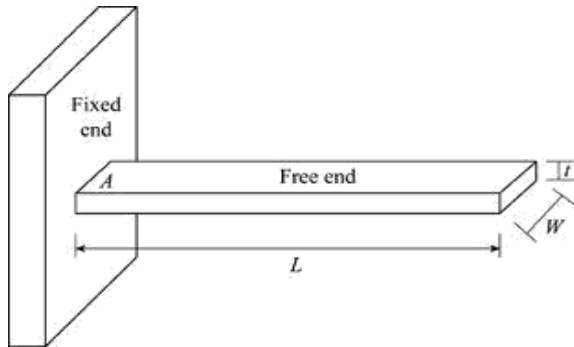
$T$  is the time period of the motion (smallest time interval after which a motion repeats itself) and is given by

$$T = \frac{2\pi}{\omega} = 2\pi \sqrt{\frac{m}{K}}$$

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

## 1.4 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.



**Fig. 7.6** A Cantilever

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.

## 1.5 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 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.

Whenever there are vibrations, there is transfer of energy which makes a wave. An understanding of vibrations and waves is required to understand our physical world. We see around us because of light waves and we hear the world around us because of sound waves.

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

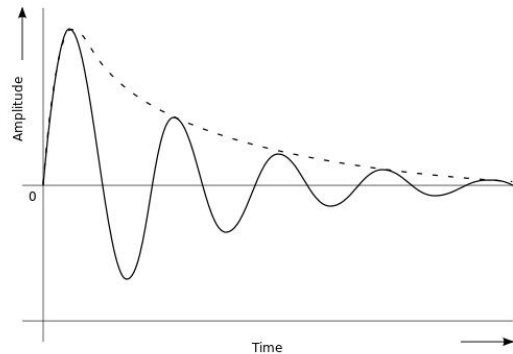
- 1) **Free Vibrations:** A force can set a resting object into motion. But when the force is a short-lived or momentary, it only begins the motion. The object moves back and forth, repeating the motion over and over again.

*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 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. The mechanical energy of the object is lost to other objects. Without a sustained forced vibration, the back and forth motion of the object eventually ceases as energy is dissipated to other objects.



**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 a closed glass box.

**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) Another example is swing of a child, which acts as a pendulum. The force with a frequency that matches with the natural frequency of the swing (its resonant frequency) makes the swing go higher and higher (maximum amplitude), while

attempts to push the swing at a faster or slower rate produce smaller amplitude. This is due to the fact that swing absorbs maximum energy when the force matches with natural frequency of swing.

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.

## 1.6 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 audible to human ears and is called audible range.
- 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. They are 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.

## 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.

**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.

### **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:

$$T = \frac{0.16 V}{\sum a \times S}$$

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

$$\text{Here } \sum a S = a_1 S_1 + a_2 S_2 + a_3 S_3 + \dots$$

where a<sub>1</sub>, a<sub>2</sub>, a<sub>3</sub> etc. are absorption coefficients of different objects in hall and s<sub>1</sub>, s<sub>2</sub>, s<sub>3</sub> 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

$$d = \frac{V \cdot t}{2}$$

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 16.6m 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. *Provide 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.

### ULTRASONICS

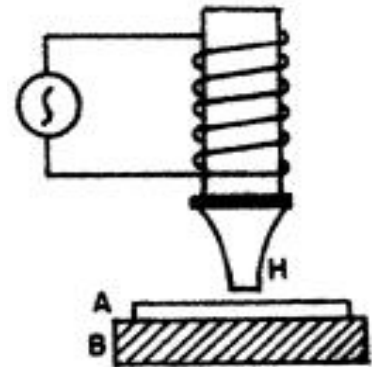
The sound waves having frequency more than 20 kHz are called ultrasonics. Their characteristics are:

- 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, Piezo electric 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 magnetostriction 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 Fig. 7.7.



**Fig. 7.7** Ultrasonic drilling

- 2) **Ultrasonic welding (cold welding):** The setup is shown in Fig. 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.

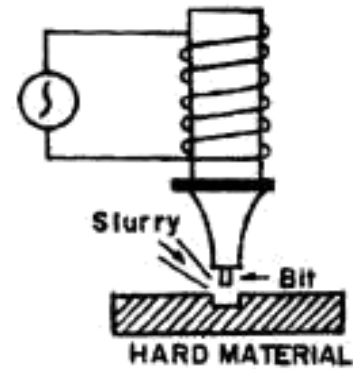


Fig. 7.8 Cold welding

- 3) **SONAR:** 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 between the transmitter and the remote object is determined using the formula

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

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 Fig. 7.9.

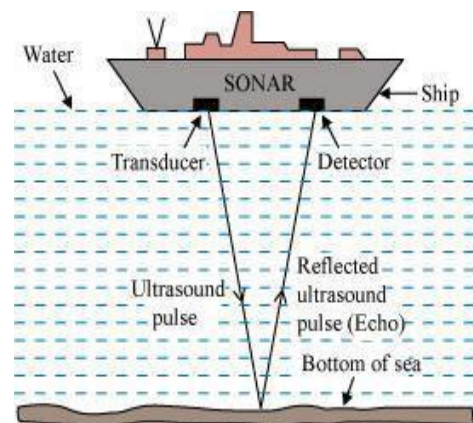


Fig. 7.9 Sound navigation and ranging

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

**Solution:**

Given, Velocity ( $V$ ) = 1.5km/s =

1.5 × 1000 = 1500m/s Frequency ( $\nu$ ) = 4.1MHz =  $4.1 \times 10^6$ Hz

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

$$\text{Wavelength, } \lambda = \frac{V}{\nu} = \frac{1500}{4.1 \times 10^6} = 3.65 \times 10^{-4} \text{ m} = 36.5 \text{ mm}$$

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

**Solution:** Given

Velocity of sound,  $V$  = 330m/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 =  $2d$

$$\begin{aligned}\text{Thus, } 2d &= V \times t = 330 \times 1 = 330\text{m} \\ d &= \frac{330}{2} = 165\text{m}\end{aligned}$$

\* \* \* \* \*

### EXERCISES

#### Multiple Choice Questions:

1. In \_\_\_\_\_ waves, matter in the medium moves forward and backward in the same direction the wave travels.  
A) Transverse  
B) Longitudinal  
C) Radio  
D) Ocean
2. When the vibrations of a body are maintained by its own elastic forces then such vibrations are called \_\_\_\_\_.  
A) Free vibrations  
B) Forced vibrations  
C) Resonant vibrations  
D) None of them
3. Sound wave cannot get \_\_\_\_\_.  
A) Reflected  
B) Refracted  
C) Diffracted  
D) Polarised
4. Echo is caused due to \_\_\_\_\_ of sound.  
A) Interference  
B) Diffraction  
C) Reflection  
D) Refraction
5. Perfect absorber has absorption coefficient of \_\_\_\_\_.  
A) 0  
B) 1  
C) Maximum  
D) Infinity
6. Standard reverberation time is given by \_\_\_\_\_.

- A) Sabine's formula
  - B) Newton's formula
  - C) Kepler's formula
  - D) None of these.
7. Which type of waves does not require matter to carry energy?
- A) Mechanical waves
  - B) Sound waves
  - C) Light waves
  - D) Ultrasonic waves.
8. In \_\_\_\_\_ waves, matter in the medium moves back and forth at right angles to the direction the wave travels.
- A) Transverse
  - B) Longitudinal
  - C) Mechanical
  - D) Sound
9. \_\_\_\_\_ is the distance from the top of one crest of a transverse wave to the top of the next crest in that wave.
- A) Wavelength
  - B) Amplitude
  - C) Frequency
  - D) Wave velocity
10. The velocity of sound waves in vacuum is \_\_\_\_\_.
- A) 220m/s
  - B) 332 m/s
  - C) 0
  - D) 360 m/s
11. Which of the following is not the application of ultrasonic?
- A) Drilling
  - B) Welding
  - C) Sonar
  - D) Radar
12. Wave is a form of disturbance. (True / False)
13. In SHM, acceleration is directly proportional to displacement. (True / False)
14. The vibrations in which amplitude of vibrations remains constant are called damped vibration. (True / False)
15. The minimum distance of an obstacle for echo to be heard is 16.6 m. (True / False).
16. Sound waves cannot travel in outer space because these are mechanical waves. (True / False).

**Short answer type questions:**

1. Define Wave motion.
2. What are types of wave motion?
3. Differentiate between transverse and longitudinal waves.
4. Define amplitude and wavelength of a wave.
5. Give relation between time period and frequency of a wave.
6. Define Simple Harmonic Motion.
7. What is a cantilever?
8. Define acoustics of buildings.
9. What is Sabine's formula?
10. Define Ultrasonic waves.
11. Establish the relation between velocity, frequency and wavelength?
12. Give full form of SONAR.
13. Name different types of vibrations.
14. What are resonant vibrations?
15. What are damped and undamped vibrations?

**Long answer questions:**

- 1) What is wave motion? Explain transverse and longitudinal wave motion with examples.
- 2) Define the terms; wave velocity, frequency and wave length. Drive the relationship between them.
- 3) Describe Simple Harmonic Motion. Give its characteristics.
- 4) What is a cantilever? Write the formula for its time period.
- 5) What are acoustics and acoustics of buildings?
- 6) Explain the terms: reverberation, reverberation time and echo.
- 7) What is coefficient of absorption of sound? Give its units.
- 8) List various methods to control reverberation time.
- 9) Explain free, forced and resonant vibrations with examples.
- 10) What is ultrasonic? Explain their engineering applications.

**Answer to multiple choice questions:**

- |      |      |          |           |
|------|------|----------|-----------|
| 1. B | 5. B | 9. A     | 13. True  |
| 2. A | 6. A | 10. C    | 14. False |
| 3. D | 7. C | 11. D    | 15. True  |
| 4. C | 8. A | 12. True | 16. True  |

## Chapter 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:

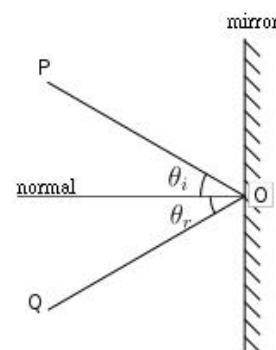
- Light travels in straight-line paths.
- It bends, or split into part, at the interface between two different media.
- It follows curved paths in a medium where refractive index changes.
- It may be reflected, absorbed or transmitted.

### 2.1 REFLECTION AND REFRACTION OF LIGHT

#### Reflection of Light

*Reflection is the bouncing back of light at an interface between two different media.*

Glassy surfaces such as mirrors exhibit specular 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. PO is the light ray incident on a glass mirror at an angle  $\theta_i$  (angle of incident) and OQ is the light ray reflected from the surface at an angle  $\theta_r$  (angle of reflection).



#### Laws of reflection:

- 1) The incident and reflected ray and the normal, all lie in same plane, and

**Fig. 8.1** Reflection of light

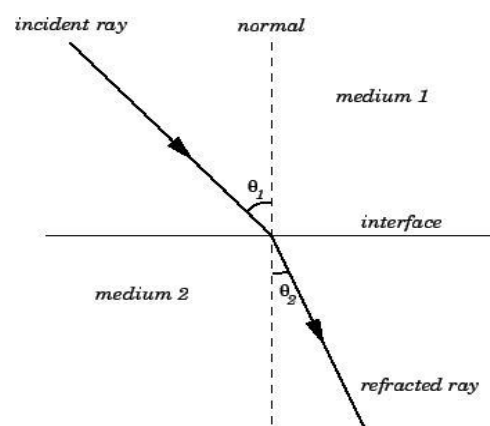
- 2) The angle between the incident ray and the normal is the same as that between the reflected ray and the normal i.e.  $\theta_i = \theta_r$

## 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.



### 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 ( $\theta_1$ ) to the sine of refracted angle ( $\theta_2$ ) is a constant for that pair of media **Fig. 8.2** Refraction of light and is equal to the **refractive index** of that media. This is also known as **Snell's law**

$${}_1\mu = \frac{\sin \theta_1}{\sin \theta_2} = \frac{\sin i}{\sin r}$$

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,

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

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.

The refractive index of some material varies with position and time. In such medium, light travels in curved path rather than straight lines. This is responsible for mirage effect observed on hot day due to different refractive index of air that causes light to bend, creating specular reflections in distance(as if water on the surface of a pool). The material having varying refractive index is useful in modern photocopy and scanning technologies.

## 2.2 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 converge at a point or appear to diverge from 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 focal length (f) of a convex lens is related to object distance (u) and image distance (v) as

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

The linear magnification of a lens is given by;  $m = \frac{v}{u}$  and holds for both convex and concave lenses and for real as well as virtual images.

### Power of lens

Power of a lens is defined as the reciprocal of the focal length measured in metres. The unit of power of lens is  $\text{m}^{-1}$  which is called **diopetre** indicated by symbol 'D'. In other words, one diopetre is the power of a lens of one metre focal length.

$$P = \frac{1}{f} \quad (f \text{ is taken in meters})$$

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.

$$P = P_1 + P_2$$

### 2.3 TOTAL INTERNAL REFLECTION (TIR)

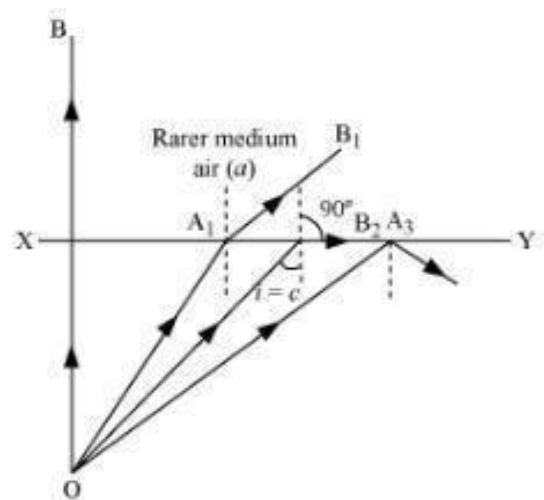
When light is reflected into a denser medium from an interface of the denser and a rarer medium, and there is no refracted light, the phenomenon is known as total internal reflection.

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.

The largest possible angle of incidence at the interface which results in a refracted ray is called the **critical angle**. At the critical angle of incidence, the refracted ray travels along the boundary between the two media i.e. the angle of refraction becomes  $90^\circ$ . 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:



**Fig. 8.3** Total internal reflection

$$\sin \theta_c = \frac{1}{\mu}$$

where  $\theta_c$  is the critical angle and  $\mu$  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.

## 2.4 Superposition of Waves

The [principle of superposition](#) states that when two or more waves overlap, the resulting displacement at any point is the algebraic sum of the individual wave displacements. The waves pass through each other without being permanently disturbed. This interaction results in constructive interference (amplified waves) or destructive interference (cancelled waves).

### Key Aspects of Superposition

- **Definition:** The total disturbance in a medium is the vector sum of individual disturbances
- **Constructive Interference:** Occurs when waves are in phase (crest meets crest), resulting in a larger amplitude, with a phase difference of  $(0, 2\pi, 4\pi, \dots)$ .
- **Destructive Interference:** Occurs when waves are  $\pi$  radians out of phase (crest meets trough), causing them to cancel out.
- **Independence:** Each wave retains its own character after passing through the superposition point.
- **Application:** Applies to all types of waves, including mechanical waves (sound) and electromagnetic waves (light).

## Interference

Wave interference is the phenomenon where two or more waves superpose (overlap) to form a resultant wave of greater, lower, or the same amplitude, based on their relative phases. It occurs in all wave types—including light, sound, and water—when waves meet while traveling along the same medium.

### Types of Wave Interference

- **Constructive Interference:** Occurs when the crest of one wave aligns with the crest of another, increasing the overall amplitude (making the wave larger).
- **Destructive Interference:** Occurs when the crest of one wave meets the trough of another, reducing or completely canceling the amplitude.

## Diffraction

Diffraction is the bending, spreading, and scattering of waves (light, sound, water) as they encounter obstacles or pass thro

ugh narrow openings. It occurs because waves bend around edges into the geometrical shadow region. This phenomenon is most pronounced when the obstacle size is comparable to the wave's wavelength.

#### Key Aspects of Diffraction

- **Mechanism:** Diffraction occurs when a wave encounters an obstacle or passes through a slit, causing it to bend around corners or spread out.
- **Wavelength Dependence:** The amount of bending depends on the wavelength; longer wavelengths generally exhibit more pronounced diffraction
- **Wave Property:** This behavior is characteristic of all types of waves, including sound waves, light waves, X-rays, and even particles like electrons.
- **Shadow Effect:** Diffraction causes sharp shadows to blur, as waves bend into the region of geometrical shadow behind an object.
- **Applications:** It is used in technology to separate light into colors (spectroscopy), study molecular structures (X-ray crystallography), and create holograms.

#### Polarization

Polarization is the process of restricting light's transverse electric field vibrations to a single plane, converting unpolarized light (vibrating in all directions) into polarized light. Key types include linear, circular, and elliptical polarization. Methods include filters (polaroids), reflection (Brewster's angle), scattering, and double refraction.

### 2.5 OPTICAL INSTRUMENTS

An optical instrument is a device which is used to view the objects. The eye is basic and essential 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.

In the present scope, we will study about two optical instruments; microscopes and telescopes.

**a) Microscope:** *A microscope is an optical instrument which enables us to see magnified image of objects that are too small to be seen by the naked eye. 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 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.

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

1. **Astronomical** (to see astronomical objects): It is used to see heavenly objects like stars and planets. The image formed in an astronomical telescope is inverted.

2. **Terrestrial** (To see objects on earth): 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.



Fig. 8.5A Telescope

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.

## 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 experiments in schools and colleges.

### 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 +4D. What is its focal length?

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

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

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

Thus, focal length of lens is 25cm

**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,  $u = -30 \text{ cm} = -0.3 \text{ m}$ , and  $f = 0.2 \text{ m}$

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

or

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

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

**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 ( $\lambda$ ) = 600 nm =  $600 \times 10^{-9} \text{ m}$  (1 nm =  $10^{-9} \text{ m}$ ).

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

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

\* \* \* \* \*

## EXERCISES

### Multiple Choice Questions:

1. The speed of light in vacuum is \_\_\_\_\_.  
A)  $3 \times 10^8$  m/s  
B)  $3 \times 10^{10}$  m/s  
C)  $3 \times 10^8$  cm/s  
D)  $3 \times 10^{10}$  mm/s
2. Spectrum is formed due to \_\_\_\_\_ of light.  
A) Reflection  
B) Refraction  
C) Diffraction  
D) Dispersion
3. A \_\_\_\_\_ lens is thick at centre and thin at ends.  
A) Concave  
B) Convex  
C) Plano-concave  
D) Plano-convex
4. A transparent medium bound by two curved surfaces is called \_\_\_\_\_.  
A) Mirror  
B) Prism  
C) Lens  
D) Binocular
5. Light travels in \_\_\_\_\_.  
A) Straight line  
B) Circular path  
C) Harmonic path  
D) Curved path
6. A lens is an optical device based on \_\_\_\_\_.  
A) Reflection  
B) Total internal reflection  
C) Diffraction  
D) Refraction
7. Changing path of light while entering second medium is called \_\_\_\_\_.  
A) Diffraction  
B) Reflection  
C) Refraction  
D) polarization
8. Power of a lens is measured in \_\_\_\_\_.  
A) Metre  
B) Watt  
C) Diopetre  
D) Volt

9. Power of a lens is always \_\_\_\_\_.  
 A) Inverse of focal length  
 B) Equal to focal length  
 C) Double the focal length  
 D) Not related to focal length
10. Simple microscope uses \_\_\_\_\_.  
 A) One concave lens  
 B) One convex lens  
 C) Two concave lens  
 D) Two convex lens
11. Simple microscope is also known as Magnifying glass (True/ False).
12. Telescope that uses three lenses is called Terrestrial telescope. (True / False)
13. An instrument that forms image on screen is called Camera. (True / False)
14. Refractive index of a medium is constant. (True / False)
15. Two lenses are used in a simple microscope. (True / False)

#### Short answer questions:

1. What are laws of reflection?
2. State laws of refraction.
3. What is Total Internal Reflection (TIR)?
4. What is critical angle?
5. Define principal focus of a lens.
6. What is lens formula?
7. What is power of a lens?
8. Give the relation between focal length and power of a lens.
9. What is a microscope?
10. What is a telescope?

#### Long answer questions:

1. Explain phenomenon of reflection of light and laws governing it.
2. Explain with diagram the refraction of light.
3. What is refractive index? How it is related to Snell's law.
4. Describe total internal reflection. Give two applications of TIR.
5. What is critical angle? Explain conditions necessary for TIR.
6. What is a microscope? Give its types and uses.
7. What is a telescope? Give various uses of telescope.

#### Answers to multiple choice questions:

- |      |       |          |          |           |          |           |      |
|------|-------|----------|----------|-----------|----------|-----------|------|
| 1. A | 2. D  | 3. B     | 4. C     | 5. A      | 6. D     | 7. C      | 8. C |
| 9. A | 10. B | 11. True | 12. True | 13. False | 14. True | 15. False |      |

## Chapter 3

# ELECTROSTATICS AND ELECTRICITY

**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.*
- *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*

The branch of physics which deals with the study of charges at rest is called electrostatics.

### 3.1. 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).

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

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

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 never changes. It 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 charge of any object is an **integer** multiple of the elementary charge (e). Thus, an object's charge can be exactly 0 e, or exactly 1 e, -1 e, 2 e, etc.,

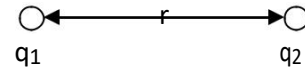
### 3.2. COULOMB LAW OF ELECTROSTATICS

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



$$F \propto q_1 q_2$$

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

$$\Rightarrow F \propto \frac{q_1 q_2}{r^2} \quad \dots\dots\dots(1)$$

$$F = K \frac{q_1 q_2}{r^2} \quad \dots\dots\dots(2)$$

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

$$K = \frac{1}{4\pi\epsilon_0} = 9 \times 10^9 \text{ Nm}^2/\text{C}^2 \text{ (in SI units system)}$$

Now from equation (2)

$$F = \frac{q_1 q_2}{4\pi\epsilon_0 r^2} \quad \dots\dots\dots(3)$$

Here  $\epsilon_0$  is electrical permittivity of vacuum. Its value is  $8.854 \times 10^{-12} \text{ N}^{-1} \text{ m}^{-2} \text{ C}^2$ .

$$\text{Let } q_1 = q_2 = q$$

$$r = 1 \text{ m}$$

then from equation (3)  $F = 9 \times 10^9 \text{ N}$

Thus *one coulomb is that much charge which produces a force of  $9 \times 10^9 \text{ N}$  at a unit charge placed at a distance of 1 m.*

Smaller units of charge;      milli Coulomb (mC) =  $10^{-3} \text{ C}$ .  
                                          micro Coulomb ( $\mu\text{C}$ ) =  $10^{-6} \text{ C}$ .

### 3.3. ELECTRIC FIELD

*It is the area 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  $\text{N/C}$  (Newton per Coulomb)

#### Electric Lines of Force:

An electric line of force is an imaginary continuous line or curve drawn in an electric field such that tangent to it at any point gives the direction of electric force at that point (Fig. 9.1).

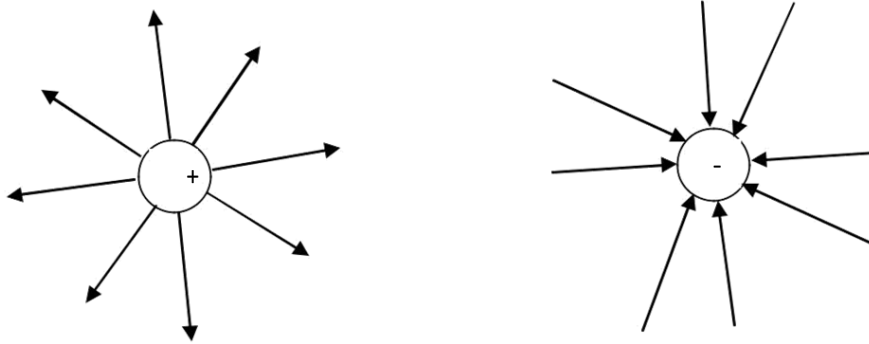


Figure 9.1

### Properties of electric lines of force

- Lines of force originate from a positive charge and terminate to a negative 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

### 3.4. 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  $\psi$  (psi).

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

$$\psi = \oint \vec{E} \cdot d\vec{S} \text{ is called electric flux.}$$

### GAUSS'S LAW

It states that net electric flux of an electric field over a closed surface is equal to the net charge enclosed by the surface divided by  $\epsilon_0$  i.e.

$$\psi = \oint \vec{E} \cdot d\vec{S}$$

$$\psi = \oint_s \vec{E} dS \cos \theta = \frac{q}{\epsilon_0}$$

**Proof:** Consider a closed surface  $S$  having a charge  $q$  placed at a point  $O$  inside a closed surface as shown in Fig. 9.2. Take a point  $P$  on the surface and consider a small area  $dS$  around  $P$ .

$$OP = r$$

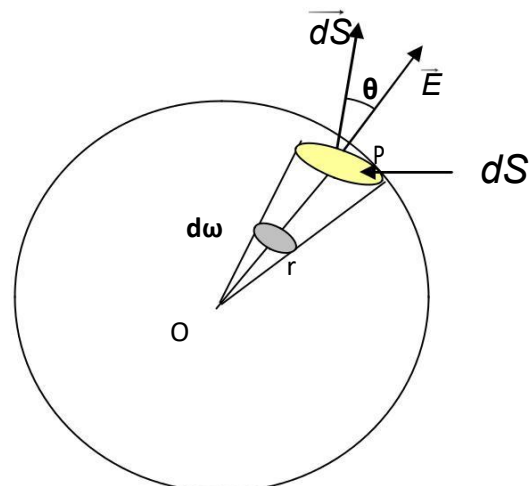


Figure 9.2

Then Electric field at  $P$  is

$$E = \frac{q}{4\pi\epsilon_0 r^2} \dots\dots\dots(1)$$

Now electric flux

$$\psi = \oint_S E dS \cos \theta$$

Putting value of  $E$  we get

$$\psi = \oint_S \frac{q}{4\pi\epsilon_0 r^2} dS \cos \theta$$

$$\psi = \frac{q}{4\pi\epsilon_0} \oint_S \frac{dS \cos \theta}{r^2}$$

$$\psi = \frac{q}{4\pi\epsilon_0} \oint_S d\omega$$

$$\psi = \frac{q}{4\pi\epsilon_0} \cdot 4\pi$$

$$\psi = \frac{q}{\epsilon_0}$$

$$\text{Hence, } \psi = \oint_S E dS \cos \theta = \frac{q}{\epsilon_0}$$

$$\therefore \frac{dS \cos \theta}{r^2} = d\omega$$

$\therefore$  Total Solid angle  $= 4\pi$

## 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  $\theta$  is angle between  $\vec{E}$  and Area vector as shown in Fig. 9.3.

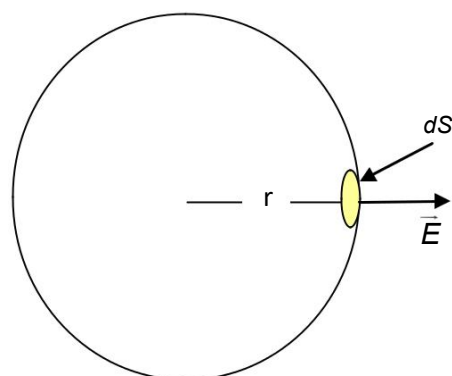


Figure 9.3

Now flux

$$\psi = \oint_S E dS \cos \theta = \frac{q}{\epsilon_0}$$

( $\because \theta = 0$ )

$$\oint_S E dS = \frac{q}{\epsilon_0}$$

$$\Rightarrow E \cdot 4\pi r^2 = \frac{q}{\epsilon_0}$$

( $\because$  Area of Sphere  $= 4\pi r^2$ )

$$\Rightarrow \boxed{E = \frac{q}{4\pi\epsilon_0 r^2}}$$

Thus the electric intensity decreases with increase in distance.

### 3.5. CAPACITOR

It is an electronic component that stores electric charge.

#### Capacitance

The ability of a system to store an electric charge.

As potential is proportional to charge

$$\begin{aligned} V &\propto q \\ \text{or } q &\propto V \\ q &= CV \\ C &= \frac{q}{V} \end{aligned}$$

Unit of capacitance: Farad (F), microfarad

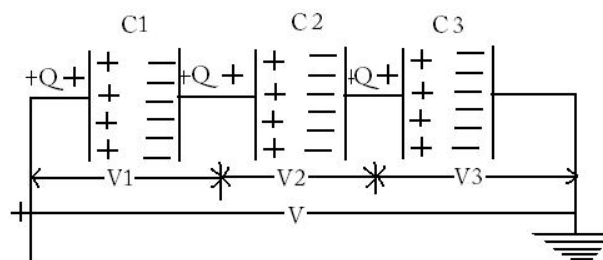
#### Grouping of Capacitors

##### Series Grouping:

A number of capacitors are said to 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 3 capacitors of capacitances  $C_1, C_2, C_3$  in series. Let  $V$  is total applied voltage.

$V_1, V_2, V_3 \rightarrow$  **voltage drops across  $C_1, C_2, C_3$**  as shown in fig. 9.4.



**Figure 9.4**

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

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

$$\text{So, } V = \frac{q}{C_1}, V = \frac{q}{C_2}, V = \frac{q}{C_3}$$

Putting in Equation (1)

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

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

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 is same.

Consider 3 capacitors of capacitances  $C_1, C_2, C_3$  connected in parallel let  $V$  is applied voltage.  $q_1, q_2, q_3 \rightarrow$  charges on capacitors  $C_1, C_2, C_3$  as shown in fig. 9.5

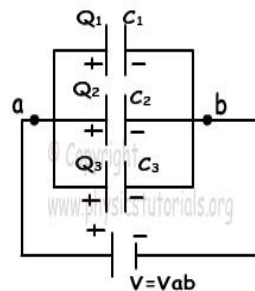


Figure 9.5

So

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

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

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

Put in equation (1)

$$CV = C_1 V + C_2 V + C_3 V$$

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

$$C = C_1 + C_2 + C_3$$

So the total capacitance increases in parallel grouping.

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

### Solved Numericals

**Example 1.** Calculate the coulomb force between two protons separated by a distance of  $1.6 \times 10^{-15}$  m.

**Solution:** Given, 2 protons; Charge on Proton =  $1.6 \times 10^{-19}$  C

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

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

$$\text{Also } \frac{1}{4\pi\epsilon_0} = 9 \times 10^9 \text{ Nm}^2/\text{C}^2$$

$$\frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r^2}$$

$$\text{Now } F = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r^2}$$

$$F = \frac{9 \times 10^9 \times 1.6 \times 10^{-19} \times 1.6 \times 10^{-19}}{(1.6 \times 10^{-15})^2}$$

$$F = 90 \text{ N}$$

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

**Solution :** Given,  $q_1 =$  Charge on alpha particle  $= 2 \times 1.6 \times 10^{-19} \text{ C}$   
 $q_2 =$  Charge on proton  $= 1.6 \times 10^{-19} \text{ C}$   
 distance,  $r = 5.12 \times 10^{-15} \text{ m}$   

$$\frac{1}{4\pi\epsilon_0} = 9 \times 10^9 \text{ Nm}^2/\text{C}^2$$

Now

$$F = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r^2}$$

$$F = \frac{9 \times 10^9 \times 3.2 \times 10^{-19} \times 1.6 \times 10^{-19}}{(5.12 \times 10^{-15})^2}$$

$$F = 17.58 \text{ N}$$

**Example 3.** Three Capacitors of capacitances  $3\mu\text{F}$ ,  $2\mu\text{F}$  and  $4\mu\text{F}$  are connected with each calculate total capacitance (a) In Series grouping (b) Parallel grouping.

**Solution:** Given,

$$C_1 = 3\mu\text{F}, \quad C_2 = 2\mu\text{F} \quad \text{and} \quad C_3 = 4\mu\text{F}$$

In Series grouping

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

$$\frac{1}{C_{\text{tot}}} = \frac{1}{3} + \frac{1}{2} + \frac{1}{4}$$

$$\frac{1}{C_{\text{tot}}} = \frac{4}{12} + \frac{6}{12} + \frac{3}{12} = \frac{13}{12}$$

$$C_{\text{tot}} = \frac{12}{13} \mu\text{F}$$

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

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

In Parallel grouping

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

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

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

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

**Solution:** Given,

$$C_1 = 1 \text{ F}, \quad C_2 = 2 \text{ F}, \quad C_3 = 3 \text{ F}$$

In series grouping

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

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

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

$$\therefore C_s = \frac{6}{11} \text{ F}$$

In Parallel grouping

$$C_p = C_1 + C_2 + C_3$$

$$C_p = 1 + 2 + 3$$

$$C_p = 6 \text{ F}$$

$$\therefore \text{Ratio} \quad \frac{C_p}{C_s} = \frac{6}{\frac{6}{11}} = 11$$

or

$$\frac{C_p}{C_s} = 11$$

### 3.6 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 flowing through the wire ( $I$ ) is given by the formula

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

where  $I$  = the electric current

$q$  = charge

$t$  = time taken

**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.

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

### 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.*

### Potential Difference (V)

It is the difference in electric potential between two points in an electric circuit, the work that has to be done in transferring unit positive charge from one point to other.

**Unit:**Volts (V)

### One Volt:

*It is defined as energy consumption of one joule per electric charge of one coulomb.*

$$1 = 1$$

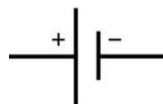
One volt is equal to current of 1 amp times resistance of 1 ohm.

### Direct Current

*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 flow from negative end of the battery to the positive end of the battery.

### Symbol of DC voltage source



It can be shown by Fig. 10.2.



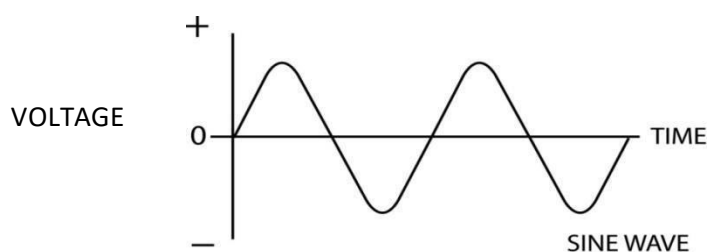
**Figure 10.2**

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

### AC (Alternating current)

As shown in Fig. 10.3, 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.

## 3.7 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.

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

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

### Symbol:



### Unit: Ohms ( $\Omega$ )

One Ohm:

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

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.

$$R \propto l \dots\dots\dots (1)$$

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

$$R \propto \frac{1}{A} \dots\dots\dots (2)$$

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

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

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

or

where  $\rho$  (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  $l = 1 \text{ m}$  and  $A = 1 \text{ m}^2$  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 ( $\Omega\text{m}$ )

### Conductivity

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

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

Where,  $\sigma$  is the conductivity and  $\rho$  is the resistivity of the conductor.

**Unit:** Siemens per meter or mho per meter

### Conductance (G)

It is the reciprocal of the resistance and it is a measure of ease with which the current flows through a substance.

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

where  $G$  = Conductance  
 $R$  = Resistance

**Unit:** mho

## 3.8 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. 10.5

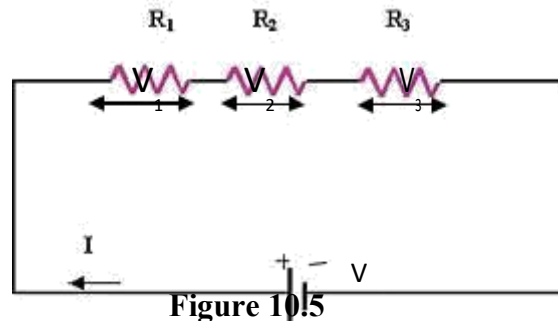


Figure 10.5

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

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

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

$$\text{get } IR = I R_1 + I R_2 + I R_3$$

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

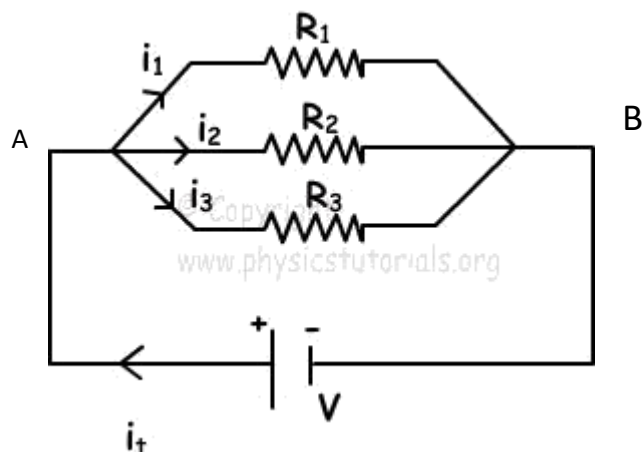
$$R = (R_1 + R_2 + R_3)$$

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. 10.6. One end of each resistance is connected to point A and the other end of each resistance is connected to the point B.



**Figure 10.6**

Let

$V$  = Potential Difference applied across A and

B Clearly, potential difference  $V$  is same across each resistance.

Let  $I$  = 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.

### 3.9 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 then

$$V \propto I$$

$$V = R I$$

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

Therefore,  $R = \frac{V}{I} = \frac{\text{Potential Difference}}{\text{Electric Current}}$

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  $I =$

If a graph is drawn between current (I) and the potential difference (V) it will be a straight line for a conductor (Fig. 10.4).

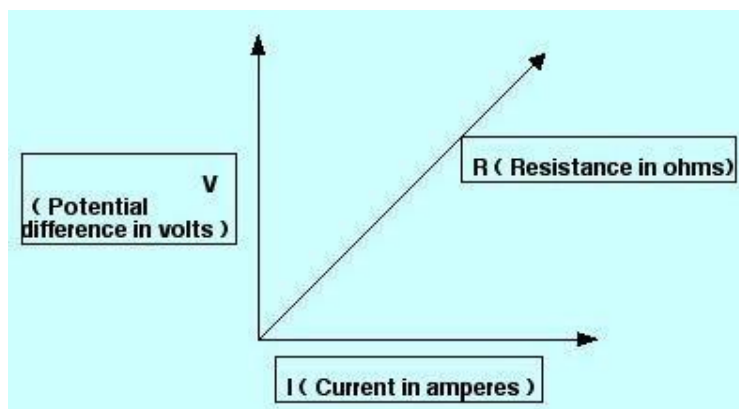


Figure 10.4

### Solved Numericals

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

**Solution.** Given,  $V = 6 \text{ V}$  and  $I = 2 \text{ A}$

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 100ohms. It is plugged into potential difference of 220 V. How much current passes through the fan?

**Solution.** Given,  $R = 100 \text{ ohms}$  and  $V = 220 \text{ V}$

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

Therefore  $I = 2.2 \text{ A}$

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

**Solution.** Given resistances,  $R_1 = 1\text{ohm}$ ,

$R_2 = 2 \text{ ohm}$

$R_3 = 3 \text{ ohm}$

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

Therefore  $R = 1 + 2 + 3 = 6 \text{ ohm}$

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

**Solution.** Given,  $R_1 = 4\text{ohm}$

$R_2 = 1\text{ ohm}$

$R_3 = 6\text{ ohm}$

Form formula we know in parallel combination

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

Hence 
$$\frac{1}{R} = \frac{1}{4} + \frac{1}{1} + \frac{1}{6} = \frac{3 + 12 + 2}{12} = \frac{17}{12}$$

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

## **EXERCISES**

### **Multiple Choice questions**

- 1) Coulomb's law is only true for point charges whose sizes are
  - A. Medium
  - B. very large
  - C. very small
  - D. none of the above
- 2) As per Coulomb's law, force of attraction or repulsion between two point charges is directly proportional to
  - A. sum of the magnitude of charges
  - B. square of the distance between them
  - C. product of the magnitude of charges
  - D. cube of the distance
- 3) If F is force acting on test charge  $q_0$ , electric field intensity E would be given by
  - A.  $E = F - q_0$
  - B.  $E = F/q_0$
  - C.  $E = F + q_0$
  - D.  $E = q_0/F$
- 4) In combination of capacitors in series, capacitors are connected
  - A. Parallel
  - B. side by side
  - C. up and down
  - D. none of the above
- 5) Coulomb's force between 2 point charges  $10\mu\text{C}$  and  $5\mu\text{C}$  placed at a distance of 150cm is
  - A. 0.2 N
  - B. 0.5 N
  - C. 2 N
  - D. 10 N
- 6) A device which stores charge is called
  - A. Resistor
  - B. Inductor
  - C. Capacitor
  - D. transistor

- 7) If medium between two charges is air, then value of constant  $k$  in SI units will be
- $5 \times 10^9 \text{ Nm}^2 \text{C}^{-2}$
  - $7 \times 10^9 \text{ Nm}^2 \text{C}^{-2}$
  - $8 \times 10^9 \text{ Nm}^2 \text{C}^{-2}$
  - $9 \times 10^9 \text{ Nm}^2 \text{C}^{-2}$
- 8) 1 micro farad ( $1\mu\text{F}$ ) is equal to
- $1 \times 10^{-9} \text{ F}$
  - $1 \times 10^{-12} \text{ F}$
  - $1 \times 10^{-6} \text{ F}$
  - $1 \times 10^{-10} \text{ F}$
- 9) In equation  $Q=CV$ ,  $C$  is constant of proportionality called capacitor's
- Power
  - Capacitance
  - Heat
  - Electric intensity
- 10) The force between two charges is 120 N. If the distances between the charges is doubled, the force will be
- 60 N
  - 30 N
  - 40 N
  - 15 N
- 11) SI unit of charge is
- Coulomb
  - Volt
  - Newton
  - Joule
- 12) The law governing force between electric charges is
- Gauss Law
  - Coulomb's law
  - Biot- Savart Law
  - Ampere's Law
- 13) Farad is the unit of
- Capacitance
  - Electric Potential
  - Force
  - Torque
- 14) Three capacitors of  $2\mu\text{F}$  are joined in parallel; their resultant capacitance is
- $6\mu\text{F}$
  - $10\text{nF}$
  - $6\text{nF}$
  - $1.5 \mu\text{F}$
- 15) Unit of Electric intensity is
- N/Coulomb
  - Joule
  - Newton
  - Coulomb
- 16) Two capacitors of 2 farad are joined in series their resultant is
- 1 F
  - 4 F
  - 3 F
  - 0.5 F

### Short Answer Questions

1. Define Electric Field
2. What are Electric Lines of force ?
3. Define the term Capacitance.
4. What is Electric flux?
5. Define Capacitor
6. What do you mean by Electric Potential?
7. Define Electric Intensity.
8. State Coulomb's Law
9. Derive expression for electric intensity at a point due to point charge.
10. Explain properties of electric lines of force.
11. Calculate total capacitance in series combination.
12. Calculate total capacitance in parallel combination
13. Explain Gauss's law
14. Define Electric Charge and its types.

### Long Answer Type Question

1. Calculate total capacitance when capacitors are connected in series and parallel grouping.
2. State and prove Gauss Law.
3. Using Gauss Theorem find electric field due to a point charge.
4. Derive Coulomb's Law.
5. Derive Coulomb's law from Gauss' law.
6. Use Gauss theorem to derive an expression for the electric field at a point due to a thin infinitely long straight line of charge of uniform charge density ?
7. Derive an expression for the electric field at a point due to uniformly charged spherical shell using Gauss' law.

### Answers to Multiple Choice Questions

|     |   |     |   |     |   |     |   |
|-----|---|-----|---|-----|---|-----|---|
| 1)  | C | 2)  | C | 3)  | B | 4)  | B |
| 5)  | A | 6)  | C | 7)  | D | 8)  | C |
| 9)  | B | 10) | C | 11) | A | 12) | B |
| 13) | A | 14) | A | 15) | A | 16) | A |

### Multiple Choice Questions

- 1) The resistance of the wire varies inversely as:
  - a) Area of cross section
  - b) Resistivity
  - c) Length
  - d) Temperature
- 2) The curve representing Ohm's Law is a
  - A. Linear
  - B. Cosine Function
  - C. Hyperbola
  - D. Parabola
- 3) Resistance is a measure of a material's opposition to
  - A. Voltage

- B. Current
  - C. Electric Force
  - D. Movement of protons
- 4) Give the name of materials which contain lots of free electrons
- A. Insulators
  - B. Conductors
  - C. Semi-conductors
  - D. None of the above
- 5) Wire wound variable resistance is known as
- A. Capacitor
  - B. Resistor
  - C. Diode
  - D. Rheostat
- 6) Specific resistance of a wire can be measured by formula
- A.  $R/L$
  - B.  $RA/L$
  - C.  $RL/A$
  - D.  $A/RL$
- 7) Sum of all potential changes in a closed circuit is zero, stated law is called
- A. Kirchhoff's first rule
  - B. Kirchhoff's second rule
  - C. Kirchhoff's third rule
  - D. Kirchhoff's fourth rule
- 8) Ohmic devices are devices that consequently
- A. Obey Ohm's law
  - B. Obey Kirchhoff's law
  - C. Violate Ohm's law
  - D. Obey law of resistances.
- 9) Product of voltage and current is known as
- A. Work done
  - B. Power
  - C. Drift velocity
  - D. E.M.F.
- 10) Current of 0.75 A, when a battery of 1.5 V is connected to wire of 5 m having cross sectional area  $2.5 \times 10^{-7} \text{ m}^2$ , will have resistivity
- A.  $1 \times 10^{-7}$
  - B.  $1.1 \times 10^{-7}$
  - C.  $2 \times 10^{-7}$
  - D.  $2.1 \times 10^{-7}$
- 11) SI unit of electric potential is
- A. Ampere
  - B. Volt
  - C. Joule
  - D. Coulomb
- 12) SI unit of resistance is
- A. Ohm
  - B. Henry
  - C. Farad
  - D. Newton
- 13) Conductance is reciprocal of
- A. Resistance
  - B. Current

- C. Voltage
  - D. Length
- 14) SI unit of specific resistance is
- A. Ohm
  - B. Ohm metre
  - C. Square of Ohm metre
  - D. Farad

### Short answer question

1. What is Electric current?
2. Define Resistance.
3. Define Specific resistance.
4. What is Conductance?
5. Explain Alternating current and Direct current.
6. Calculate the total resistance when resistances are connected in series.
7. Calculate the total resistance when resistances are connected in parallel.
8. Explain ohm's law.
9. Write short note on electric power.
10. Explain Kirchhoff laws.
11. If a wire is stretched to double of its length. What will be the new resistivity?

### Long Answer type questions

1. Calculate the total resistance when resistances are connected in series and parallel.
2. Explain heating effect of current. Derive the formula for it and what are its applications?
3. a) Three resistors  $1\ \Omega$ ,  $2\ \Omega$  and  $3\ \Omega$  are combined in series. What is the total resistance of the combination?  
b) If the combination is connected to a battery of emf 12 V and negligible internal resistance, obtain the potential drop across each resistor.
4. Differentiate between AC and DC.
5. Explain Kirchhoff's law of current (KCL) and Kirchhoff's law of voltage (KVL).
6. If the resistance of a circuit is  $12\ \Omega$  and the current of 4 A passes through it calculate the potential difference. [Ans 48 V]
7. Electric fan takes a current of 0.5 amp when operated on a 200 V supply. Find the resistance. [Ans 440 ohms]
8. Calculate the total resistance when three resistances of 4 ohm, 8 ohm and 12 ohm are connected in series. [ Ans 24 ohm ]
9. Calculate the total resistance when resistances of 2 ohm and 2 ohm are connected in parallel. [ Ans 1 ohm ]
10. Calculate the power generated in a current of 2 A passes through a conductor having a potential difference of 220 V. [ Ans 440 W ]

### Answers to multiple choice questions

|    |   |     |   |    |   |    |   |
|----|---|-----|---|----|---|----|---|
| 1) | A | 2)  | A | 3) | B | 4) | B |
| 5) | D | 6)  | B | 7) | B | 8) | A |
| 9) | B | 10) | A |    |   |    |   |

## Chapter 4

# CLASSIFICATIONS OF MATERIALS AND THEIR PROPERTIES

**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.*
  
- *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*
- 

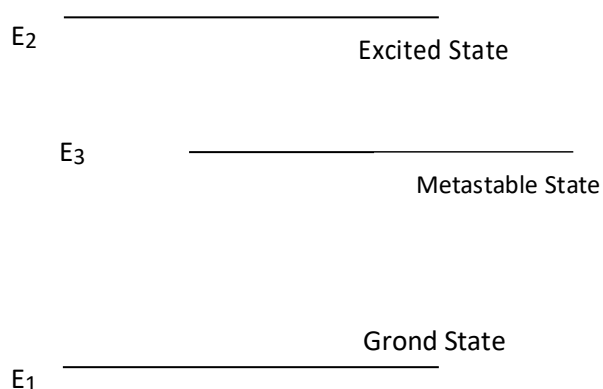
### 4.1 ENERGY LEVEL AND ENERGY BANDS

#### 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:

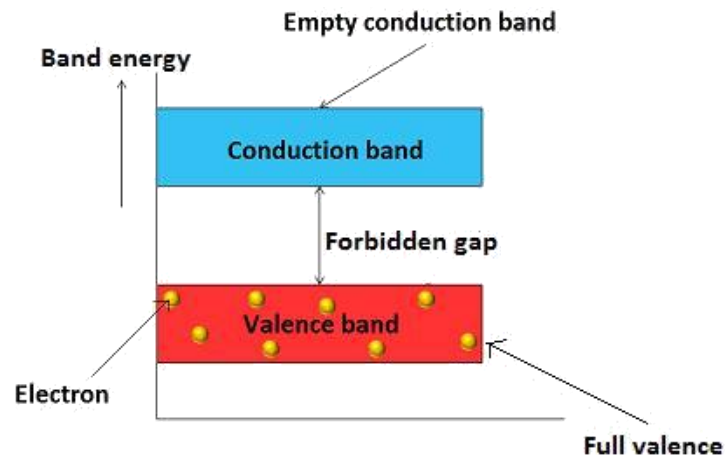
1. **Ground level:** This refers to the lowest energy state in the system ( $E_1$ ). Thus the completely de-excited atoms would occupy this level.



2. **Excited level:** any level above the ground state is excited state ( $E_2$ ). 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 lies in between the excited and ground levels ( $E_3$ ). Its lifetime is 100 times more than excited state.

### **Energy Bands:**

When 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.

## 4.2 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  $E_g = 5 - 6 \text{ eV}$ . 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.

**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  $1 - 2 \text{ eV}$ .

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) etc.

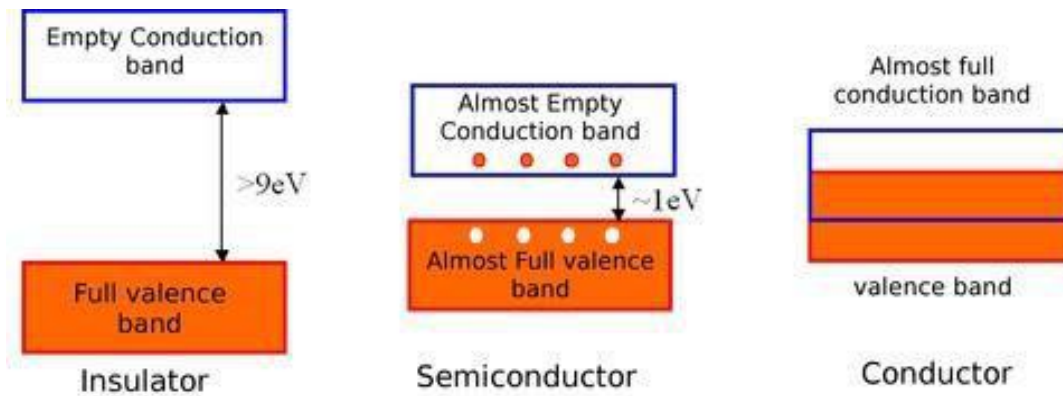


Figure 12.2

## 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).

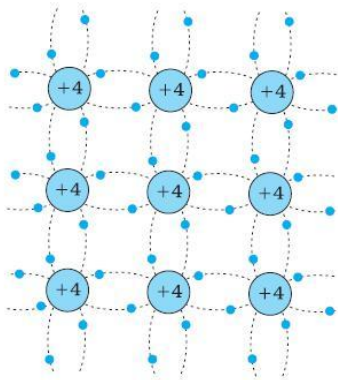


Figure 12.3

They have four valence electrons. Each of the four electrons forms a *covalent bond* with neighboring 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.  $n_e = n_h$

## Extrinsic Semiconductors

A doped semiconductor is called an extrinsic semiconductor. The addition of a desirable impurity to a semiconductor is called **doping** and the impurity atoms added are called dopants.

### 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.  $n_e \gg n_h$

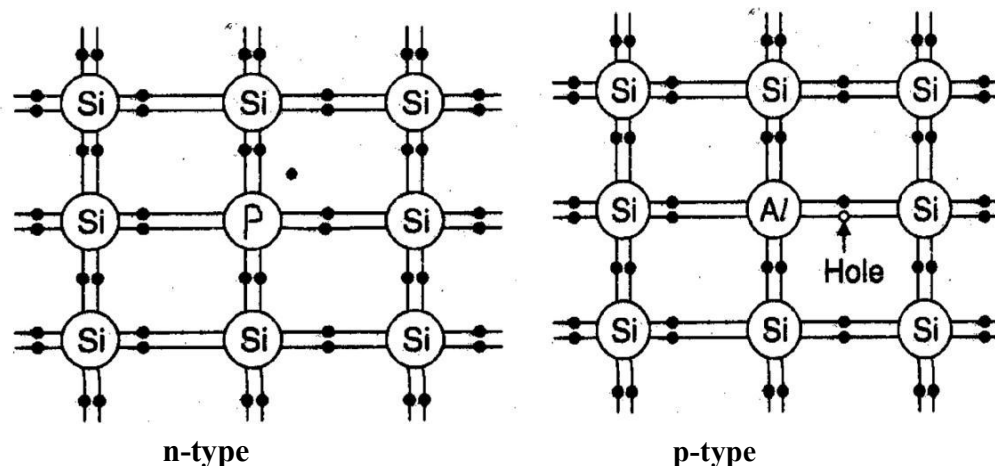


Figure 12.4

### p-Type Semiconductor:

When a small amount of trivalent impurity (e.g. Boron, Aluminum 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.  $n_h \gg n_e$

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

## 4.3 INTRODUCTION TO MAGNETISM

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/meter

### **Magnetic Intensity (H):**

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

### **Magnetic Permeability ( $\mu$ ):**

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

### **Magnetic susceptibility ( $\chi$ ):**

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. The magnetic dipoles in these substances tend to align opposite to the applied field and tends 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

#### **2. Paramagnetic materials:**

Paramagnetic substances are those which get weakly magnetized when placed in an external magnetic field. 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.

### 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.

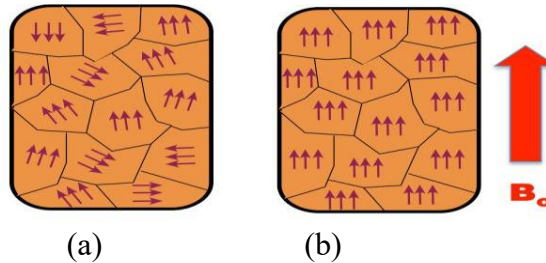


Figure 11.1

These domains are usually randomly oriented as shown in Fig. 11.1 (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. 11.1 (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.

## 4.2 MAGNETIC FIELD

The space around a magnetic material or a moving electric charge within which the force of magnetism can be experienced.

Unit: Tesla ( $\text{Wb/m}^2$ )

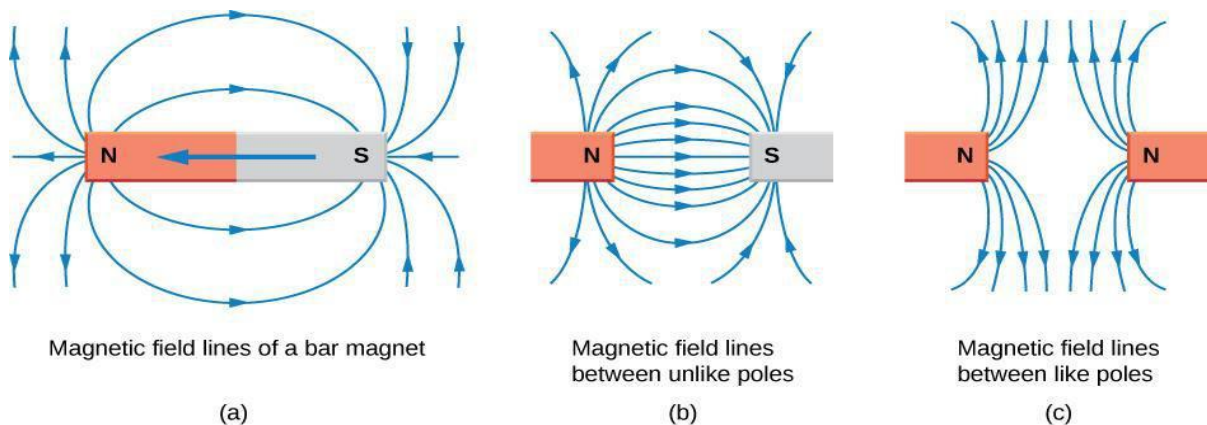


Figure 11.2

### 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. 11.2).

### Properties of magnetic lines of force

- (i) The magnetic field lines of a magnet form 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.

## 4.5 ELECTROMAGNETIC INDUCTION

The induction of an electromotive force by the motion of a conductor across a magnetic field or by a change in magnetic flux in a magnetic field is called **electromagnetic induction**.

It is used in electrical motor, generator etc. to generate electricity.

### EXERCISES

#### Multiple Choice Questions

- 1) What kind of a device is a diode?
  - A. Bilateral
  - B. Linear
  - C. Nonlinear
  - D. Bipolar
- 2) How is nonconducting diode biased?
  - A. Forward
  - B. Inverse
  - C. Poorly
  - D. Reverse
- 3) When the diode current is large, the bias is
  - A. Forward
  - B. Inverse

- C. Poor
- D. Reverse

- 1) The direction of a magnetic field within a magnet is
  - A. Front to back
  - B. north to south
  - C. south to north
  - D. west to south
- 2) When the speed at which a conductor is moved through a magnetic field is increased, the induced voltage
  - A. Increases
  - B. decreases
  - C. reaches zero
  - D. remains constant
- 3) An electromagnetic field exists only when there is
  - A. Current
  - B. voltage
  - C. increasing current
  - D. decreasing current
- 4) When the north poles of two bar magnets are brought close together, there will be
  - A. No force
  - B. Downward force
  - C. Force of attraction
  - D. Force of repulsion
- 5) E.M.F can be induced in a circuit by
  - A. changing magnetic flux density
  - B. changing area of circuit
  - C. changing the angle
  - D. all of above
- 6) Total number of magnetic field lines passing through an area is called
  - A. magnetic flux density
  - B. magnetic flux
  - C. e.m.f
  - D. voltage
- 7) Basic source of magnetism \_\_\_\_\_.
  - A. Charged particles alone
  - B. Movement of charged particles
  - C. Magnetic dipoles
  - D. Magnetic domains
- 8) Example for para-magnetic materials
  - A. super conductors
  - B. alkali metals

- C. transition metals
  - D. Ferrites
- 9) Example for ferro-magnetic materials
- A. super conductors
  - B. alkali metals
  - C. transition metals
  - D. Ferrites

### **Short answer Questions**

1. What do you mean by energy level?
2. Define energy band.
3. What do you mean by forbidden gap?
4. What is conduction and valance band in material?
5. What is unit used for measuring Forbidden gap?
6. What is forbidden gap for Si, Ge?
7. Explain type of material on the basis of Energy band.
8. Differentiate between a conductor and an insulator.
9. Define Semiconductor with example
10. Define Doping.
11. What are Dopants?
12. What are p- type semiconductors?
13. What are n- type semiconductors?
14. What is intrinsic semiconductor?
15. What is extrinsic semiconductor?
16. Define magnetic flux and write its unit.
17. Define electromagnetic induction with example
18. Define magnetic field.
19. What is unit of magnetic field?
20. What is magnetic susceptibility?
21. Write applications of EMI.
22. Define magnetic field intensity.
23. What is the relation between Magnetization and Magnetic field?

### **Long answer Questions**

1. Distinguish between conductors and semiconductors.
2. What is meant by energy band? How is it formed?
3. What does doping mean? How do we obtain the p and n type semiconductor?
4. What is the difference between intrinsic and extrinsic semiconductors?
5. What are magnetic lines of force? Write their properties.
6. Explain type of magnetic materials.
7. Explain ferromagnetic materials with their magnetic domains theory.

8. Explain difference between electric field and magnetic field.
9. Differentiate between paramagnetic and ferromagnetic materials with examples.
10. What is electromagnetic induction? Give its application along with its working.

## Chapter 5

### 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.*

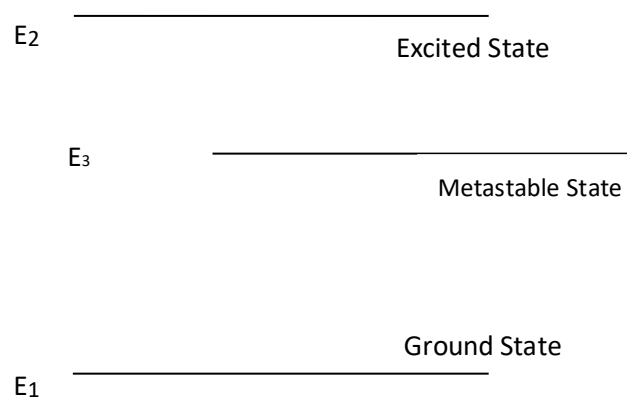
#### 5.1 LASER

**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 type of energy levels:

1. **Ground level:** This refers to the lowest energy state in the system ( $E_1$ ). 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 ( $E_2$ ). The atom can stay in excited state only for a very short time varying from  $10^{-8}$  to  $10^{-10}$  s. 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 ( $E_3$ ). Its lifetime is 100 times more than excited state and atom can stay in this state for a longer time.

## The Emission Process

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 take place in two ways:

### **I. Spontaneous Emission:**

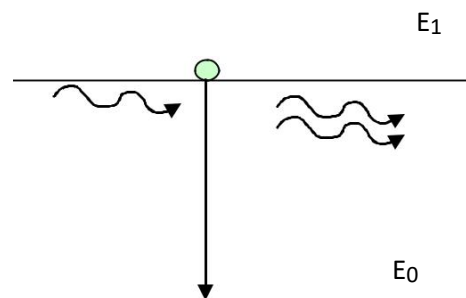
Spontaneous emission is the process of light emission in which the atoms in excited state ( $E_1$ ) come back to ground state ( $E_0$ ) after  $10^{-8}$  seconds, without any external radiation (see Fig.13.2). The atoms in excited state, release **radiation of energy**  $h\nu = E_1 - E_0$  in the form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



**Figure 13.2** Spontaneous emission process

### **II. Stimulated Emission:**

If an excited atom is irradiated with a photon having energy  $h\nu = E_1 - E_0$  before the spontaneous emission process, then the excited atom will lose the energy in the form of two photons 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 the 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 the excited state ( $N_2$ ) becomes more than the number of atoms in the ground state ( $N_1$ ), this condition is known as Population Inversion. This condition is a must for stimulated 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 are non-coherent. While in a laser all the emitted photons have the 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 a 1 milliwatt laser would appear many thousand times more intense than 100 Watt ordinary lamp.

### **5.2 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 at least 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 liver 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.

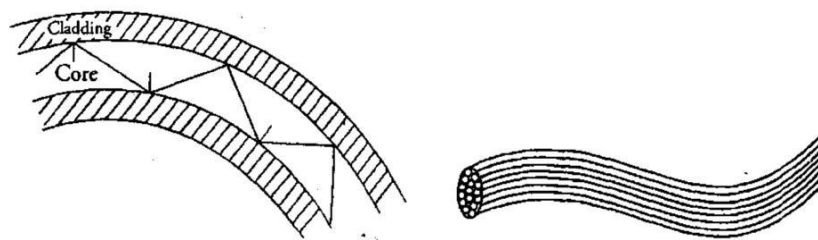
### **5.3 OPTICAL FIBRE**

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 **fiberoptics***

**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:

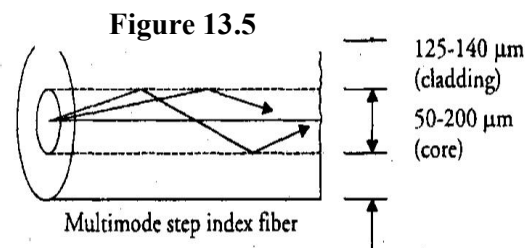
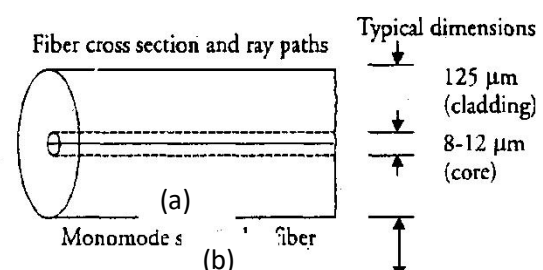
**Monomode fibre:** It has a very narrow core of diameter about 8-12  $\mu\text{m}$  or less and

**Multimode fibre:** It has a core of the cladding is relatively big 125  $\mu\text{m}$  as relatively large diameter such as 50-200 shown in Fig. 13.5 (a). As the name implies, monomode fibre sustains only one suggests the multimode fibre contain many mode of propagation that is why it is also hundreds of modes of propagation known as single mode fibre. simultaneously. The signals do not

intermix with each other. This is most commonly used optical fibre.

**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.

## 5.4 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, nanopolymers, 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 nanotubes 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 vapors. Various types of nanostructures such as carbon nanotubes, grapheme, 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.

## EXERCISE

### Multiple Choice Questions

- 1) Which is correct regarding laser?
  - A. Laser is an intense light.
  - B. Laser is monochromatic.
  - C. Laser is coherent.
  - D. All of the above.
- 2) If we can alter the distribution of atoms so that more atoms are in higher energy levels than lower energy levels. This is called . . . . .
  - A. Energy inversion.
  - B. Population inversion.

- C. Molecular inversion.
  - D. Atomic Inversion.
- 3) In laser, the light amplification is achieved due to
- A. Stimulated emission.
  - B. Spontaneous emission.
  - C. Stimulated absorption.
  - D. Spontaneous absorption.
- 4) Light emitted due to spontaneous emission is - - - - - .
- A. Incoherent.
  - B. Polychromatic.
  - C. Less directional.
  - D. All the above .
- 5) Multimode step index fibre has :
- A. Large core diameter and large numerical aperture.
  - B. Large core diameter and small numerical aperture.
  - C. Small core diameter and large numerical aperture.
  - D. Small core diameter and small numerical aperture.
- 6) **A multimode step index fibre has a core diameter of range ....**
- A. 50-200  $\mu\text{m}$
  - B. 100-300 nm
  - C. 200-**500  $\mu\text{m}$**
  - D. 200-500 nm
- 7) The fibres mostly not used nowadays for optical fibre communication system are:
- A. Single mode fibres.
  - B. Multimode fibres.
  - C. Plastic fibers.
  - D. Multimode graded index fibres.
- 8) **If angle of incidence is larger than critical angle ..... occurs.**
- A. Total internal reflection.
  - B. Reflection.
  - C. Diffraction.
  - D. Refraction.
- 9) The size range of **nanoparticles is between ..... nm.**
- A. 100-1000
  - B. 0.1-10
  - C. 1-100
  - D. 0.01-1
- 10) Which of the following is the application of nanotechnology to food science and technology?
- A. Seed germination.
  - B. Food safety and preservation.

- C. Product development.
- D. All of the above.

### Short answer Questions

1. Define energy level.
2. Give full form of LASER.
3. What is principle of Laser?
4. What is meant by population inversion?
5. What is the working principle of optical fibre?
6. Name the type of optical fibres.
7. What are nanomaterials? Give an example.
8. What is size range of nanomaterial?

### Long answer Questions

1. Explain the characteristics of laser. Also differentiate between laser beam and ordinary light beam.
2. Describe the two processes in which emission takes place. Also Distinguish between two emission processes.
3. What is the primary requirement to produce laser beam? What are the main properties of laser beam? Write atleast five applications of laser light.
4. Distinguish between monomode fibre and multimode fibre. Write some uses of optical fibres.
5. What is nanotechnology? Give and explain at least five applications of nanotechnology

### Answers to multiple choice questions

- |    |   |     |   |    |   |    |   |
|----|---|-----|---|----|---|----|---|
| 1) | D | 2)  | B | 3) | A | 4) | D |
| 5) | A | 6)  | A | 7) | A | 8) | A |
| 9) | C | 10) | D |    |   |    |   |