

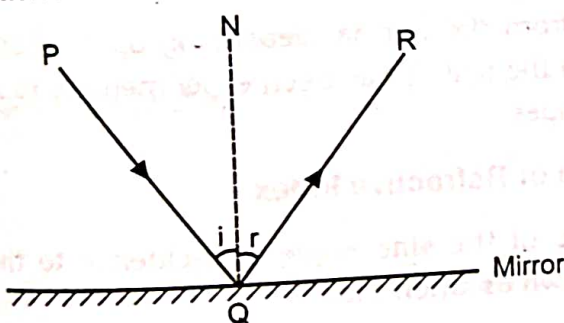
LIGHT, LASER AND SOUND

4.1 PROPERTIES OF LIGHT

Reflection, Refraction, Snell's law, Physical significance of refractive index, Definition of dispersion, Polarization and diffraction of light along with ray diagram, Principle of superposition of waves, Interference of light, Constructive and destructive interference.

4.1.1 Reflection

When a ray of light is allowed to fall on a reflecting surface such as mirror, it is observed that light reflects in the same medium as shown.



PQ = Incident ray
QR = Reflected ray
NQ = Normal to reflecting surface

Fig. 4.1

Angle made by incident ray with normal is called angle of incidence i.e. $\angle PQN$.

Angle made by reflected ray with normal is called angle of reflection i.e. $\angle NQR$.

Laws of reflection :

- (1) The angle of incidence is equal to the angle of reflection, $i = r$.
- (2) The incident ray, normal and reflected ray, lie in one plane.

If angle of incidence is zero i.e. Incident light is along the normal then reflected light returns along the same path in which light is incident.

Instead of PQ if QR becomes incident ray then PQ becomes reflected ray, this is the principle of reversibility of light.

4.1.2 Refraction

We know that in a homogeneous medium, a ray of light travels in a straight line. But when a ray of light is incident on a plane transparent medium such as glass, it is observed that in the second medium, the ray of light deviates from its original path as shown in Fig. 4.2.

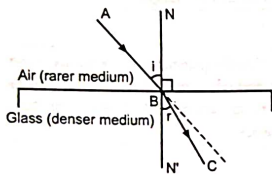


Fig. 4.2

AB = Incident ray
 BC = Refracted ray
 NN' = Normal
 $\angle i$ = Angle of incidence
 $\angle r$ = Angle of refraction

This bending of light is called as *refraction*.

The bent ray BC is called as *refracted ray*.

The refracted ray bends towards or away from the normal depending upon whether the second medium is optically denser or rarer than the first. It has been experimentally found that in the second medium, velocity of light also changes.

Law of Refraction and Physical Significance of Refractive Index

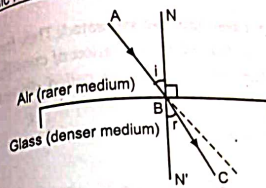
Snell's law : For any two media, the ratio of the sine angle of incidence to the sine angle of refraction is constant. This law is known as Snell's law.

Thus $\frac{\sin i}{\sin r} = \text{Constant}$

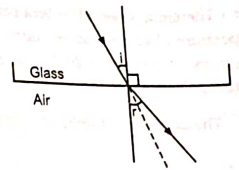
where, i - Angle of incidence
 r - Angle of refraction.

This constant is called refractive index of second medium with respect to first and is denoted by ${}_1\mu_2$.

$\therefore \frac{\sin i}{\sin r} = {}_1\mu_2 = \frac{\mu_2}{\mu_1} = \text{Constant}$



Case 1



Case 2

Fig. 4.3

Case 1 : When light enters from air (rarer) into glass (denser) medium, ray bends towards normal. Thus, $i > r$.

$\therefore \frac{\sin i}{\sin r} = \text{Constant} > 1$

Constant is called refractive index of glass with respect to air and is denoted as ${}_a\mu_g$.

$\therefore {}_a\mu_g = \frac{\sin i}{\sin r} > 1$

Also ${}_a\mu_g = \frac{\text{Velocity of light in air}}{\text{Velocity of light in glass}}$

Case 2 : When light enters from glass (denser) medium into air (rarer) medium, ray bends away from normal. Thus, $i < r$.

$\therefore \frac{\sin i}{\sin r} = \text{Constant} < 1$

Constant is called refractive index of air with respect to glass and is denoted as ${}_g\mu_a$.

$\therefore {}_g\mu_a = \frac{\sin i}{\sin r} < 1$

Also ${}_g\mu_a = \frac{\text{Velocity of light in glass}}{\text{Velocity of light in air}}$

Thus ${}_a\mu_g = \frac{1}{{}_g\mu_a}$

4.1.3 Dispersion

The light rays of each colour have certain angle of deviation of their own i.e. the angle of deviation of different rays are different.

White light is made of seven colours when this light incident on a prism all the seven colours have the same angle of incidence but since they have different angle of deviation they get separated when they come out of the prism.

Therefore, when white light passes through a prism, seven rays get separated. They form a spectrum of seven colours - dispersion. The dispersion is defined as separation of constituent colours of incident light by the prism and the medium prism (glass) is called dispersive medium.

The dispersion of white light by a prism is shown in Fig. 4.4.

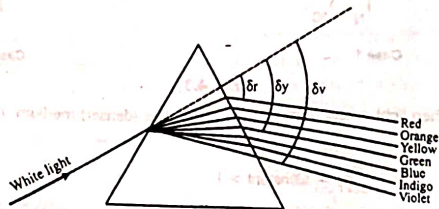


Fig. 4.4 : Dispersion of white light

4.1.4 Polarisation

1. Let ordinary light fall on tourmaline crystal. The cut section of crystal A acts as slit 'S'.

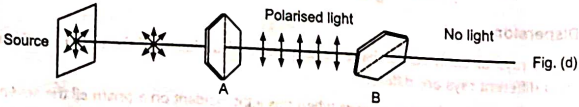
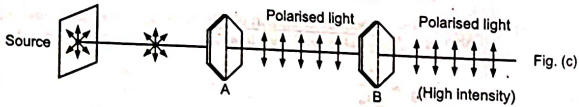
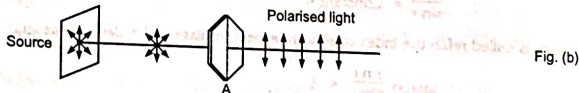
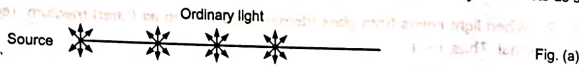


Fig. 4.5

Light coming out of crystal 'A' is polarised. [Fig. 4.5 (b)]

- If another crystal B is placed so that axes of crystal 'A' and crystal 'B' are parallel to each other, then light coming out of crystal 'B' is polarized and light is bright. [Fig. 4.5 (c)]
- If crystal 'B' is slowly rotated, then light coming out of crystal 'B' becomes dimmer. As we go on rotating crystal 'B' the light coming out of it becomes dimmer and dimmer. When 'B' is at right angles to 'A' no light comes out of 'B'. [Fig. 4.5 (d)]

If crystal 'B' is further rotated then intensity of light coming out of 'B' gradually increases and is maximum again when two crystal slits are parallel. This shows that light is a transverse wave motion.

The above experiment shows that light coming out of crystal 'A' is not symmetrical in all directions about the direction of propagation and its vibrations are only in one plane perpendicular to direction of propagation i.e. polarized light.

The light which has acquired the property of one sidedness is called polarized light.

Plane passing through the direction of propagation and perpendicular to plane of vibration is known as plane of polarization.

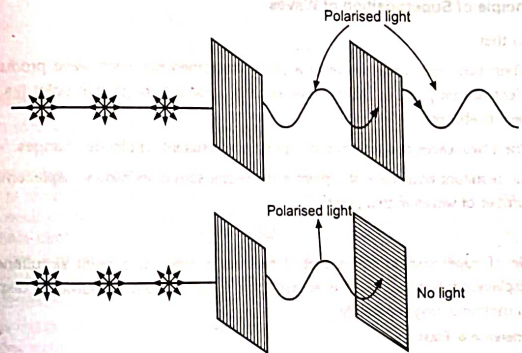


Fig. 4.6 : Diagram to understand concept of polarization

(Dec. 2010)

4.1.5 Diffraction

The waves bend round obstacles placed in their path.

The amount of bending depends upon the size of the obstacle and wavelength of wave.

The deviation is small when the wavelength of light is small in comparison to dimension of obstacle or aperture or slit.

But when the size of aperture is comparable with the wavelength of light, this deviation increases.

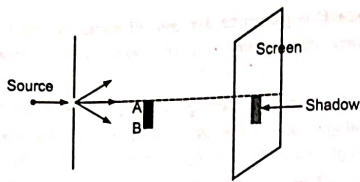


Fig. 4.7

As shown above geometrical shadow on the screen is never sharp.

A small portion of light bends around the edge into the shadow.

Diffraction : Definition : Thus, when light falls on obstacles or small apertures whose size is comparable with wavelength of light, then the light bends round the corners of the obstacles or apertures and enters in geometrical shadow. This bending of light is called diffraction.

4.1.6 Principle of Superposition of Waves

It states that :

- (1) When two light waves arrive at a point simultaneously, each wave produces its own effect at that point as if that wave alone is passing through that point (as if the other wave is absent).
- (2) When two waves of light arrive at a point, the resultant amplitude changes.
- (3) The resultant amplitude at a point is the vector sum of individual displacements due to number of waves at that point.

OR

Principle of superposition states that, if two waves arrive at a point simultaneously, the resultant displacement at that point is always equal to vector sum of individual displacements due to each motion acting separately.

Interference & Elasticity

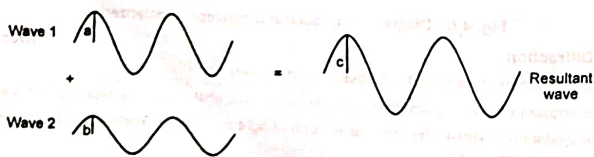


Fig. 4.8 : Wave 1 and wave 2 are in phase

Hence, amplitude of resultant wave

$$c = a + b$$

where,

a - Amplitude of 1st wave

b - Amplitude of 2nd wave

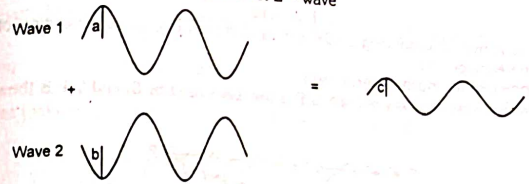


Fig. 4.9 : Wave 1 and wave 2 are opposite in phase

Hence, amplitude of resultant wave,

$$c = a - b$$

where,

a - Amplitude of 1st wave

b - Amplitude of 2nd wave

4.1.7 Interference

[In order to understand the interference concept, consider the interference phenomenon in case of water.]

Demonstration : Consider steady water in the water tank. Drop two small stones at the same time at short distance from each other. Circular ripples spread out over the surface of water from each of two stones. Alternate circles having elevated portion i.e. crest and another set of alternate circles having trough portion spreads out. These ripples travel radially outward from these two stones and they cross each other and the interference effect is observed. At certain point, crest of one wave coincides with crest of other wave. At this point the surface of water gets displaced to the maximum extent.

At some other point, crest of one wave coincides with trough of other wave. At this point water remains still.]

Interference of light

When two or more light waves meet in a region, they interfere to produce a new wave, whose instantaneous amplitude is the vector sum of those of original waves.

When two waves are in same phase, then the crest of one wave coincides with the crest of other wave and trough of one wave also coincides with trough of another wave. The resultant amplitude is maximum and brightness is obtained.

On the other hand, when two waves are opposite in phase, then the crest of one wave coincides with trough of another wave and vice versa. The resultant amplitude is minimum and darkness is obtained.



Fig. 4.10

This phenomenon of producing brightness or darkness due to superposition of waves is called as interference of light.

Path difference (Path length difference) :

Let S_1 and S_2 be two sources of light. S_1P is the wave send by S_1 and S_2P is the wave send by S_2 .

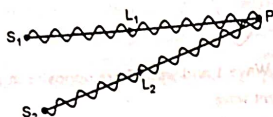


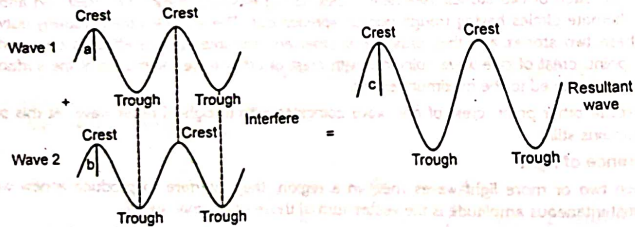
Fig. 4.11

The distance (length) covered by first wave is L_1 and distance covered by second wave is L_2 . Then $L_2 - L_1$ is the path difference.

$$\begin{aligned} \text{Path difference} &= S_2P - S_1P \\ &= L_2 - L_1 \end{aligned}$$

4.1.8 Constructive Interference (Brightness of Light)

When two waves arriving at a point are in same phase i.e. crest of first wave coincides with crest of another and trough coincides with trough, then such two waves reinforce (assist, helps) each other and hence amplitude of resultant wave increases (i.e. $c = a + b$).



$$c = a + b$$

where,

a = Amplitude of first wave

b = Amplitude of second wave

c = Amplitude of resultant wave

Fig. 4.12

But Intensity of light is directly proportional to the square of amplitude (Intensity \propto Amplitude²), hence brightness or constructive interference is obtained.

Conditions for Constructive Interference (Brightness) :

Conditions for constructive interference (brightness) of light are as follows :

- (1) The two waves must be in phase.
- (2) The path difference of two waves must be integral multiple of wavelength λ .

i.e. $\text{p.d.} = n\lambda$
 where, $n = 0, 1, 2, 3 \dots$

Then crest of one wave will coincide with crest of other wave and trough to trough. Then such two waves (help) reinforce each other and brightness is observed.

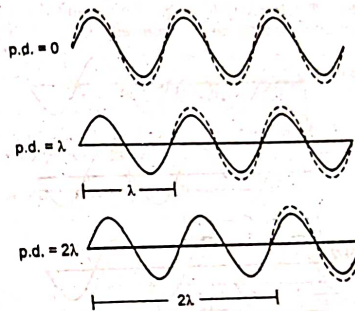


Fig. 4.13

4.1.9 Destructive Interference (Darkness of Light)

When two waves arriving at a point are opposite in phase i.e. crest of one wave coincides with trough of other wave and vice versa.

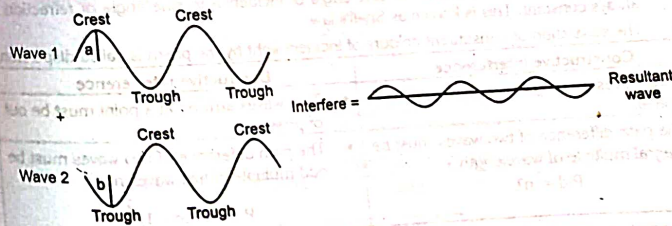


Fig. 4.14

Then such two waves partially or completely cancel (oppose) each other and hence amplitude of resultant wave decreases ($c = a - b$). But intensity of light is directly proportional to square of amplitude, hence darkness or destructive interference is obtained.

Conditions for Destructive Interference (Darkness) :

Conditions for destructive interference are as follows :

- (1) The two waves must be out of phase.
- (2) The path difference of two waves must be odd multiple of half wavelength.

i.e. $p.d. = \left(n - \frac{1}{2}\right) \lambda$

or $(2n - 1) \frac{\lambda}{2}$ where $n = 1, 2, 3, \dots$

Then crest of one wave will coincide with trough of other and vice a versa. Then such two waves cancel (oppose) each other and darkness is observed.

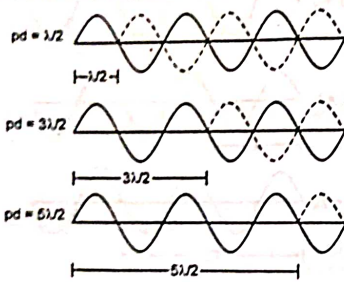


Fig. 4.15

SUMMARY

- When light enters from one medium into another, the ray of light bends (changes its path). This property of light is called as refraction.
- For given pair of media, ratio of sine angle of incidence to sine angle of refraction is always constant. This is known as Snell's law.
- The separation of constituent colours of incident light by the prism is called dispersion.

Constructive Interference	Destructive Interference
<ul style="list-style-type: none"> • Two waves arriving at a point must be in phase. • The path difference of two waves must be integral multiple of wavelength λ. $P.d = n\lambda$. • The point appears bright. 	<ul style="list-style-type: none"> • Two waves arriving at a point must be out of phase. • The path difference of two waves must be odd multiple of half wavelength. $P.d. = (2n - 1) \frac{\lambda}{2}$ • The point appears dark.

FORMULAE

1. $\mu = \frac{\sin i}{\sin r}$, where μ - Refractive index
 i - Angle of incidence
 r - Angle of refraction

2. $a\mu_g = \frac{\text{Velocity of light in air}}{\text{Velocity of light in glass}} = \frac{\mu_a}{\mu_g}$

where $a\mu_g$ - Refractive index of glass with respect to air

or $i\mu_2 = \frac{\text{Velocity of light in medium 1}}{\text{Velocity of light in medium 2}} = \frac{\mu_2}{\mu_1}$

SOLVED EXAMPLES

Example 1 : An equilateral glass prism under minimum deviation condition has an angle of incidence 40° . Find its refractive index. (S. 2001 - 4 M)

Solution : $i = 40^\circ$, $A = 60^\circ$ (\because prism is equilateral), $\mu = ?$

We have,

$\mu = \frac{\sin i}{\sin r}$

$\mu = \frac{\sin i}{\sin (A/2)} = \frac{\sin (40)}{\sin (60/2)} = \frac{\sin (40)}{\sin (30)}$

$\mu = 1.285$

Example 2 : The refractive index of glass with respect to air is 1.51 and velocity of light in air is 3×10^8 m/s. Calculate the velocity of light in glass. (W. 2002 - 4 M)

Solution : Given :

$a\mu_g = 1.51$

$v_{\text{air}} = 3 \times 10^8$ m/s

$v_{\text{glass}} = ?$

$a\mu_g = \frac{\text{Velocity of light in air}}{\text{Velocity of light in glass}}$

Velocity of light in glass = $\frac{\text{Velocity of light in air}}{a\mu_g} = \frac{3 \times 10^8}{1.51}$

Velocity of light in glass = 1.986×10^8 m/s

Example 3 : Refractive index of glass with respect to air is 1.5. Refractive index of water with respect to air is 1.2. Calculate refractive index of water with respect to glass.

Solution : Given : Method 1 :

$${}_a\mu_g = 1.5$$

$${}_a\mu_w = 1.2$$

$${}_g\mu_w = ?$$

$$\text{i.e. } {}_g\mu_w = \frac{v_g}{v_w} = ?$$

We have,

$${}_a\mu_g = \frac{v_a}{v_g}$$

\therefore

$$1.5 = \frac{v_a}{v_g} \quad \dots (1)$$

and

$${}_a\mu_w = \frac{v_a}{v_w}$$

\therefore

$$1.2 = \frac{v_a}{v_w} \quad \dots (2)$$

Dividing equation (2) by equation (1),

$$\therefore \frac{1.2}{1.5} = \frac{v_a/v_w}{v_a/v_g}$$

$$\therefore \frac{1.2}{1.5} = \frac{v_g}{v_w}$$

$$0.8 = \frac{v_g}{v_w}$$

Thus,

$${}_g\mu_w = \frac{v_g}{v_w} = 0.8$$

OR

Method 2 :

$${}_a\mu_g = 1.5$$

$${}_a\mu_w = 1.2$$

$${}_g\mu_w = ?$$

$${}_a\mu_g = 1.5 = \frac{\mu_g}{\mu_a} \quad \dots (1)$$

$${}_a\mu_w = 1.2 = \frac{\mu_w}{\mu_a} \quad \dots (2)$$

Dividing equation (2) by equation (1),

$$\frac{1.2}{1.5} = \frac{\mu_w/\mu_a}{\mu_g/\mu_a}$$

$$0.8 = \frac{\mu_w}{\mu_g} = \mu_w$$

Example 4 : If the broadcasting frequency of wave is 20×10^6 Hz, calculate its wavelength. (Given : Velocity of light = 3×10^8 m/s)

(Dec. 2010)

Solution : Given :

$$n = 20 \times 10^6 \text{ Hz}$$

$$v = 3 \times 10^8 \text{ m/s}$$

$$\lambda = ?$$

We have,

$$v = n\lambda$$

$$\lambda = \frac{v}{n} = \frac{3 \times 10^8}{20 \times 10^6}$$

$$\lambda = 15 \text{ m}$$

QUESTIONS

1. What is refraction of light? State laws of refraction.
2. State Snell's law of refraction.
3. State the principle of superposition of waves.
4. What is interference of light?
5. What is constructive and destructive interference?
6. State conditions for constructive and destructive interference.
7. Define diffraction.
8. Define refraction, dispersion, diffraction.

PROBLEMS

1. Calculate the velocity of light in glass of refractive index 1.5, if velocity of light in air is 3×10^8 m/s.
Ans. $v_g = 2 \times 10^8$ m/s.
2. Refractive index of glass with respect to air is 1.5. Refractive index of water with respect to air is 1.2. Calculate refractive index of glass with respect to water.
Ans. ${}_w\mu_g = 1.25$

4.2 LASER

Light Amplification by Stimulated Emission of Radiation (LASER), Working principle of laser, Absorption or Stimulated absorption, Spontaneous emission, Stimulated emission, Optical pumping (three energy level laser system), Properties or Characteristics of laser, Helium-Neon laser (He-Ne gas laser).

4.2.1 Light Amplification by Stimulated Emission of Radiation (LASER)

The term LASER stands for Light Amplification by Stimulated Emission of Radiation. The laser is a device that produces a light beam with some remarkable properties :

- (1) **The light is coherent :** The light with the waves, all exactly in same phase.
- (2) **The light is monochromatic :** The light whose waves all have the same frequency or wavelength.
- (3) **The light has unidirectionality :** The light produces sharp focus.
- (4) **The beam is extremely intense :** The light has extreme brightness.

In order to understand the concept properly observe the pictorial difference given below.



- (a) Ordinary light (phase and frequency/wavelength mismatching)
- (b) Monochromatic incoherent light (frequency/wavelength is same but phase is mismatching)
- (c) Monochromatic coherent light (LASER) (phase, frequency/wavelength all are matching)

Fig. 4.15

4.2.2 Working Principle of Laser

We know that in order to force water from lower level to higher level, we need some energy and similarly energy is given out when water falls from higher level to lower level.

An atom must be imparted with some energy so that it gets excited from lower energy level to higher energy level. Similarly energy is emitted by an atom when transition takes place from

higher energy level to lower energy level. Emission of energy is equal to the difference of two energy levels. Emission is in the form of photon.

$$E = h\nu = (E_2 - E_1)$$

i.e.

E - Energy of photon

where,

h - Planck's constant

ν - Frequency of radiation

E_2 - Energy of higher level

E_1 - Energy of lower (ground) level

When such a photon is incident on an atom, then atom absorbs this energy and gets excited i.e. moves from lower energy level E_1 to higher energy level E_2 (excitation). [Refer Fig. 4.16 (a)]. This excited state is unstable (non-equilibrium). The atom is not willing to remain in excited state for longer time. In course of time, the atom jumps from excited state to lower state. During this transition, emission of energy takes place in the form of photon.

The atom can remain for unlimited time in ground state but it can remain in excited state for limited time only. This limited time for which atom remains in excited state is known as life time. The life time of excited hydrogen atom is of the order of 10^{-8} sec.

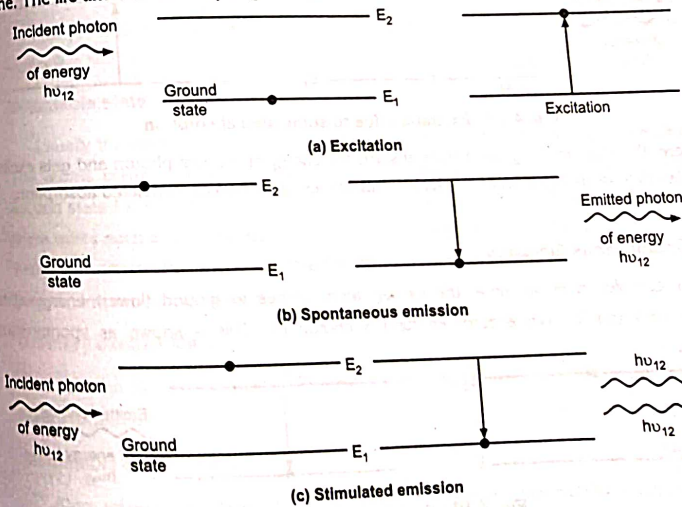


Fig. 4.16

Soon after the life time of excited state, atom returns to ground state (de-excitation) by emitting a photon of energy $h\nu$. This emission process is known as spontaneous emission. [Refer Fig. 4.16 (b)].

The another form of emission is stimulated emission. [Refer Fig. 4.16 (c)]. When the atom is in excited state and before coming it to ground state the atom is triggered due to an action of incident photon. The interaction between the excited atom and incident photon can trigger the excited atom to make a transition to ground state. The transition generates another photon which is identical to the incident photon (same phase i.e. coherent, same wavelength, i.e. monochromatic, same direction).

This process of forced emission of photons due to incident photon is called as stimulated emission.

4.2.3 Absorption or Stimulated Absorption

When a photon of energy $h\nu = E_2 - E_1$ is incident on an atom then the atom gets excited i.e. moves from lower energy level E_1 to higher energy level E_2 .

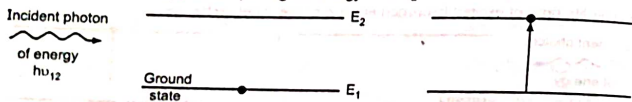


Fig. 4.17 : Excitation due to stimulated absorption

Here, the atom in the ground state absorbs the energy of incident photon and gets excited (stimulated) towards higher energy level E_2 . This process is known as stimulated absorption.

4.2.4 Spontaneous Emission

After completion of life time, the excited atom comes to ground (lower) energy state spontaneously (on its own accord) emitting a photon $h\nu$. This is known as spontaneous emission.

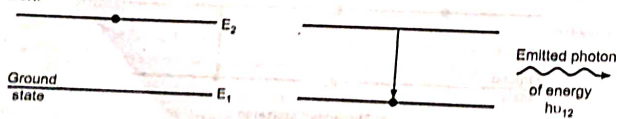


Fig. 4.18 : Spontaneous emission

The spontaneous emission depends on type of particle and type of transition but is independent of outside circumstances. Radiations which are emitted spontaneously are random in directions, random in phase. Thus, radiation in this case is a random mixture of quanta having different wavelengths, different phase. Thus, such a radiation is incoherent and has a broad spectrum.

4.2.5 Stimulated Emission

When the atom is in excited state and before coming it to ground (lower) state if the atom is triggered due to an action of incident photon. The interaction between the excited atom and incident photon can trigger the excited atom to make a transition to ground state. The transition generates another photon which is identical to the incident photon (same phase i.e. coherent, same wavelength i.e. monochromatic, same direction).

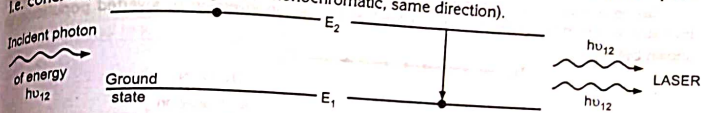


Fig. 4.19 : Stimulated emission

This process of forced emission of photons due to incident photon is called as stimulated emission.

Metastable state :

Usually the number of excited atoms in a system are less than that of non-excited atoms. The atoms prefer ground state for longer (unlimited) time. On the contrary, they remain in excited state for a limited time called life time. The life time of hydrogen is 10^{-8} sec. However, there exists such a excited state in which life time is greater than 10^{-8} sec. This state is called as metastable state. The relaxation time for metastable state is 10^{-6} to 10^{-3} seconds. This state plays an important role in laser.

Ordinary excited state :

Atom remains in excited state for very very small time (10^{-8} sec) and comes down to ground state immediately.

Metastable excited state :

Atom relaxes in excited state for long time (10^{-3} sec) and then comes down to ground state.

Population Inversion :

Population means number of active atoms occupying an energy state.

Usually population of lower energy (ground) level is high and that of higher energy level is low as shown below :

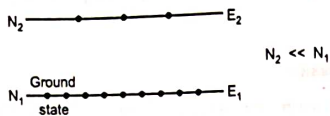


Fig. 4.20

In order to produce stimulated emission properly, population of higher excited state should be greater than that of low energy (ground) state.

Making population of higher energy level more than that of ground state is called population inversion or i.e. making $N_2 \gg N_1$ is called as population inversion or inverted population as shown below.

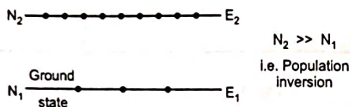


Fig. 4.21

Population inversion : Definition : Making population of active electrons in higher energy level (N_2) more than the population of active electrons in lower energy level (N_1) is called population inversion.

A system in which population inversion is achieved is called as active system.

The process of raising the atoms from lower energy state to higher excited energy state is called as pumping.

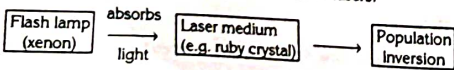
4.2.6 Pumping Methods

Pumping : Definition : The process of raising the atoms from lower energy state to higher excited energy state is called as pumping.

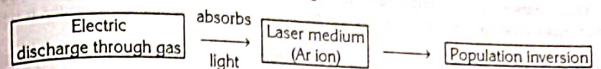
Optical pumping : Definition : The process of raising the atoms from lower energy state to higher energy excited state using light medium is called as optical pumping.

There are several methods to achieve population inversion, which is necessary for laser action to take place.

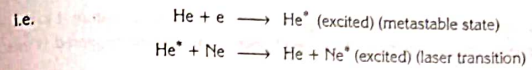
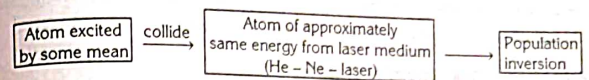
I. Optical pumping used generally for solid-state lasers.



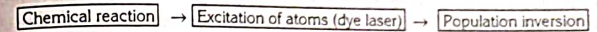
II. Direct electron excitation (Electric pumping) :



III. Inelastic-atom-atom collision



IV. Chemical reaction (chemical pumping)



This reaction gives hydrogen fluoride molecule in excited state.

Optical Pumping (Three energy level laser system)

Proper lasing action can be produced using three energy level laser system than that of two energy level laser system.

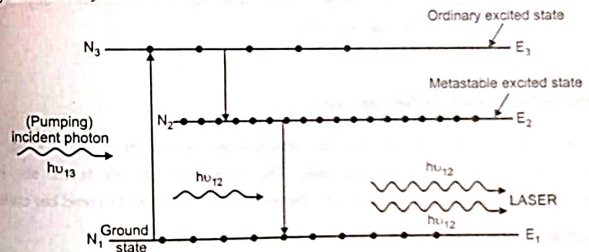


Fig. 4.22

Optical pumping i.e. photon of energy $h\nu_{13}$ is incident as shown because of which atoms get excited from energy level E_1 to energy level E_3 . Here atoms relax for very very short time (i.e. life time is less than 10^{-9} sec) and hence atoms make transition to energy level E_2 . This transition is not in the visible range. Energy level E_2 is a metastable (has life time 10^{-6} to 10^{-8} sec).

10^{-3} sec). Hence, atoms relax here for longer time. Hence, population of energy level E_2 becomes more than that of E_1 i.e. making $N_2 \gg N_1$ required population inversion is done.

If atom is triggered due to an action of an incident photon of energy $h\nu_{12}$, then as excited atom gets stimulated and follows downward transition from E_2 to E_1 . During this transition, the atom emits a photon along with incident photon in the same direction, which produces unidirectional, intense, monochromatic and coherent laser radiations.

4.2.7 Properties or Characteristics of Laser

- 1. Coherence (same phase) :** Laser light is perfectly coherent in nature. i.e. the waves are exactly in phase with one another. The emitted photon after getting triggered is exactly in phase with incident photon.
- 2. Monochromaticity (same wavelength or frequency) :** The laser light is perfectly monochromatic. The light emitted by laser is much more monochromatic than that of any conventional monochromatic source.
- 3. Unidirectionality (sharp focus) :** Conventional light source emits light in all directions. But laser emits (spreads) light in one direction. The width of laser beam is very narrow and can travel to long distance without spreading. Hence, it can be focussed sharply.
- 4. High intensity (extreme brightness) :** Since emitted photon and incident photon are in same phase, laser light is much more brighter (intense) than that from any of the conventional source. It can vaporize hardest metal.

4.2.8 Helium-Neon Laser (He-Ne Gas Laser)

The gas atoms are characterized by sharp energy levels as compared to the solid. For continuous laser beam, gas lasers are used. The advantages of gas lasers are high monochromaticity and stability of frequency. He-Ne laser is commonly used to read bar codes.

Construction :

It consists of fused quartz tube having length of about 80 cm and diameter of about 1.5 cm. This tube is filled with a mixture of helium (He) and neon (Ne) gas. The mixture consists 10 parts of He and 1 part of Ne. Hence, there is majority of helium atoms (90%) and minority of neon atoms (10%). Perfect reflector is fixed at one end and partial reflector is fixed at other end of the tube. The active material is excited by means of high frequency generator.

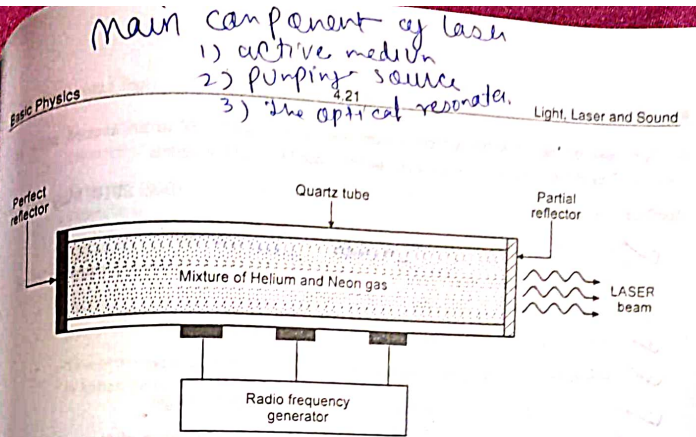


Fig. 4.23 : He-Ne gas laser

Working :

An electric discharge is produced in the gas by means of electrodes outside the tube connected to a source of high frequency alternating current. Collisions with electrons from the discharge excite He and Ne atoms to metastable states respectively 20.61 and 20.66 eV.

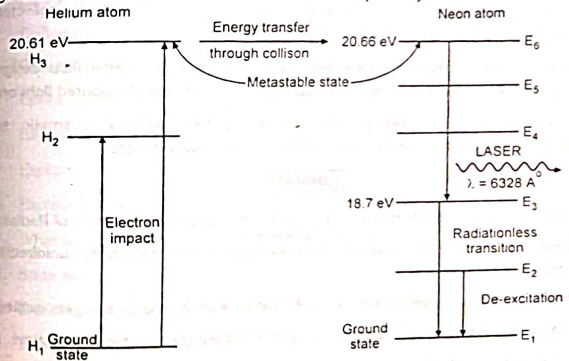


Fig. 4.24 : Energy level diagram for He-Ne laser

As the neon higher levels E_4 and E_6 are closed to excited energy levels H_2 and H_3 of helium, hence the probability of helium atoms transferring their energy to excited neon atoms through collision is greater. Thus, the purpose of helium atom is to help to achieve population inversion. Actual lasing atoms are neons.

The laser transition in Ne is from metastable state at 20.66 eV to an excited state at 18.7 eV. This is the laser whose narrow red beam is used to read bar codes.

Applications of Laser :

(Dec. 2010, May 2011)

- ✓ Lasers are used to read bar code in shopping malls, library etc.
- Lasers are used for engraving and embossing of printing plates e.g. number plate, name of company, monogram of the company.
- ✓ Lasers are used in cutting, drilling (peening) and welding metals.
- ✓ Lasers are used in surgery for destroying kidney stone, cancer cells.
- ✓ In military, lasers are used to direct the weapons towards the target.
- ✓ Lasers are used to measure distance of the planets. e.g. distance of moon from the earth.
- ✓ Lasers are used in holography, printers.
- ✓ Lasers are used by dentist for dental surgery.
- ✓ Lasers are used for 3D laser scanners - analyse the real world object - collected data can be used to construct digital 3 dimensional models.
- ✓ Laser pointer or laser pen - Laser pen is a small portable and visible laser designed to highlight some interesting part by focussing small bright spot of coloured light on to it.
- ✓ Lasers are used in eye surgery, soft tissue laser surgery, cosmetic surgery (e.g. removing tatoos, scars, stretch marks, wrinkles, sunspots etc.)

SUMMARY

- The term LASER stands for Light Amplification by Stimulated Emission of Radiation.
- Laser has remarkable properties like coherency, monochromaticity, unidirectionality and extreme brightness.
- When photon is incident on an atom, then atom absorbs energy and gets excited.
- ✓ The limited time for which an atom remains in excited state is called as life time.
- There are two types of emission :
 - (1) Spontaneous emission.
 - (2) Stimulated emission.

- The process of forced emission of photon due to incident photon is called as stimulated emission.
- Ordinary excited state : Atom remains in excited state for very small time and comes down to ground state.
- Metastable excited state : Atom relaxes in excited state for long time and then comes down to ground state.
- Making population of higher energy level more than that of ground state is called as population inversion.
- ✓ The process of raising the atoms from lower energy state to higher excited energy state is called as pumping.

QUESTIONS

1. Give full form of laser.
2. What do you mean by lasers ?
3. Define spontaneous emission and explain.
4. Define stimulated emission and explain.
5. Define population inversion.
6. Define optical pumping.
7. Define active system.
8. Explain working principle of laser.
9. Explain population inversion.
10. Explain optical pumping.
11. What is ordinary excited state and metastable state ?
12. State and explain properties of laser.
13. Explain construction, working of He-Ne gas laser with diagram.
14. Explain mechanism of production of laser.
15. Define the term life time of state during production of laser.
16. Draw energy level diagram for He-Ne laser.
17. State applications of laser.

Handwritten notes in Hindi on the right page, including a definition of laser and a list of applications.

लॉसर का पूरा नाम है - Light Amplification by Stimulated Emission of Radiation

लॉसर के गुण हैं -

- 1. एक ही दिशा में चलने वाले प्रकाश किरणें (Coherence)
- 2. एक ही रंग के प्रकाश किरणें (Monochromaticity)
- 3. एक ही तरंगदैर्घ्य के प्रकाश किरणें (Unidirectionality)
- 4. अत्यधिक चमक (High Intensity)

लॉसर के दो प्रकार हैं -

1. Spontaneous Emission
2. Stimulated Emission

लॉसर के उपयोग हैं -

- 1. बार कोड पढ़ने के लिए (Barcode)
- 2. लेजर कटर (Laser Cutter)
- 3. लेजर सर्जरी (Laser Surgery)
- 4. लेजर प्रिंटर (Laser Printer)
- 5. लेजर डेंटल सर्जरी (Laser Dental Surgery)
- 6. लेजर स्कैनर (Laser Scanner)
- 7. लेजर पेन (Laser Pen)
- 8. लेजर ऑपरेशन (Laser Operation)
- 9. लेजर टैटो रिमूव (Laser Tattoo Removal)
- 10. लेजर स्किन ट्रीटमेंट (Laser Skin Treatment)
- 11. लेजर सूर्यदाह (Laser Sunburn)
- 12. लेजर आँखों की सर्जरी (Laser Eye Surgery)
- 13. लेजर कैंसर ट्रीटमेंट (Laser Cancer Treatment)
- 14. लेजर कटिंग (Laser Cutting)
- 15. लेजर वेल्डिंग (Laser Welding)
- 16. लेजर लिथोग्राफी (Laser Lithography)
- 17. लेजर प्रिंटिंग (Laser Printing)
- 18. लेजर डेटा स्टोरेज (Laser Data Storage)
- 19. लेजर रिसर्च (Laser Research)
- 20. लेजर एंटी-कॉन्ट्रिब्यूट (Laser Anti-Counterfeit)

4.3 SOUND

Definition of wave motion, amplitude, period, frequency and wavelength, relation between velocity, frequency and wavelength, equation of progressive wave, transverse wave and longitudinal wave, definition of stationary wave, node and antinode, free and forced oscillations, definition of resonance with examples, formula for velocity of sound with end correction.

4.3.1 Concept of a Wave Motion

Wave motion is a form of disturbance which travels through the medium due to repeated periodic motion of the medium particle about its mean position.

It is one of the methods of transfer of energy.

A wave motion can be explained on the basis of SHM.

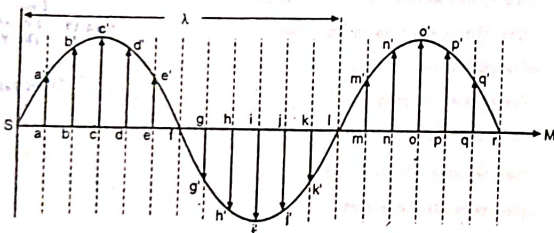


Fig. 4.25

Suppose S is a source of light, SM is one of the rays; a, b, c, d, ... are particles of material medium along SM which are equidistant.

When light energy starts from S, it sets 'a' into vibrations. 'a' in turn sets 'b' into vibrations. 'b' in turn sets 'c' into vibrations and so on. Thus energy travels from one point to other.

Each particle of medium performs SHM of same period and amplitude. As the particle starts vibrating after some lapse of time, they are not in same phase.

The above phenomenon is considered in another way. The oscillations of a, b, c, ... are shown at a moment. i.e. at one moment positions of particles of material medium will be as shown in Fig. 4.26.

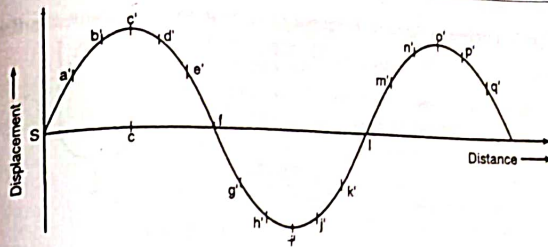


Fig. 4.26

The resulting curved line joining these positions at the same moment represents a wave.

The propagation of wave requires medium having elasticity, inertia and little resistance.

(i) **Amplitude (a)** : The maximum displacement of the oscillation in the wave is called amplitude. In Fig. 4.26, cc' is the amplitude.

(ii) **Periodic time of period (T)** : All oscillations of points a, b, c, ... take the same time to complete one oscillation.

The time taken to complete one oscillation in the wave is called period. Its unit is second.

(iii) **Frequency (n)** : The number of oscillations completed in one second is called frequency n. Its unit is hertz (Hz).

$$1 \text{ Hz} = 1 \text{ osc/sec.}$$

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

(iv) **Phase** : The phase of particle at any instant is the state (i.e. displacement, direction, position) of motion of particle at that instant.

The particle having same displacement, direction and position are said to be in the same phase.

In Fig. 4.25, a and m are in same phase, b and n are in same phase. But notes a and e are not in same phase even though they seem to be, because they are not identical by all means i.e. their positions are different.

(v) **Wavelength (λ)** : The distance between two consecutive points in the wave, which are in same phase, is called wavelength and denoted by symbol λ (lambda).

In short, it is the length of one full wave. Its unit is meter or Angstrom unit, denoted by Å° or Å.U.

4.3.2 Relation between Velocity, Frequency and Wavelength

(Dec. 2010)

We have,

$$\text{Velocity} = \frac{\text{Distance covered}}{\text{Time taken}}$$

When disturbance travels through one full wave, then,

$$\text{Distance covered} = \text{Wavelength}$$

$$\text{Time taken} = \text{Period}$$

$$\therefore \text{Velocity} = \frac{\text{Wavelength}}{\text{Period}}$$

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

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

$$v = n\lambda$$

This is the relation between velocity, frequency and wavelength.

4.3.3 Transverse Wave and its Characteristics

In this wave, the particles of material medium are vibrating up and down but (disturbance) wave travels in horizontal (right) direction.

1. The wave, in which direction of vibration of particles of material medium are perpendicular to the direction of propagation of wave, is called transverse wave.
2. Wave travels in the form of alternate crest and trough.
3. Material medium needs elasticity of shape.
4. Density and pressure of medium remains same.
5. Wave travels through solids only.
6. e.g. Light wave.
7. Every particle of material medium performs SHM of same amplitude and period.

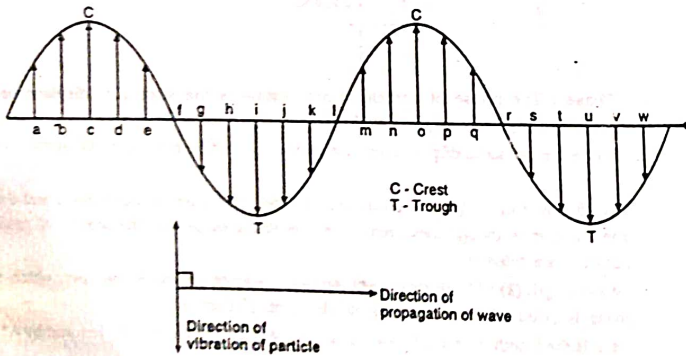


Fig. 4.27

4.3.4 Longitudinal Wave and its Characteristics

(Dec. 2010)

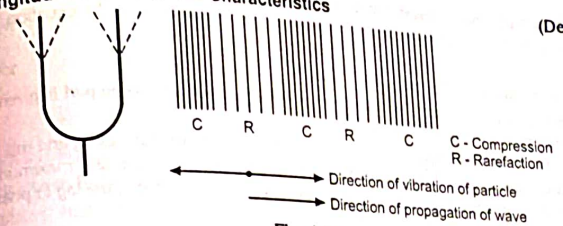


Fig. 4.28

In this wave, the particles of material medium are vibrating to and fro and the wave is travelling in horizontal direction (right).

1. The wave in which direction of vibration of particle is parallel to the direction of propagation of wave is called longitudinal wave.
2. Wave travels in the form of alternate compression and rarefaction.
3. Material medium needs elasticity of volume.
4. Pressure and density of medium changes. It is more at compression and less at rarefaction.
5. Wave travels through liquids and gases.
6. e.g. Sound wave.
7. Every particle of material medium performs SHM of same amplitude and period.

4.3.5 Equations of a Progressive Wave

In case of a simple harmonic progressive wave, each successive particle of the medium describes a simple harmonic motion, in which the phase differs regularly from one particle to the next. Every next particle is behind the previous particle in phase. If y represents the displacement of a particle in SHM and x represents its position in space, the relation between them may be as shown by the graph, in Fig. 4.29 at a particular time.

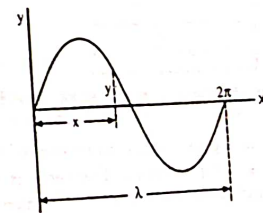


Fig. 4.29

In the graph, the displacement of the particle at $x = 0$ is zero and every next particle lags behind in phase and hence the displacement of any particle is given by the equation

$$y = a \sin(\omega t - \alpha)$$

where α depends upon the mean position of the particle in space.

Note : As per curriculum, derivation is not expected, but here some part is given for proper understanding and memorizing the equations.

From the graph, it is clear that the vibrations repeat after the distance λ , and this distance is known as the wavelength. Hence λ is the distance between two successive maximum values in the graph. At a distance λ , $\alpha = 2\pi$ (radians). Hence for any distance x , the lag in phase is equal to $\frac{2\pi x}{\lambda}$.

For distance Phase difference

$$\lambda \rightarrow 2\pi$$

$$\text{for } x \rightarrow \alpha = ?$$

$$\alpha = \frac{2\pi x}{\lambda}$$

Hence,

$$y = a \sin\left(\omega t - \frac{2\pi x}{\lambda}\right)$$

If n is the frequency of the SHM of each particle of the medium, we have, $\omega = 2\pi n$

$$\therefore y = a \sin\left(2\pi n t - \frac{2\pi x}{\lambda}\right)$$

$$\therefore y = a \sin 2\pi\left(n t - \frac{x}{\lambda}\right)$$

Since $n = \frac{1}{T}$, (T = period of SHM)

$$\therefore y = a \sin 2\pi\left(\frac{t}{T} - \frac{x}{\lambda}\right)$$

Since $n = \frac{v}{\lambda}$,

$$\therefore y = a \sin 2\pi\left(\frac{vt}{\lambda} - \frac{x}{\lambda}\right)$$

$$\therefore y = a \sin \frac{2\pi}{\lambda}(vt - x)$$

All the above equations represent a wave motion travelling in the positive direction of x -axis with a velocity, $v = n\lambda$.

When the prongs of the tuning fork vibrate with a certain frequency 'n', it performs simple harmonic motion. Due to this, compressions and rarefactions are alternately formed and they move ahead. Thus a sound wave travels with a certain velocity 'v' in the form of

alternate compressions and rarefactions. The distance between the centres of any two successive compressions and rarefactions is equal to the wavelength λ . (Refer Fig. 4.29)

Hence, Velocity, $v = \frac{\text{Distance}}{\text{Time}} = \frac{\lambda}{T}$

$$v = n\lambda$$

4.3.6 Stationary Waves or Standing Waves

Principle of Superposition of Waves :

It states that, when two waves travelling through the medium arrive at a point simultaneously, each wave produces its own displacement independent of the other.

The resultant displacement at that point changes.

The resultant displacement at that point is equal to the vector sum of the displacements due to the two waves.

Definition of stationary or standing wave : A stationary or standing wave is the resultant wave produced due to the superposition of two identical progressive waves with same amplitude, frequency, wavelength and velocity and travelling along the same straight line but in opposite direction.

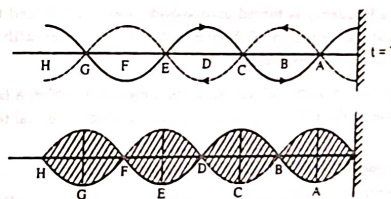


Fig. 4.30 : Stationary waves

Nodes, Antinodes, Distance between two successive nodes and antinodes :

Nodes : The points in the stationary waves which have resultant displacement zero are called nodes.

Antinodes : The points in the stationary waves which have resultant displacement maximum are called antinodes.

Distance between two successive nodes and antinodes (Nodes and antinodes are equally spaced) :

The distance between two successive nodes is $\frac{\lambda}{2}$ i.e. nodes are equally spaced.

The distance between two successive antinodes is $\frac{\lambda}{2}$ i.e. antinodes are equally spaced.

4.3.7 Free and Forced Oscillations (Vibrations)

(Dec. 2010)

A body, if disturbed from its position of rest and allowed to vibrate freely on its own, vibrates with a frequency called the 'natural frequency' and the oscillations are called free or natural oscillations. OR When an object is made to oscillate freely on its own, then such oscillations are called free oscillations.

Every body, small or large, has its own natural frequency. A machine, a building, a dam or a bridge has its own natural frequency of vibration. It is also possible to impose upon a body an external frequency other than its natural frequency. Then the body will start vibrating with this new frequency. Such oscillations in which another frequency is forced upon the body are called 'forced oscillations'. OR When an object is forced to oscillate with a frequency of external oscillating source, then such oscillations are called forced oscillations. Thus, if a simple pendulum is suspended from a fixed support, it will perform free oscillations, but if the support itself vibrates with a certain frequency, then the pendulum after sometime starts performing forced oscillations with the frequency of the support.

(If the amplitude of oscillations continuously goes on decreasing with time, then the oscillations are called the 'damped oscillations'.)

4.3.8 Resonance

Definition : If a frequency is forced upon a body and if the forced frequency matches (is equal to) the natural frequency of the body, the body vibrates with a large amplitude. The phenomenon is called "Resonance".

Hence, "resonance" may be defined as a phenomenon in which a body vibrates with a large amplitude due to the effect of a forced frequency which is equal to natural frequency of the body.

Examples of Resonance :

1. If two exactly tuned 'Tanpuras' are kept side by side and if a wire of one is plucked, then the corresponding wire of the other Tanpura also starts vibrating even though it is not actually plucked.
2. When we tune a radio receiver set, the frequency of radio waves received in the set is adjusted equal to the natural frequency of the set. or Frequency of radio receiver becomes equal to frequency of transmitted waves of transmitting station, then we get clear and loud sound.
3. The phenomenon of resonance is of importance in 'Acoustics' where it is useful to obtain a strong response to a weak sound.
4. The soldiers are not allowed to march in regular steps while crossing a bridge as there is a possibility that due to resonance between the forced frequency of their regular (left-right) steps and the natural frequency of vibration of the bridge, large amplitude vibrations may be developed in the bridge and it may subsequently collapse.

4.3.9 Formula for Velocity of Sound with End Correction

A metal tube of known diameter 'D' is immersed in water and kept at downmost position. A tuning fork of known frequency 'n' is made to vibrate and held at the mouth of the tube as shown in Fig. 4.31. The metal tube is adjusted (by moving up) such that loud sound is heard. Fix the position of the tube where loud sound is heard and record the length 'l' of air column.

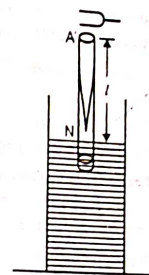


Fig. 4.31

Formula for velocity of sound :

$$v = 4nL$$

i.e.

$$v = 4n(l + 0.3D)$$

where,

v = Velocity of sound

n = Frequency of tuning fork

l = Resonating length of air column

(0.3 D) = End correction

L = (l + 0.3 D) = Corrected resonating length

SUMMARY

- Wave motion is a form of disturbance which travels through the medium due to repeated periodic motion of the medium particle about its mean position.
- **Amplitude :** The maximum displacement of the oscillation in the wave is called amplitude.
- **Periodic time or Period (T) :** The time required to complete one oscillation in the wave is called as period.
- **Frequency (n) :** The number of oscillations completed in one second is called as frequency.
- **Phase :** The phase of a particle at any instant is the state i.e. displacement, direction, position of motion of particle at that instant.

- 1. **Wavelength (λ)** : The distance between two consecutive points in the wave, which are in same phase, is called as wavelength.
- 1. **Relation between v , n and λ** is $v = n\lambda$.
- 1. **Transverse wave** : The wave in which direction of vibration of particles of material medium is perpendicular to the direction of propagation of wave.
- 1. **Longitudinal wave** : The wave in which direction of vibration of particle is parallel to the direction of propagation of wave is called as longitudinal wave.
- 1. **Stationary or standing waves** : It is the resultant wave produced due to superposition of two identical progressive waves with same amplitude, frequency, wavelength and velocity and travelling along same straight line but in opposite direction.
- 1. **Free oscillations** : A body if disturbed from its mean position of rest and allowed to vibrate freely on its own, vibrates with natural frequency, then these vibrations are called free vibrations (oscillations).
- 1. **Forced oscillations** : The oscillations in which another frequency is forced upon the body are called forced oscillations.
- 1. **Resonance** : It is defined as a phenomenon in which a body vibrates with a large amplitude due to effect of forced frequency matches with natural frequency of the body.

Transverse wave	Longitudinal wave
1. Definition : The wave in which direction of vibration of particles of material medium is perpendicular to the direction of propagation of wave is called transverse wave.	1. Definition : The wave in which direction of vibration of particles of material medium is parallel to the direction of propagation of wave is called longitudinal wave.
2. Wave travels in the form of alternate crests and troughs.	2. Wave travels in the form of alternate compressions and rarefactions.
3. Material medium needs elasticity of shape.	3. Material medium needs elasticity of volume.
4. Density and pressure of medium remain same.	4. Density and pressure of medium change. It is maximum at compression and minimum at rarefaction.
5. Wave travels through solid only.	5. Wave travels through liquids and gases.
6. e.g. Light wave.	6. e.g. Sound wave.

SOLVED EXAMPLES

Examples on relation $v = n\lambda$ and resonance only (As per curriculum) :

Example 1 : A tuning fork of frequency 384 Hz produces sound wave of wavelength 86 cm. Find the velocity of sound.

Solution : Given :

$$n = 384 \text{ Hz}$$

$$\lambda = 86 \text{ cm} = 0.86 \text{ m}$$

$$v = ?$$

$$v = n\lambda = (384)(0.86)$$

We have,

$$v = 330.24 \text{ m/s}$$

Example 2 : The velocity of wave is 300 m/s. If the frequency of vibration of wave is 300 Hz, calculate the wavelength.

Solution : Given :

$$v = 300 \text{ m/s}$$

$$n = 300 \text{ Hz}$$

$$\lambda = ?$$

$$v = n\lambda$$

We have,

$$\lambda = \frac{v}{n} = \frac{300}{300}$$

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

Example 3 : A body produces waves of wavelength 33 cm. What is the frequency of vibration if velocity of propagation is 330 m/s?

Solution : Given :

$$\lambda = 33 \text{ cm} = 0.33 \text{ m}$$

$$n = ?$$

$$v = 330 \text{ m/s}$$

$$v = n\lambda$$

We have,

$$n = \frac{v}{\lambda} = \frac{330}{0.33}$$

$$n = 1000 \text{ Hz}$$

Example 4 : An air column of length 17 cm in a resonance tube resonates when fork of 500 Hz is used. Calculate the velocity of sound.

Solution : Given :

$$l = 17 \text{ cm} = 0.17 \text{ m}$$

$$n = 500 \text{ Hz}$$

$$v = ?$$

$$v = 4l = 4 \times (500) \times (0.17)$$

$$v = 340 \text{ m/s}$$

Example 5 : Find the corrected length of air column in a resonance tube of diameter 4 cm, if the length of the resonating air column, for the first resonance is 18.8 cm.

Solution : $l = 18.8$ cm, diameter = $D = 4$ cm, corrected resonating length = ?

Corrected resonating length, $L = (l + 0.3 D) = [18.8 + (0.3 \times 4)]$

$$\boxed{L = 20 \text{ cm}}$$

Example 6 : A tuning fork of frequency 512 Hz resonates with an air column of length 14.4 cm. The end correction is 6 mm. Calculate the velocity of sound in air.

Solution : Given : $n = 512$ Hz

$$l = 14.4 \text{ cm}$$

End correction, $e = 6 \text{ mm} = 0.6 \text{ cm}$

$$v = 4n(l + e)$$

$$= 4(512)(14.4 + 0.6) = 30720 \text{ cm/s}$$

$$\boxed{v = 307.2 \text{ m/s}}$$

Example 7 : A vibrating body sends waves of 110 cm wavelength in air and 480 cm wavelength in water. If velocity of sound in air is 330 m/s, find velocity of sound in water.

Solution : Given : $\lambda_{\text{air}} = 110 \text{ cm} = 1.1 \text{ m}$

$$\lambda_{\text{water}} = 480 \text{ cm} = 4.8 \text{ m}$$

$$v = n\lambda$$

$$\therefore v_{\text{air}} \propto \lambda_{\text{air}} \quad \dots (1)$$

$$\text{and } v_{\text{water}} \propto \lambda_{\text{water}} \quad \dots (2)$$

Dividing equation (2) by (1),

$$\frac{v_{\text{water}}}{v_{\text{air}}} = \frac{\lambda_{\text{water}}}{\lambda_{\text{air}}}$$

$$\therefore v_{\text{water}} = \frac{\lambda_{\text{water}}}{\lambda_{\text{air}}} \times v_{\text{air}} = \frac{4.8}{1.1} \times 330$$

$$\boxed{v_{\text{water}} = 1440 \text{ m/s}}$$

Example 8 : In a resonating tube experiment, resonating length for a tuning fork of 512 Hz frequency is 16 cm. Calculate the resonating length for tuning fork of frequency 384 Hz. Also find velocity of sound at room temperature neglecting end correction.

Solution : Given :

$$n_1 = 512 \text{ Hz}$$

$$l_1 = 16 \text{ cm}$$

$$n_2 = 384 \text{ Hz}$$

$$l_2 = ?$$

We have,

$$v = 4n_1 l_1$$

i.e.

$$v = 4 \times 512 \times 16$$

$$v = 4 \times (512) \times (16)$$

$$v = 32768 \text{ cm/s}$$

or

$$\boxed{v = 327.68 \text{ m/s}}$$

Now,

$$n \propto \frac{1}{l}$$

\therefore

$$n_1 \propto \frac{1}{l_1} \quad \dots (1)$$

and

$$n_2 \propto \frac{1}{l_2} \quad \dots (2)$$

Dividing equation (1) by (2),

$$\frac{n_1}{n_2} = \frac{l_2}{l_1}$$

\therefore

$$l_2 = \frac{n_1}{n_2} \times l_1$$

\therefore

$$l_2 = \frac{512}{384} \times 16$$

\therefore

$$\boxed{l_2 = 21.33 \text{ cm}}$$

QUESTIONS

1. Define wave motion.
2. Define amplitude, period, frequency, phase and wavelength.
3. State relation between velocity, frequency and wavelength.
4. Define transverse wave and longitudinal wave.
5. Define transverse wave and state its characteristics.
6. Define longitudinal wave and state its characteristics.
7. Distinguish between transverse and longitudinal waves.
8. State equation of progressive wave with symbol meanings.
9. Define stationary (standing) wave.
10. Define nodes and antinodes.
11. Define free oscillations, forced oscillations and resonance.
12. State formula for velocity of sound with end correction with symbol meanings.

PROBLEMS

- Find the corrected length of air column in a resonance tube of diameter 2.5 cm, if the length of the resonating air column, for the first resonance is 16 cm.
Ans. Corrected length $L = 16.75$ cm.
- A tuning fork of frequency 512 Hz produces sound wave of wavelength 64 cm. Find the velocity of sound.
Ans. $v = 327.68$ m/s.
- The velocity of wave is 320 m/s. If the frequency of vibration of wave is 480 Hz, calculate the wavelength.
Ans. $\lambda = 0.667$ m.
- A body produces waves of wavelength 50 cm. What is the frequency of vibration if velocity of propagation is 320 m/s?
Ans. $n = 640$ Hz.
- Calculate the velocity of sound if resonating length 14 cm is observed for a tuning fork of frequency 512 Hz.
Ans. $v = 286.72$ m/s.
- A tuning fork of frequency 480 Hz resonates with air column of length 16 cm. The end correction is 0.5 cm. Calculate the velocity of sound in air.
Ans. $v = 316.8$ m/s.



MODERN PHYSICS

5.1 PHOTOELECTRICITY

Photoelectric effect, Planck's hypothesis (Planck's quantum theory), Characteristics of photoelectric effect, Definitions, Einstein's photoelectric function, Photoelectric cell, Applications of photoelectric cell.

5.1.1 Photoelectric Effect

It is found that certain metals like magnesium, zinc, lithium when exposed to ultraviolet light, then electrons are emitted. Some alkali metals like sodium, potassium are sensitive to even visible light. i.e. when light falls on alkali metals, electrons are emitted. Thus, when light of suitable frequency (wavelength) is incident on metallic surface, electrons are emitted from metal surface. As the effect takes place under the influence of light (photo), it is called as **photoelectric effect** and emitted electrons are called as **photoelectrons**.

Converted
Light energy (photo) $\xrightarrow{\hspace{1cm}}$ Electrical energy
into

For most of the metals, the photoelectric effect is observed when ultraviolet light falls on them. However, for alkali metals like Na and K, the effect is observed even with visible light. The photoelectric effect was detected by Hertz in 1887.

5.1.2 Planck's Hypothesis (Planck's Quantum Theory)

Planck proposed the quantum theory for explanation of energy distribution in a black body radiation. According to this theory, energy is not emitted and absorbed continuously, but in a discrete (intermittent) units or packets (bundle). These energy packets are called as photons or quanta.

The photons are electrically neutral and travel with speed of light i.e. radiation is considered as shower of photons.