27

WAVE PROPERTIES OF LIGHT

27.1 INTRODUCTION

In the previous two lessons of this book, you studied about phenomena of reflection, refraction, dispersion and scattering of light. While explaining these phenomena, we talked about situations such as what would happen if a beam (a group of rays) of light is reflected from a polished surface or if a beam of light passes through an optically transparent medium. Such statements do not give any information about what light is made of? In other words, till now in the book, we have not talked about the constituents of light. Let us learn about this aspect of light in the present lesson.

The question you may like to ask is : What carries the light — a form of energy? In other words, what transports light — material particles or waves, from one point to another. What are the basic principles of the wave theory of light? Does wave theory successfully predict the experimental observations pertaining to optical phenomena such as reflection, refraction, interference etc.? In the present lesson, we will attempt to answer these questions.

27.2 OBJECTIVES

After studying this lesson, you should be able to,

- *give brief account of different theories of nature of light;*
- *state Huygen's principle and apply it to explain the propagation of wave front; reflection and refraction of light;*
- *explain the phenomenon of interference and diffraction of light;*
- *explain diffraction of light by a single-slit;*
- *define the terms polarisation of light, plane of vibration, plane of polarisation, angle of polarisation and plane polarised light; and*
- *describe a method for producing plane polarised light.*

27.3 NATURE OF LIGHT : WHAT CARRIES THE LIGHT?

Let us begin our discussion on the nature of light with a seemingly simple question : What is light? On the basis of your everyday experiences and observations, you will perhaps make one or more of the following statements in response to this question:

- Light travels in straight line.
- Light casts shadow of an object kept in its path.
- Light carries energy and enables us to 'see' things in our surroundings.

In these statements, what you are saying essentially refers to *what light does*. These statements do not say anything about the constituents of light. The question, however, requires you to make a statement regarding *what light is made of?* To elaborate the question, let us consider an example. Suppose you are asked: what is sound made of? You are aware that sound is made of waves generated by vibrations of material particles. In view of this example our question as regards light can be rephrased as: Is light made of material particles or waves? Or, in other words, what carries the light — material particles or waves? The answer to this question was obtained on the basis of a series of observations (such as those mentioned by you in the beginning of this section!) of optical phenomena. However, as you will learn in the following, the views about the nature of light were modified as new information and experimental observations accumulated.

27.3.1 Corpuscular Theory of Light

One of the earliest efforts to understand the nature of light and its behaviour was made by Isaac Newton in the 17th century. The theory proposed by Newton is known as ***corpuscular (or particle) theory.*** According to this theory, ***light consists of a stream of tiny, light in weight and elastic particles called corpuscles.*** These particles are emitted by a source of light such as an incandescent bulb or the Sun. After emission from the source, these particles travel with a very high velocity. With these basic presumptions about the corpuscles constituting light, Newton could tentatively explain phenomena like rectilinear propagation, reflection and refraction. However, this theory is of only historical significance and it has been now completely discarded.

Major limitations of the corpuscular theory came to the fore when it could not account for the experimental observations about velocity of light in different media. According to the corpuscular theory, the velocity of light should be high in a denser medium compared to its velocity in a rarer medium contrary to the experimental fact. Further, experimental observations on interference of light obtained by Thomas Young, about which you will learn later in this lesson, posed the greatest challenge to the corpuscular theory. Apart from other things, interference of light refers to observation of points of darkness on a screen where two beams of light reach under certain conditions. Such a situation is unthinkable if light is supposed to be made of particles because, two particles coming together, cannot destroy each other. Therefore, it was felt necessary to look for some other theory about the nature of light which could explain these experimental observations. These experimental findings regard with to the velocity of light in different media, interference of light etc. could be understood on the basis of wave theory of light.

27.3.2 Wave Theory of light

Christian, Huygen's, a contemporary of Newton, proposed the wave theory of light. His description of nature of light as a wave was very much influenced by the concept of mechanical waves, particularly the sound waves. You may recall that one of the prerequisites for propagation of sound waves is the existence of a material medium. That is why sound wave cannot travel in vacuum. Secondly, sound waves in air are longitudinal waves. Drawing parallels from such a well established theory of mechanical waves, Huygens proposed that light also consists of longitudinal waves which travel through a hypothetical medium called ether. This hypothetical medium has the strange property of occupying all space - even the vacuum! The vibrations from the source of light are propagated in the form of waves and the energy carried by them is distributed equally in all directions. However, it was only when Huygens propositions about the wave nature of light were considerably modified by Fresnel and others that optical phenomena like reflection, refraction, interference, polarisation etc. could be explained,

One of the important modification made to Huygens theory was that light waves are transverse in nature and not a longitudinal one. Further, Huygen's also did not say anything about how light waves are produced. His theory essentially dealt with phenomena pertaining to propagation of light. J. Maxwell at the fag end of 19th century predicted theoretically that light waves are electromagnetic waves which are generated by oscillatory motion of charged particles like electrons. And, as far as propagation of these electromagnetic waves is concerned, they do not require any material medium though they are capable of travelling in such media. Therefore, there was no need of an hypothetical medium-either-as proposed by Huygen. These theoretical predictions of Maxwell regarding the electromagnetic wave nature of light were subsequently observed experimentally by Hertz. Many features of wave phenomenon are similar for wave processes of different nature. Therefore, while studying the various optical phenomena, we shall use the information about waves as discussed in the lesson on Waves and Oscillations. But, before we do that, le us complete this story about the theories of nature of light.

27.3.3 Quntum Theory of light

The wave theory or the electromagnetic wave theory of light remained unchallenged until the beginning of the 20th century. A few experimental observations on the interaction of light with matter on atomic scale could not be explained by the wave theory.

To account for such observations, *quantum theory of light* was proposed. *According to the quantum theory, energy and hence light is not emitted from a source in a continuous stream (like wave) such as water flowing from a large-diameter pipe. Instead, it is emitted in discrete packets, called* **quanta**, something like individual droplets of water spraying from the nozzle of a garden hose. You might have noticed that when a large number of individual droplets of water start coming out of the nozzle, it is difficult to distinguish it from a continuous flow of water. Similarly, when a large number of quanta are involved, they exhibit properties of a continuous wave. Deviations from the predictions of Maxwell's electromagnetic theory or the classical wave theory occur only when quanta (or photons) constituting light interact ***individually*** with atomic systems. However, you must note here that the quantum theory of light does not take us back to the corpuscular theory of light as proposed by Newton. ***It simply says that light, under certain special circumstances, do behave as particle preserving all its wave characteristics on a macroscopic level optical phenomenon.***

For macroscopic level optical phenomena, Huygen's wave theory works very well. Therefore, we will learn about Huygen's wave theory in the next section and with its help, derive the well known laws of reflection and refraction of light.

INTEXT QUESTIONS 27.1

1) *According to the corpuscular theory, velocity of light in a rarer medium is greater than its velocity in a denser medium. (True/False)?*

   ....

2) *According to the wave theory, how velocity of light changes with medium.*

   ....

3) *Can the experimental observations pertaining to interference of light be explained on the basis of corpuscular theory.?*

   ....

4) *Does, Huygen's original proposition, that light is a longitudinal wave, contradict the polarisation of light observed experimentally.*

   ....

5) *How does quantum theory of light differ from corpuscular theory?*

   ....

6. *Distinguish between the corpuscular and wave theories of light.*

   ....

27.4 HUYGEN'S PRINCIPLES

According to Huygen's weave theory, every source of light emits waves which spread in all directions. The spreading out or the propagation of these waves from the source of light follows a principle which is known as ***Huygen's principle.*** Let us first understand the concept of wave front.

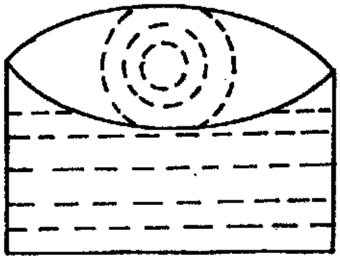

Fig. 27.1: *Circular water wavefronts*

Take a wide based trough full of water (Fig. 27.1) drop a small piece of stone in it. What do you observe? You find that circular ripples due to up and down motion of water particles spread out from the point where stone touched the water surface. If you look carefully at these ripples, you will notice that each point on the circumference of any of these ripples is in the same state of motion (called in phase). That is, each point on the circumference of a ripple oscillates with the same amplitude and same phase. In other words, we can say that *the circumference of a ripple is the locus of the points which are in the same phase of vibration. Such a locus of points is known as* ***wave front.*** Therefore, the circular water ripples spreading out from the point of disturbance on the water surface represent a **circular wave front.** Obviously, the distance of every point on a wave front is the same from the point of disturbance on the water surface i.e. the source of waves. Similarly, for a point source of light emitting in an isotropic medium, the locus of points where the waves are in the same phase of motion will be a sphere. Thus, a point source of light ***emits spherical wave fronts.*** Also a slit source of light will emit ***cylindrical wave fronts.*** *The line perpendicular to the wave front represent the direction of motion of the wave front. This line is called the ray of light and a bundle of such rays is called a beam of light.* When the source of light is at a large distance, any small portion of the wave front can be considered to be a ***plane wave front.***

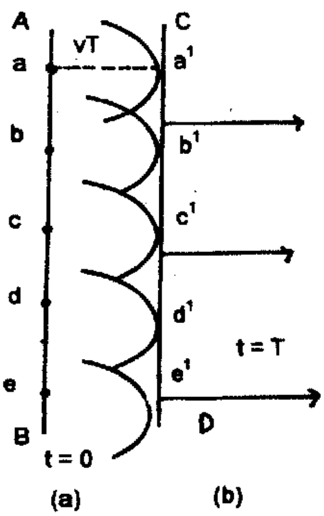

Fig. 27.2: *Construction of a plane wave front at time t = T*

After having discussed what a wave front is, let us now come back to ***Huygen's principle.*** According to this principle, *any wave motion can be described in terms of the motion of wave fronts.* To do so, every point on a wave front should be considered as a source of secondary waves. These secondary waves travel with the same speed as the original wave. Envelop of these secondary waves after a given time interval gives the secondary wave front at that instant. Thus, if the initial, shape, position, direction of motion and the speed of the wave front is known, its position at a later time can be ascertained by geometrical constructions. In fact, Huygen's principle provides us a set of guidelines for geometrical representation of propagation of light as waves. With the help of this principle, and the resulting geometrical construction, we can make predictions regarding the motion of light waves. Note that the wave front does not travel in backward direction.

27.4.1 Propagation of Waves

Now, let us use Huygen's principle to describe the propagation of light waves in terms of the propagation of wave fronts. Fig. 27.2 shows the shape and location of a plane wave front AB at time $t = 0$. You should note here that the line AB lies in a plane perpendicular to the plane of the page. Dots represented by a, b, c .... on the wave front AB are the sources of secondary waves. All these sources emit secondary waves at the same time and they all travel with the same speed along the direction of motion of the wave front AB. In Fig. 27.3 , the circular arcs represent the wavelets emitted from a, b, c, ... These wavelets have been obtained by drawing arcs of radius, $r = vt$, where, v is the velocity of the wave front and t is time at which we wish to obtain the wave front, taking each point a, b, c ..... as centre. The surface tangent, CD, to all these wavelets, represent the new wave front at time t.

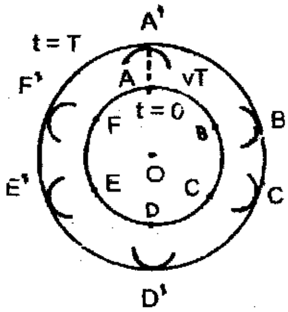

Fig. 27.3: *Construction of circular wavefront using Huygen's prin ciple*

Let us take another example of Huygen's construction for an expanding circular wave front. Refer to Fig. 27.3 which indicates a circular wave front, centred at O, at time $t = O$. A, B, C .... represent point sources on this wave front. Now to draw the wave front at a later time $t = t$, what would you do? You should draw arcs, from each of secondary wave from the points A, B, C ..., of radius equal to the speed of the expanding wave front multiplied by t. These arcs will represent the wavelets emitted from the sourcelets A, B, C ...... The surface tangent to all these wavelets will give a circular wave front A′, B′, C′, ... This is the shape and location of the expanding circular wave front at time $t = t$.

We hope you have understood the technique of Huygen's construction after going through above two examples. Now, you may like to ask what is the ***physical significance of Huygen's construction?*** By determining the shape and location of a wave front at subsequent time with the help of its shape and location at an earlier instant, we are essentially describing the propagation of the wave front. Since wave front is simply a way of representing a wave, the propagation of wave will be in accordance with the movement of its wavefront. Therefore, Huygen's construction enables us to describe the wave motion and hence the propagation of light. Let us test this technique of describing the propagation of light by using it to predict the laws of reflection and refraction in the following.

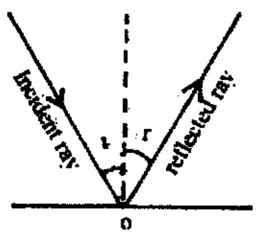

Fig.27.4(a) *Reflection of light from a plane mirror.*

27.4.2 Varification of Laws of Reflection

You have studied the well known law of reflection of light in lesson 25. When a beam of light AO falls on a flat, polished surface called a plane mirror, it is reflected along OR as shown in Fig. 27.4.

The law of reflection says that

Angle of incidence (i) = Angle of Reflection (r)

Let us see how this law can be predicted by Huygen's wave theory. To do so, we will use Huygen's construction.

Refer to Fig. 27.4(b) which shows a wave front PQ incident on a plane mirror AB. As you know, the direction of motion of this wave front is indicated by lines perpendicular to the wave front. Thus, the angle of incidence, i is ∠NPP′ which is equal to ∠QPR. The incident wave front PQ touches the mirror surface at point P which will act like a source of secondary waves. During the line the wavelet from point Q reaches the mirror surface at R, the secondary wavelet from point P will travel a distance equal to QR. Thus, to find out the position of the reflected wave front, we draw an are of radius QR from point P. The, tangent to this arc from point R, that is, the plane RS will represent the reflected wave front. Here, you may note that, by the time wave point from point P reachers the point S, point R has just begun to emit secondary wavelets, that is, the wavelet emitted from point R has zero radius. Now, RS will be true reflected wave point if secondary wavelets from any point on PQ, say M. reach the reflected wave Point at M in the same time during which secondary wave t from P reaches S. That is,

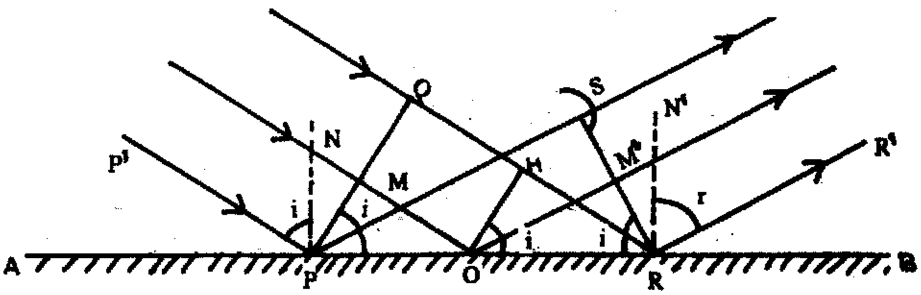

Fig.27.4(b) Huygen's construction of reflection of light

$$MO + OM' = QR = PS \qquad (27.1)$$

Let us draw perpendicular OH from point O, on QR turning to triangles PQR and PRS, we have

$$\angle PQR = \angle RSP = \pi/2,$$

$$QR = PS, \text{ and}$$

PR is common to both the triangles.

Hence, triangles PQR and PRS are congruent,

$$\therefore \angle QPR = \angle SRP = i \qquad (27.2)$$

Again, OH is parallel to PQ

$$\therefore \angle QPR = \angle HOR = \angle i \quad (27.3$$

Further, triangles HOR and M'RO are also congruent, because

$$\therefore \angle HOR = \angle M'OR = \angle i$$

$$\angle OHR = \angle RM' = \pi/2$$

and OR is common.

Hence, $OM' = HR$

or $QR = QH + HR = MO + OM'$

This proves that RM'S is the true reflected wave front.

Now, the angle of reflection r is $\angle N'RR'$.

and $\angle N'RR' = \angle SRP = \angle r$

But, from eqn (27.1)

$$\angle SRP = \angle i$$

$$\therefore \angle i = \angle r$$

angle of incidence = angle of reflection.

Thus, law of reflection follows from Huygens principle.

Thus, Huygen's construction do predict correctly the law of reflection. Now, let us see whether Huygen's construction predicts the law of refraction or not.

27.4.3 Varification of Law of Refraction

You have studied that refraction of light refers to the phenomenon when a beam of light experiences bending after entering from one optically transparent medium to another. This bending of light beam is shown schematically in Fig. 27.5. You may note from the figure that as the light beam enters from a rarer medium (air) to a denser medium (glass), it bends towards the normal to the plane separating these two media. Refraction occurs because of light the velocity of light is different in different medium. However, you must remember that *in no medium, the velocity of light can be greater than its velocity in vacuum.*

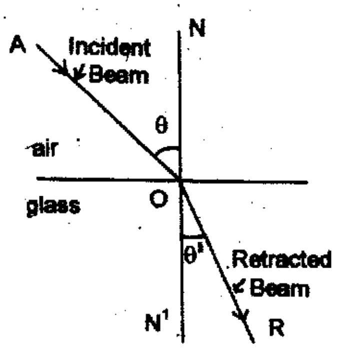

Fig. 27.5: *Refraction of a beam of light incident at boundary of two media*

Since the velocity of light is different in different media, the corresponding wave fronts will also move with different velocities in different media. Does this have any effect on the shape of the wave fronts incident at the boundary separating two media? Let us investigate it with the help of Huygen's construction.

To do so, let us consider a light beam AO incident from air medium (refractive index μ_1) on to a surface of an optically transparent material medium (with refractive index μ_2). Let the angle of incidence be i and angle of refraction be r as shown in Fig. 27.5. The incident wave fronts are the lines perpendicular to the incident beam AO. Similarly, the refracted wave fronts are the lines perpendicular to the refracted beam OR. You may recall that to construct any of these wave fronts using Huygen's construction, we only need to know the shape, location and the speed of the proceeding wave front.

The velocity of light in any medium depends ts upon the refractive index of the medium and the expression is given as,

$$v = c/\mu \qquad \text{......(27.4)}$$

where, v , c , and μ are the velocity of light in the medium, velocity of light in vacuum and refractive index of the medium respectively.

The path travelled by light in time t with velocity v can be expressed as

$$l = vt = t\,(c/\mu)$$

Thus, for our present case indicated in Fig. 27.6, we have,

l_1 = path travelled by light in the medium of refractive index μ_1 during time t

$$l_1 = t\,(c/\mu_1) \qquad (27.5)$$

and l_2 path travelled by light in the medium with refractive index μ_2 during the same time, t

$$l_2 = t\,(c/\mu_2) \qquad (27.6)$$

Now, let $\mu_2 > \mu_1$, that is, medium with refractive index μ_2 is denser than the medium with refractive index μ_1. This condition, alongwith Eqns. (27.5) and (27.6) leads us to the conclusion that

$$l_2 < l_1$$

This relation is of utmost significance for us when we try to understand the phenomenon of refraction using Huygen's construction. Now let us again refer to Fig. 27.6 and construct the wave front P′Q′ with the help of preceding wave front PQ.

Let P, M and Q represent sources of secondary waves on the wave front PQ. The wavelets emitted from points P and M will have radius l_1 - the path travelled by them in the medium with refractive index μ_1 in time t. Whereas, the wavelet emitted from point Q will have radius l_2 path travelled by the wave front in the medium with refractive index μ_2 during the same time t. Now, it is obvious that PP′ > QQ′ and hence the wave front P′Q′ will not be parallel to PQ. Rather, P′Q′

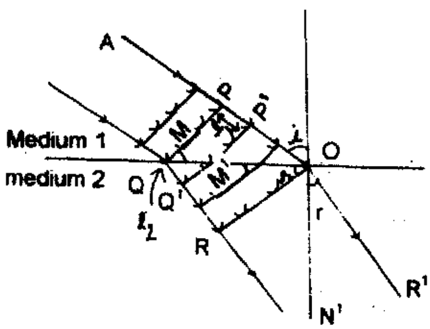

Fig. 27.6 : *Huygen's construction for refraction of light: $\mu_2 > \mu_1$*

will be slightly tilted towards point Q. The line normal to the wave front in medium 2 will be tilted towards the normal NN′. Thus, you have explained refraction of light by Huygen's construction.

To obtain an expression relating the angle of incidence and the angle of refraction with the refractive indices of the two media, let us consider angles PQO and PON. Since line PQ is perpendicular to line PO and line QO is perpendicular to line ON, we can write,

$$\angle PQO = \angle PON = \angle i = \text{angle of incidence.}$$

Similarly, you should convince yourself that

$\angle QOR = \angle r$ = angle of refraction.From right triangles PQO and QOR, we can write,

$$\sin i = \frac{PO}{OQ}$$

and $$\sin r' = \frac{QR}{OQ}$$

$$\therefore \quad \frac{\sin i}{\sin r} = \frac{PO}{OQ} \quad \frac{OQ}{QR} = \frac{PO}{QR} \qquad (27.7)$$

Now, from the geometry of the figure 27.6 PO is equal to l_1 multiplied by an integer (3 in present case) and QR is equal to l_2 multiplied by the same integer. Hence

$$\frac{PO}{QR} = \frac{l_1}{l_2}$$

Using eqns (27.5) and (27.6), we have,

$$\frac{PO}{QR} = \frac{\mu_2}{\mu_1} \qquad (27.8)$$

From eqns (27.7) and (27.8), we can write,

$$\frac{\sin i}{\sin r'} = \frac{\mu_2}{\mu_1}$$

$$\mu_1 \sin i = \mu_2 \sin r' \qquad (27.9)$$

Equation (27.9) is the mathematical representation of the Snell's law of refraction. Therefore, we have correctly predicted the law of refraction using Huygen's wave theory.

After having predicted some of the laws of optical phenomena using geometrical construction based on Huygen's wave theory, we will now discuss a few more optical phenomena which find an explanation only in the domain of the wave theory of light. One such phenomenon is called the interference of light which you will study now.

INTEXT QUESTIONS 27.2

1) *What is the mutual orientation of a wave front and the direction of propagationof the wave?*

....

2) *A source of secondary waves is emitting wavelets at an instant t = 0s. Calculate the ratio of the radii of wavelets at t = 3s and t = 6s.?*

....

27.5 INTERFERENCE OF LIGHT

Let us first do a few 'home-experiments'. Prepare a soap solution by some detergent powder in water. Dip a wire loop into the soap solution and shake it. When you take out the wire loop, you will find a thin film on it. Bring this soap film near a light bulb and position yourself along the direction of the reflected light from the film. What do you observe? You will observe beautiful colours.

In the above experiment, why was the reflected light from the soap film coloured? To answer this question, we will have to understand the phenomenon of ***interference of light. In simple terms, interference of light refers to superposition of light coming from two different sources.*** The phenomenon of interference of light was first observed experimentally by Thomas Young in 1802 in his famous two-slit experiment. This experimental observation played a significant role in establishing the wave theory of light. The basic theoretical principle involved in the phenomenon of interference as well as diffraction of light is the *superposition principle.* This you have studied in details in lesson 23.

27.5.1 Young's Experiment

The Young's experimental set-up is shown schematically in Fig. 27.7. In the experiment, the sunlight was allowed to pass through a pin hole S and then, at some distance away, through two pin holes S_1 and S_2. S_1 and S_2 are equidistant from S and are close to each other. As you learnt in Huygen's wave theory of light, spherical wave fronts would spread out from pin hole S which is further divided into two wavefronts by S_1 and S_2 which would superpose with each other. As a consequence of superposition of two set of dentical waves from S_1 and S_2, an interference pattern consisting of alternate bright and dark fringes are produced on the screen P. The explanation of the observed fringe pattern in Young's interference experiment, as per the wave theory is as follows.

(a) Constructive Interference: You may recall from the previous sub-section on superposition principle that the points such as A on the screen P will have maximum displacement (or amplitude) because the crest due to one set of waves coincide with the crest due to another set of waves. In other words, at this point, the waves are arriving in phase with each other and hence the total amplitude is much higher than the amplitude of the individual waves. The same holds true for points where trough of one set of waves coincides with the trough of another set of waves. Hence such points are also represented by A. Such points will appear bright because intensity of light wave is proportional to the square of the amplitude. Superposition of waves at these points leads to what is known as ***constructive interference.***

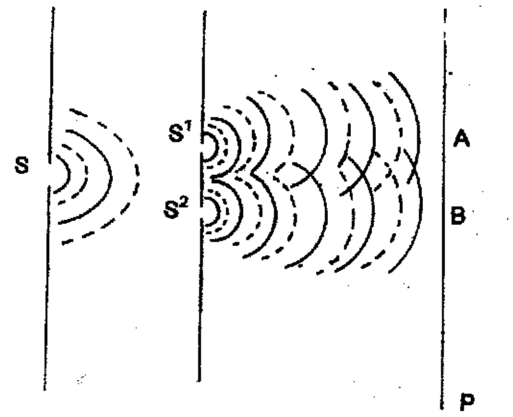

Fig. 27.7: *Schematic arrangement of Young's double-slit experiment.*

(b) Destructive Interferece: On the other hand, points such as B, where crest due to one set of waves coincide with the trough of the other set of waves and vice-versa, the total amplitude will be zero. It is so because the two waves reach these points completely out of phase. As a result, such points will have almost zero amplitude and zero intensity and will appear dark on the observation screen. These points represen the ***destructive interference.***

(c) Coherent Sources: The pinholes S_1 and S_2 represent two special type of light sources. To obtain observable fringe pattern on the screen, these two pinholes must send waves of nearly equal amplitude and with a constant phase difference between them. Such sources of light, as mentioned earlier, are called ***coherent sources.*** In Young's interference experiment, this condition was ensured by illuminating the pinholes S_1 and S_2 by light coming from a narrow pinhole S and by keeping the separation between S_1 and S_2 very small (of the order of one tenth of a millimeter). S is illuminated by a monochromatic source of light such as sodium vapour lamp.

(d) Intensity of fringes: Let us now recall the expression for the intensity of the bright and dark fringes in the interference pattern for harmonic waves. The concept underlying the phenomenon of interference is the superposition of two harmonic waves which you have already studied in lesson 23 on Elastic Waves. Let the phase difference between these two waves be ρ. We can write y_1 and y_2, the displacements at point P due to the two waves as,

$$y_1 = a \sin \omega t$$

and, $$y_2 = a \sin (\omega t + \delta)$$

where ρ is the phase difference between them.

The intensity of the resultant wave at point P can be expressed as,

$$I = A^2 = 4a^2 \cos^2 \delta/2 \qquad (27.10)$$

To see the dependence of intensity on the phase difference between the two waves, let us consider the following two cases.

Case1: When the phase difference, $\delta = 0, 2\pi, 4\pi ..., n2\pi$

$$I = 4a^2 \cos^2 0$$

$$= 4a^2 \text{ (bright fringes)}$$

Case 2 : When, $\delta = \pi, 3\pi, 5\pi, ... (2n+1)\pi$

$$I = 4a^2 \cos^2 (\delta/2)$$

$$= 0 \qquad \text{(dark fringes)}$$

Case (1) representing the phase difference equal to integral multiple of 2π corresponds to the situation when the two waves arrive at the observation screen 'in-phase' and hence the resultant intensity (or the brightness at those points is more than due to individual wave (which is equal to a^2). Case (2), where phase difference between two superposing waves is an odd multiple of π, correspond to the situation when the two superposing waves arrive on the screen 'out of phase'. Thus, such points have zero intensity and will appear dark on the screen.

(e) Phase Difference and Path Difference

It is obvious from above that to know whether a point on the observation screen will be bright or dark, we need to know the phase difference between the waves arriving at that point. The phase difference can be expressed in terms of the path difference between the waves during their journey from the sources to a point on the observation screen. You know that when waves begin their journey from S_1 and S_2 they are in phase. Thus, whatever phase difference is observed between them at point P is because of different path lengths travelled by them upto P from S_1 and S_2. From Fig. 27.8, we can write the path difference,

$$\Delta = (S_2P - S_1P)$$

Now, the path difference of one wavelength is equivalent to phase difference of 2π. Thus, we may write the relation between the phase difference (δ) and the path difference (Δ) as.

$$\Delta = \frac{\lambda}{2\pi}\delta \qquad (27.11)$$

From Eqn. (27.10), bright fringes (or constructive interference) are observed when the phase difference is

$$\delta = n\,2\pi$$

Substituting this in Eqn. (27.11) the path difference for observing bright fringes is

$$(\Delta)_{bright} = \frac{\lambda}{2\pi}.2n\pi = n\lambda \qquad (27.12)$$

Where $n = 0, 1, 2, ...$

Similarly, for dark fringes, from Eqn. (27.11) we get

$$(\Delta)_{dark} = (\lambda/2\pi)\,[(2n+1)\pi] = (2n+1)\,\lambda/2 = (n+\frac{1}{2})\lambda \qquad (27.13)$$

Where, $n = 0, 1, 2, \ldots\ldots\ldots$

After having derived expressions for bright and dark fringes in terms of path difference and the wavelength of the light used, let us find an expression for path difference in terms of distance between source and the screen (D), separation between the pin holes (d) and location of the point P on the screen (x).

since

$$\Delta = S_2P - S_1P = S_2A = d\ \sin\theta$$

Assuming that is very small, we may write,

$$\sin\theta \approx \tan\theta \approx \theta$$

$$\sin\theta = x/D$$

$$\Delta = d\ \sin\theta = \frac{d}{D}$$

Hence, the path differences

$$\Delta = \frac{dx}{D} \qquad (27.14)$$

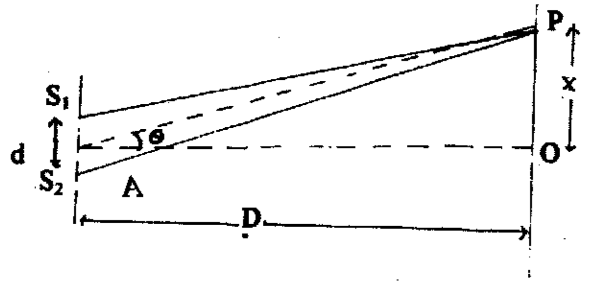

Fig. 27.8: *Calculation of fringe width*

Substituting Eqn. (27.14) in Eqn. (27.12) and (27.13) we have

$$\frac{dx}{D} = n\lambda$$

$$(x)_{bright} = \frac{n\lambda D}{d};\ n = 0, 1, 2, \ldots. \qquad (27.15)$$

and $$\frac{dx}{D} = (n+\frac{1}{2})$$

or $$(x)_{dark} = (n+\frac{1}{2})\frac{\lambda D}{d};\ n = 0, 1, 2\ \ldots\ldots. \qquad (27.16)$$

Expressions (27.15) and (27.16) give the positions of bright and dark fringes on the observation screen.You may now ask : How wide is a bright or a dark fringe? To find out, what we should do is to calculate the location of two consecutive bright (or dark) fringes and take their difference. Let us do it for bright fringes.

$$(x)_{n=3} = 3\ \frac{\lambda D}{d}$$

and $\quad (x)_{n=2} = 2 \dfrac{\lambda D}{d}$

Therefore the fringe width, $\beta = (x)_{n=3} - (x)_{n=2} = \dfrac{\lambda D}{d}$ (27.17)

You should convince yourself that ***fringe width of an interference pattern remains the same for any two consecutive value of n.***

Now, let us talk about the intensity of bright and dark fringes in the interference pattern. When two light waves arrive at a point on the screen out of phase, they interfere destructively and give dark fringes. You may ask : Does not this phenomenon violate the law of conservation of energy because energy carried by two light waves seem to be destroyed? It is not so; the energy conservation principle is not violated in the interference pattern. Actually, the energy which disappears at dark fringes reappears at bright fringe. You may note from Eqn. (27.10) that the intensity at bright fringes is four times the intensity due to individual wave. Therefore, in an interference fringe pattern, shown in Fig. (27.8), the energy is redistributed and it varies between $4a^2$ and zero. Each beam, acting independently, will contribute a^2 and hence, in the absence of interference, the screen will be uniformly illuminated with an intensity $2\alpha^2$ due to light from two similar sources. This is the average intensity shown by the broken line in the Fig. 27.8.

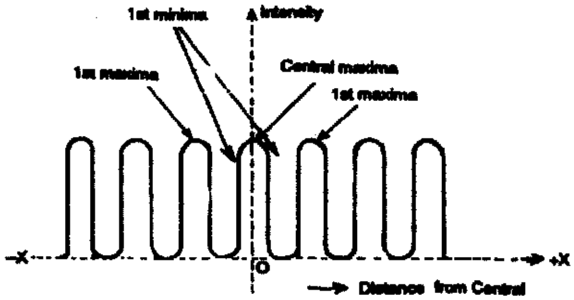

Fig. 27.9 : *Intensity distribution is an interference.*

You have seen that observed interference pattern in the Young's experiment can be understood qualitatively as well as quantitatively with the help of wave theory of light.

INTEXT QUESTIONS 27.3

1) *When two waves superpose, on what factors does the resultant displacement at any point in the region of overlap depend ?*

   ....

2) *In Young's experiment, how the constructive interference is produced on the observation screen?*

   ....

3) *Can we observe an interference fringe pattern when the light is coming from two bulbs?*

   ....

4) *If we replace pin holes S_1 and S_2 by two incandescent light bulbs, can we still observe the bright & dark fringes on the screen?*

....

5) *What are coherent sources?*

....

27.6 DIFFRACTION OF LIGHT

In an earlier lesson of this book, you were told that rectilinear propagation is one of the characteristics of light. The most obvious manifestation of the rectilinear propagation of light is the formation of shadow. But, if you examine the phenomenon of formation of shadow carefully, you find that, as such, these are not sharp at the edges. For example, the law of rectilinear propagation is voilated when light passes through very narrow aperture or falls on an obstacle of very very small dimensions. At the edges of the aperture or the obstacle, light bends into the shadow region and does not propagate along a straight line. ***This bending of light around the edges of an obstacle is known as diffraction.***

Before further discussing the phenomenon of diffraction of light, you may like to observe diffraction of light yourself. Here are a few simple situations where you can observe diffraction of light. Look at street light at night and nearly close your eye lashes. How do you find the street light? You will observe that light appears to be streaking out from the bulb. This happens due to diffraction (bending) of light round the corners of your eyelids.

In the above situations, you will notice that the dimensions of the diffracting obstacle/aperture were very-very small. To observe diffraction effect, either of the following conditions must be obtained :

a) *The size of the obstacle or the aperture should be of the order of the wavelength of the incident wave, or*

b) *The separation between the obstacle or aperture and the observation screen should be considerably larger (a few thousand times) than the size of the obstacle or aperture.*

On the basis of above experiment (done by you!) and the resulting conclusion, it is easy to understand why we normally do not observe diffraction of light and light appear to travel in straight line. You know that the wavelength of light is of the order of 10^{-6} m. Therefore, *to observe diffraction of light, we need to have obstacles or aperture having dimensions of this order!*

27.6.1 Interference and Diffraction

Interference and diffraction of light are basically similar phenomena. In both these phenomena the waves after passing through a small circular aperture spread out in the form of spherical waves. And beyond the aperture, these spherical waves spread out and superpose in accordance with the Huygen's principle and superposition principle.

However, while discussing the interference phenomenon in the light of Huygen's wave theory, the two slits or the pinholes were pressumed to be very narrow such that each may be considered as accommodating only one ***source of secondary*** waves. Whereas, in case of diffraction, as you will learn in the following subsection, the aperture is considered to be of appreciable width so that it may accommodate many sources of secondary waves. Therefore, ***we may say that interference is the superposition of secondary waves emanating from two different secondary sources whereas diffraction is the phenomenon of superposition of secondary waves emanating from the same aperture.*** However, the fact of the matter remains that both these phenomena are the consequences of the way the wave spread and the way they superpose. You will also see in the following section that interference between secondary wavelets gives diffraction.

27.6.2 Diffraction at a Single Slit

After having studied about the phenomenon of diffraction, it is time to study one of the simplest diffraction pattern. Such a diffraction pattern is produced by what is known as single slit. When a beam of light is incident on a barrier with a narrow slit, the light beyond the barrier deviates from its rectilinear path. Diffraction of light produces a pattern of bright and dark fringes of varying intensities on an observation screen beyond. The question is : How light gets diffracted and how these fringes are produced? Let us attempt to answer these questions with the help of Huygen's wave theory and superposition of waves.

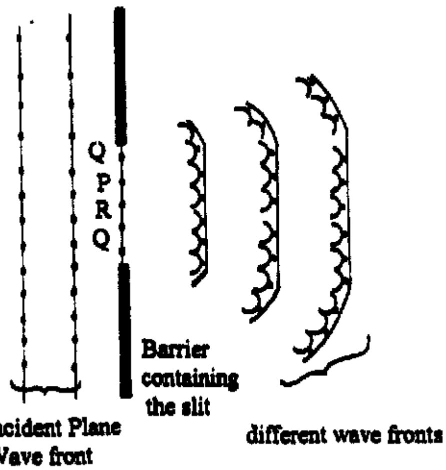

Fig.27.10(a) *Huygen's construction for diffraction of light from a narrow slit.*

Refer to Fig.27.10(a)which shows plane wave fronts incident on the barrier containing the slit. As these wave fronts fall on the barrier, only that part of the wave front will pass through which is incident on the slit. This part of the wave front continue to propagate to the right of the barrier. However, the shape of the wave front does not remain plane beyond the slit. It is so because according to Huygen's principle, the shape of wave front is determined by the way wavelets, spread. For example, in the central part of the wave front to the right of the barrier, the wavelet emitted from point P spread because of the presence of wavelets on its both sides emitted from Q and R. Since the shape of the wave front is determined by the surface tangent to these wavelets, the central part of the wave front remains plane as it propagates. On the other hand, for the wavelets emitted from the points Q, Q′ near the edges of the slit, there are no wavelets beyond the edges with which it may superpose. Since superposition results in keeping the shape of the wave front as plane, absence of such superposing wavelets for wavelets emitted from points near the edges allows them to deviate from plainness. In other words, the behaviour of the wavelets at the edges is governed by the tendency of the wavelets to spread. As a result, the plane wave front of restricted extent bend around its edges. Therefore, the plane wave front, after passing through the slit in the barrier no longer maintains, its plane shape.

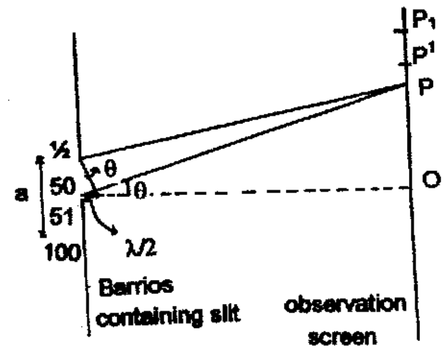

Fig.27.10(b) *Schematic representation of a single slit diffraction.*

A single slit diffraction apparatus is shown schematically in Fig. 27.10(b)After passing through the slit, light gets diffracted into a range of directions and produce a diffraction pattern on the observation screen. A typical intensity distribution of the diffraction pattern is shown in Fig. 27.11. You may notice in Fig. 27.11 that the ***central maximum*** is too bright (indicated by high value of intensity) as well as wide. Also, there are maxima, called **secondary maxima**, of lesser intensity, distributed systematically with respect to central maximum.

To understand the ***intensity distribution*** of the single slit diffraction pattern, we should find out the nature of superposition of waves reaching the observation screen. In order to apply Huygen's principle, let us divide the width '*a*' of the slit into, say, 100 equal parts. Each of these can be considered as a sources of secondary waves. The wavelets emanating from these points spread into the region to the right of the slit. Since the part of the plane wave front incident on the slit arrive at the slit simultaneously, points all the points are oscillating in phase. Therefore, the wavelets emitted by these points are all in phase at the time of leaving the slit. Now let us consider the effect of superposition of these wavelets at point O on the screen. The symmetry of the Fig. 27.10 shows that wavelets emitted from source 1 and 100 will arrive in phase at point O. It is so because both the wavelets travel equal path length in arriving at O. And, when they started their journey from respective points on the slit, they were in phase. Hence, they arrive at O in phase and superpose in such a

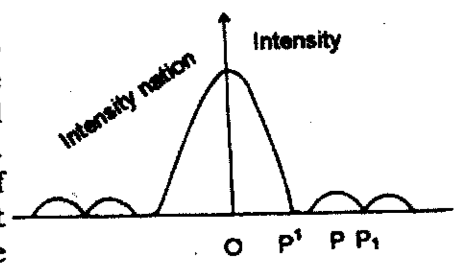

Fig. 27.11: *Intensity distribution of a single slit diffraction pattern*

way to give resultant amplitude much more than that due to any of the individual wavelets from source 1 and 100. Similarly, for each wavelet from source 2 to 50, we have a corresponding wavelet from source 99 to 51 which will produce constructive interference (enhancement in intensity) at point O. Thus, point O will appear bright on the observation screen.

Now let us consider an off-axis point P on the observation screen. Suppose point P is such that the *path difference* between the source at edges i.e. sources 1 and 100 is *equal to* λ. Thus, the path difference between the wavelets from source 1 and 51 will be nearly equal to $\lambda/2$. You may recall from interference of light that the wavelets coming from source 1 and 51 will arrive at P out of phase and give rise to destructive interference. Similarly, wavelets from source 2 and 52 and all such pair of wavelets will give rise to destructive interference at point P. Therefore, we will have intensity minimum at point P. Similarly, at point P_1 for which the path difference between the sources at edges is equal to 2λ, we will again get a minimum.

Lastly, let us consider a point P′ between P and P_1 for which the *path difference is* $3\lambda/2$. To find out intensity at such a point, we divide the wave front at the slit into 3 equal parts. In such a situation, wavelets from the corresponding sources of two parts will have a path difference $\lambda/2$ when they reach p. Thus they will cancel each other and produce destructive interference. However, wavelets from third portion of the wave front will all contribute constructively (pressuming that practically the path difference for wavelets from this part is zero) and produce brightness at P′. Since only one third of the wavefront is contributing towards the intensity at P′ as compared to O where the whole wavefront is contributing, the intensity at P′ will be roughly one third of that of the intensity at O. Points P′ and all other similar points are known as secondary maxima. A typical intensity distribution pattern for a single slit is shown in Fig. 27.11.

However, you must note here that this is only a qualitative and a rather simplified explanation of diffraction at a single slit. You will study more rigorous analysis of this phenomena if you pursue higher studies in physics.

INTEXT QUESTIONS 27.4

1. *Does the phenomenon of diffraction show that light does not travel along a straight line path?*

   ....

2. *Distinguish between interference and diffraction of light.*

   ....

3. *Why intensity of the principal maximum and secondary maxima of a single slit diffraction are not same?*

   ....

27.7 POLARISATION OF LIGHT

In the previous two sections of this lesson, you learnt about the phenomena of interference and diffraction of light. While discussing the phenomena of interference and diffraction, we did not need to know whether the light waves are longitudinal or transverse wave. Instead, polarisation of light indicated that light is a transverse wave. Let us learn about this phenomenon now.

The first thing which might be bothering you is : What is the polarisation of wave? ***Polarisation is a property of transverse waves which refers to the situation when the oscillations of the particles of a medium are along a fixed plane perpendicular to the direction of motion of the mechanical wave.*** In the context of polarisation of light, there are electric field vector and magnetic field vector which oscillate and constitute light wave. *Polarisation of light refers to a situation when electric field vector (or the magnetic field vector) oscillates only along a fixed plane perpendicular to the direction of propagation of light.*

27.7.1 Mechanical Model To Show Polarisation

To illustrate what is meant by polarisation consider a mechanical wave on a rope. Refer to Fig. 27.12 which shows a rope whose one end is fixed and the other end is held by the hand. You know that moving the rope up and down by hand, transverse wave can be generated in the rope. You also know that unlike longitudinal wave, in the transverse wave on the rope, the direction of oscillation of the particles on the rope is perpendicular to the direction of motion of the wave. In Fig. 27.12, OA represents the direction of oscillation of rope particles and OB represents direction of wave motion.

Now let the rope pass through two wooden plates with vertical slits in each of them. The slits are aligned along OA. Let the free end of the rope be moved up and down and transverse waves be generated. When the vertical slits S_1 and S_2 (whose width is slightly more than the thickness of the rope)both are parallel to OA, the direction of oscillation of the rope, the wave on the rope passes through both the slits as shown in

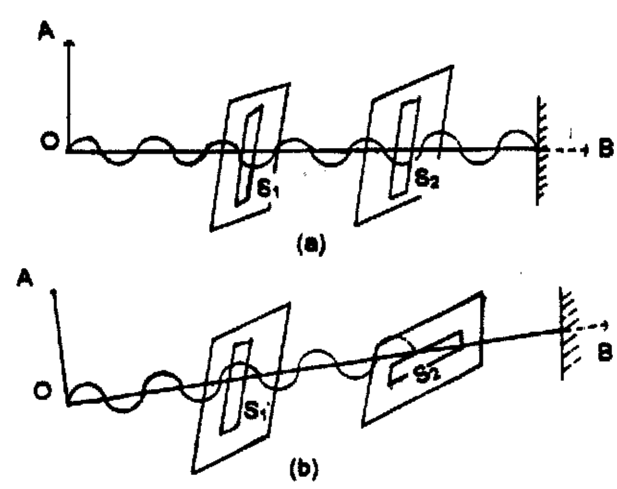

Fig. 27.12: *Transverse wave on a rope passing through slit*

part (a) of the figure. Now let us keep S_1 in the same position and rotate the slit S_2 in such a way that S_1 and S_2 are at right angles to each other, as shown in part (b) of Fig. 27.12. Once again, let us generate transverse wave by moving the free end of the rope up and down. In this case, we find that the wave on the rope passes through S_1 but is stopped at slit S_2. As a result, there is no wave beyond the slit S_2. Why has it happened? Once the wave passes through S_1, only those oscillations are present which are parallel to OA. Once this wave reaches S_2, which can only allow oscillations perpendicular not only to OB but also to OA (i.e. along the direction perpendicular to the plane of the page), it is stopped because component of OA along S_2 will be zero. Transverse wave beyond slit S_1, in which the direction of ***vibration of particles is not only perpendicular to the direction of wave motion but also along a fixed line (OA) are called polarised wave.***

Now let us see what may happen if we keep the above experimental set up unaltered and generate longitudinal waves in the rope. In that situation, the direction of oscillation and direction of wave motion both will be along OB. Therefore, whatever may be the orientation of slits S_1 and S_2, the longitudinal wave will pass through both the slits.

From the above experiment with rope and slits we conclude that ***any wave motion showing polarisation behaviour must be a transverse wave.***

Now let us consider light which is also a kind of wave motion. Therefore, if it shows polarisation behaviour, we can safely conclude that light is a transverse wave. Light shows polarisation or not? To investigate polarisation of light, we use certain materials, in crystalline form, which act as slits of atomic dimensions appropriate for light waves. One such material is called ***tourmaline.*** Tourmaline crystal has the characteristic of allowing the incident light to pass through only when the electric field vector oscillates along the transmission axis of the crystal. Let us do an experiment with an ordinary source of light and tourmaline crystal.

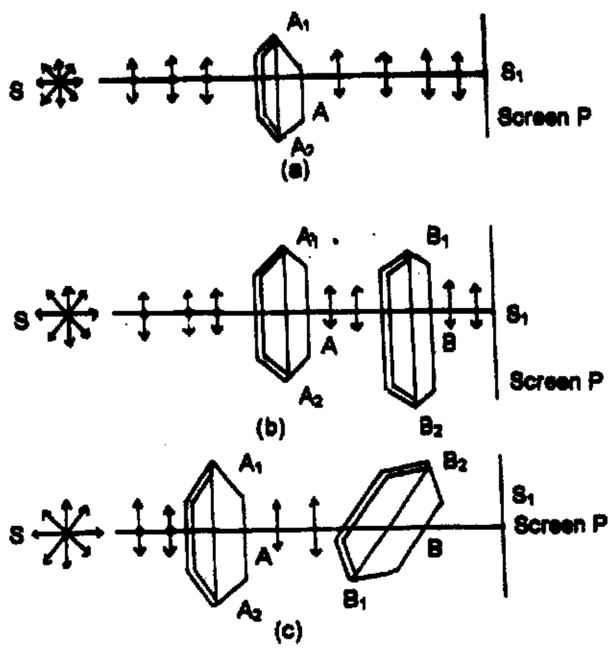

Fig. 27.13: *Polarization of light*

Fig. 27.13 (a), (b), (c) S is a source of light in front of which a tourmaline crystal A and a screen P are placed. When light passes through the crystal a bright spot is observed on the screen. As the crystal A is rotated around the axis SS', no change in the brightness of the light spot is observed on the screen.

Let us place another tourmaline crystal B between A and the screen P as shown in 27.13(b). Let its transmission axis be B_1B_2. When the transmission axes A_1A_2, and BB_1 are parallel to each other the intensity of the spot of light on the screen remains the same as when only crystal A was present.

Now, keeping A fixed, let us rotate crystal B slowly around the axis SS'. We will observe that the intensity of the light spot on the screen diminishes gradually. Finally, when the transmission axes of crystals A and B are in a crossed position, as shown in Fig. 27.13(c), the light spot on the screen disappears. The question is : How do we explain this disappearance of the spot of light on the screen?

Above experimental observations can be understood if we consider light to be a transverse wave - something like the transverse wave on the rope discussed earlier. Any natural source of light such as the Sun or an incandescent bulb emits light whose electric field vibrations take all possible orientations perpendicular to the direction of propagation of light. Such a source is represented by S in Fig. 27.13 and the light emitted by them is known as ***unpolarised light.*** When such an unpolarised beam of light coming from the source S falls on tourmaline crystal A, only the electric field vibrations parallel to the transmission axis A_1A_2 are allowed to pass through. Hence, the light beyond A has only those electric field vibrations which are parallel to A_1A_2, hence are polarised. When this beam of light falls on another crystal B, its passage through B will depend on the relative orientation of the transmission axes of crystals A and B. When the transmission axes of A and B are parallel as in part (b) of Fig. 27.13, the light beam will pass through B undiminished and we observe a bright spot on the screen. When the transmission axis of B is at right angles to that of A, the electric field vibrations of the light falling on B is at right angles to its transmission axes. Thus, the electric field vibration will have no component along B_1B_2 and no light is transmitted through B, as shown in part (c) of the Fig. 27.13. This results in disappearance of the spot of light on the screen. Thus, you have seen that polarisation of light can be understood if light be considered as transverse wave.

It is interesting to note here that human eye cannot distinguish between polarised and unpolarised light. We can only register the intensity of light. As you have learnt above, when an unpolarised light is passed through a tourmaline crystal, it becomes ***plane polarised.*** (See Fig. 27.13) The intensity of this plane polarised light also gets reduced because all electric field vibrations, except the one, of the unpolarised light are blocked by the crystal. Therefore, you may appreciate, that sunglasses made of such materials can be very comfortable for our eyes in summer. One polarising material is herpathite which when embedded in a sheet of introcellulose gives a plastic material called

polaroid. Polaroid sunglasses have this property of cutting off the intensity of light falling on our eye without affecting the colour of the incident light.

Let us now learn about some of the terminologies related to phenomenon of polarisation in general and polarisation of light in particular. ***Crystal A which polarises the incident light is called polariser.*** The second crystal B, ***which analyses whether the incoming light is polarised or not is called an analyser.*** In fact, it is just a matter of convention to call these two crystals by two different names. Both are basically polarisers having the property to allow only that light to pass through whose electric field vibrations are parallel to their transmission axes. Further, the plane containing the direction of motion of the wave and the direction of vibration of the particles of the rope or the electric field in light is known as ***plane of vibration.*** The plane perpendicular to the plane of vibration is known as plane of polarisation. Further, as mentioned earlier, ordinary source of light emits unpolarised light in which electric field vibrations take all possible orientations perpendicular to the direction of the light propagation. From elementary trigonometry, you know that any direction in a plane can be resolved into two mutually perpendicular directions. For example, electric field vector represented by OA in Fig. 27.14 can be resolved into OA sin θ along oy and OA cos θ along ox. Similarly any vector in the plane of the paper can be resolved along ox and oy. Therefore, an unpolarised light wave can be considered as a superposition of two waves whose electric field vectors are mutually perpendicular. Thus, unpolarised light beam can be represented by two mutually perpendicular electric field vibration. The most common way to denote an unpolarised light beam is by the sign in which the arrow indicates the vibration parallel to the plane of the page and the dot indicates the vibration perpendicular to the plane of the page.

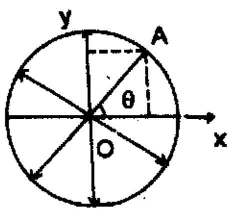

Fig. 27.14: *Resolution of vector along two mtually perpendicular directions*

With this background information about geometrical representation of unpolarised and polarised light beams, let us learn about the way polarised light is produced.

27.7.2 Production of Polarised Light

One of the simplest method of polarising light is its reflection from a polished surface. This phenomenon of polarisation by reflection was first discovered by Malus in 1808. He discovered that if a beam of light is incident at certain angle on the polished surface of a glass plate, the reflected beam was plane polarised. Refer to Fig. 27.15(a) shows a beam of unpolarised light, AO, incident on a glass plate. The reflected beam is shown by OR and the transmitted beam is shown by OT. When the reflected beam was investigated with the help of an analyser, it was found that the beam was partially plane polarised.

However, for certain angle of incidence, called the ***polarising angle,*** i_p, the reflected beam was found to be completely plane polarised as shown in Fig. 27.15(b). Later on, it was discovered by Brewster that when the light beam is incident at polarising angle, the reflected and transmitted (or refracted) beams are not only polarised but are also normal to each other. This discovery indicated that polarisation by reflection of light from glass or other dielectric material is intimately related to the refractive index of the material. To find the dependence of polarising angle on the refractive index of the material, we use Snell's law,

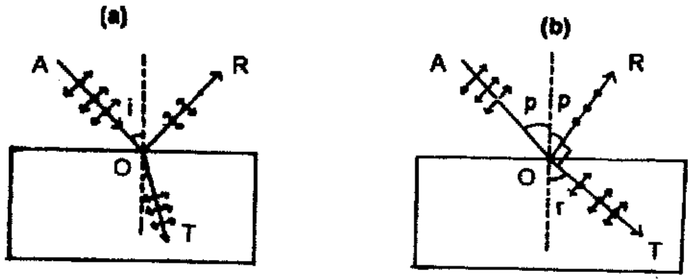

Fig. 27.15: *Polarisation of reflected and refracted light*

$$\mu = \frac{\text{sine of angle of incidence}}{\text{sine of angle of refraction}} = \frac{\sin i}{\sin r}$$

From the geometry of Fig. 27.15(b), we have,

For, $i = i_p$, ROT $= 90°$; $\sin r = \sin(90 - i_p) = \cos i_p$

$$\mu = \frac{\sin i_p}{\sin r} = \frac{\sin i_p}{\cos i_p} = \tan i_p$$

$$\boxed{\mu = \tan i_p}$$

This is known as ***Brewster's law*** and indicates that the polarising angle i_p depends on the refractive index of the material. You may ask : why the unpolarised light gets plane polarised after reflection? Well, to understand this, you need to know how light or the electromagnetic waves are generated as well as reflected and refracted by a material. You will learn about these when you study physics in higher classes.

INTEXT QUESTIONS 27.5

1. *Can you observe the polarisation of light if it were a longitudinal wave? Explain your answer.*

   ....

2. *Is it correct to say that the direction of motion of a wave may not lie in the plane of polarisation?*

   ....

3. *Suppose a beam of unpolarised light is incident on a set of two polaroids. If you want to block the light completely, with the help of these polaroids, what should be the angle between the transmission axes of these polaroids?*

   ....

4. *Does sound in air exhibit polarization?*

   ....

27.9 WHAT YOU HAVE LEARNT

- Light is a form of energy and it has dual nature.
- According to Newton's Corpuscular theory, the light is made up of tiny particles whereas Huygen's wave theory suggests light as a wave.
- The Corpuscular theory can not explain the phenomena of interference, diffraction etc.
- According to Plank's quantum theory, light is made up of quanta of energy called ***Photons.***
- According to Huygen's wave theory, light energy flows out of the source in the form of wave-fronts.
- The continuous locus of all particles of the medium vibrating in the same phase at one instant of time is called the ***wave-front.***
- If two light sources emit light waves of same frequency, same amplitude and move along the same path maintaining constant phase difference between them, they are said to be coherent.
- When two coherent waves superpose each other, redistribution of energy takes place at different points, this is called the ***interference of light.***
- For constructive interference, phase difference = $2n\pi$ and for distructive interference, phase difference = $(2n - 1)\pi$.
- The bending of light near the boundary of the obstacle or the aperture and encroching into the shadow region is called ***diffraction of light.***
- The phenomenon in which the direction of vibrations of light get confined in one particular plane containing the direction of propagation is called the ***polarisation of light.***

27.10 TERMINAL QUESTIONS

1. Explain in brief the theories describing the nature of light.
2. State the Huygen's wave theory. With the help of Huygen's wave theory the propagation of light waves.
3. Predict the laws of reflection on the basis of Huygen's wave theory.
4. What is principle of superposition of waves? Explain the interference of light.
5. How would you demonstrate that the light waves are transverse in nature?
6. State and explain Brewster's law.

7. Describe Young's double slit experiment to produce interference. Deduce an expression for the width of the interference fringes.
8. What would happen to the interference pattern obtained in Young's double slit experiment when,
   (i) one of the slits is closed.
   (ii) the experiment is performed in water instead of air,
   (iii) the source of yellow light is used in place of green light source.
   (iv) the separation between the two slits is gradually increased.
   (v) white light is used in place of monochromatic light.
   (vi) the separation between the slits and the screen is increased.
   (vii) two slits are slightly moved closer.
   (viii) each slit width is increased.
9. The polarising angle for a medium is 60°. What will be the critical angle for this medium?
10. What is a wavefront? What is the direction of a beam of light with respect to the associated wavefront?
11. In young's experimental set-up, the slit separation is 2 mm and the distance between the slits and the observation screen is 100 cm. Calculate the path difference between the waves arriving at a point 5 cm away from the point where the line dividing the slits touches the screen.
12. With the help of Huygens construction, explain the phenomenon of diffraction.
13. For a material of refractive index 1.42, calculate the polarising angle for a beam of unpolarised light incident on it.
14. Distinguish between polarized and unpolarized lights.

CHECK YOUR ANSWERS

Intext Questions 27.1

1. False
2. It is more in vacuum or air than in other media
3. No
4. Yes
5. (i) In its basic assumption (ii) in constituents of light (iii) in propagation of light.

Intext Questions 27.2

1. Perpendicular to each other ($\theta = \pi/2$)
2. $\frac{1}{2}$

Intext Questions 27.3

1. a) Relative phase b) Crest
   c) Incoherent d) Energy
2. No, it is so because two independent sources of light will emit light waves with different wavelengths amplitudes and the two set of waves will not have any constant phase relationship. Such sources of light are called incoherent sources. And as told earlier, for observing interference of light, the sources of light must be coherent. When light waves are coming from two incoherent sources, the points on the screen where two crests or two troughs superpose at one instant to produce brightness may receive, at other instant, the crest of the wave from one source and trough from the other and produce darkness. Thus, the whole screen appears uniformly illuminated if pinholes S_1 and S_2 are replaced by two incandescent light bulbs.
3. Two sources emitting light
   (a) of same frequency and wavelength
   (b) in phase or having constant phase difference
   (c) same ampolitude and period.
   (d) from very close angle

Intext Question 27.4

1. Yes
2. Interference is the superposition of secondary waves emanating from two different secondary sources whereas diffraction is the superposition of secondary waves emanating from the same aperture.
3. Due to increasing path difference betweeh wavelets.

Intext Question 27.5

1. No. Because, in a longitudinal wave, the direction of vibrations is the same as the direction of motion of the wave.
2. No.
3. 90° or 270°
4. No.

TERMINAL QUESTIONS

1. Refer to section 27.4
2. 0.1 mm
3. Refer to section 27.6
4. From Brewster's law, we have $i_p = 54°$
5. See Section 27.7