Chapter 9

PHYSICAL OPTICS

LEARNING OBJECTIVES

At the end of this chapter the students will be able to:

Understand the concept of wavefront.

State Huygen's principle.

Use Huygen's principle to explain linear superposition of light.

Understand interference of flight.

Recognize and express colour patterns in thin films.

Describe the formation of Newton's rings.

Understand the working of Michelson's interferometer and its uses.

Explain the meaning of the term diffraction.

Describe diffraction at a single slit.

Derive the equation for angular position of first minimum.

Derive the equation $d \sin \theta = m\lambda$.

Carry out calculations using the diffraction grating formula.

Describe the phenomenon of diffraction of X-rays by crystals.

Understand the effect of rotation of Polaroid on polarization.

Understand how plane polarized light is produced and detected.

Light is a type of energy which produces sensation of vision. But how does this energy propagate? In 1678, Huygen's, an element Dutch scientist, proposed that light energy from a luminous source travels in space as waves. The experimental evidence in support of wave theory in Huygen's time was not convincing. However, Young's interference experiment performed for the first time in 1801 proved wave nature of light and thus established the Huygen's wave theory. In this chapter you will study the properties of light, associated with its wave nature.

Q.1 Define wave front with its types.

Ans. WAVE FRONTS

"Such a surface on which all the points have the same phase of vibration is known as wave front."

Explanation

Consider a point source of light 'S'. The waves emitted from the source propagated in all direction with a speed 'c'. After time 't' these waves will reach the surface of sphere with centre as a source of light and radius as ct.

Every point on the surface of sphere will be set into vibration by the waves. As the distance of all these points from the source is the same, as their state of vibration will be identical. With the time passing the waves moves farther giving rise to new wave fronts. All these wave fronts will be concentric spheres of increasing radius. Thus we can say that the waves propagated in sphere by the motion of wave fronts. There are two types.

(1) Spherical wave fronts.

(2) Plane wave fronts.

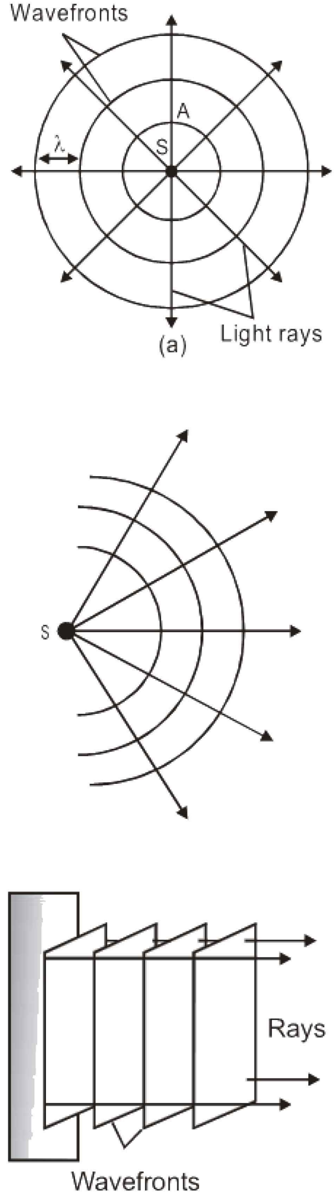


Fig. Spherical wave fronts (a) and plane wavefronts (b) spaced a wavelength apart. The arrows represent rays.

Spherical Wave Fronts

The wave fronts in which the electromagnetic waves are propagated in spherical form with the source is called spherical wave front.

The spherical wave fronts transmitted energy equally in all directions and the direction in which the energy is travel is called a ray.

Plane Wave Fronts

A small portion of spherical wave fronts which is far away from the source is called the plane wave fronts.

The plane wave fronts are parallel to each other and the rays are perpendicular to each plane surface.

Do You Know?

[illegible]

Q.2 State and explain Huygen's principle.

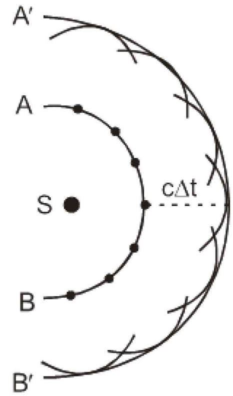
Ans. HUYGEN'S PRINCIPLE

This principle used to determine the shape and location of the new wave fronts. Huygen's principle enables us to determine the shape and location of the new wavefronts. This principle consist of two parts.

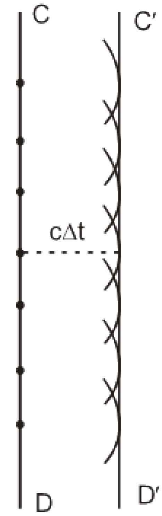
(1) Every point of a wave front considered as a source of secondary wavelets which spread out in forward direction with a speed equal to the speed of propagation of the waves.

(2) The new position of the wavefront after a certain time can be found by constructing a surface that touches all the secondary wavelets.

AB represents the wavefront at any instant. In order to determine the wavefront at time $t + \Delta t$, draw secondary wavelets with centre at various points on the wavefront AB and radius as $c\Delta t$ where c is the speed of the propagation of the waves as shown in fig. The new wavefront at time $t + \Delta t$ is $A'B'$ which is a tangent to all the secondary wavelets.



(a) Spherical Wavefront



(b) Plane wavefront

Fig. Huygens' construction for determining the position of the wavefronts AB and CD after a time interval Δt. $A'B'$ and $C'D'$ are the new positions of the wavefronts.

Q.3 What is the interference of light? Write down the condition of interference.

Ans. INTERFERENCE OF LIGHT WAVES

Definition

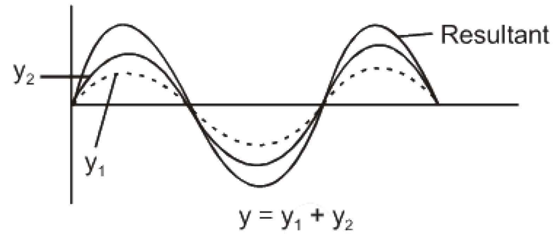
"When two light waves of same frequency and amplitude traveling in the same direction are superposed in such a way that they reinforce at some points while they cancel at the other points, they are set to produce interference of light waves."

There are two types of interference of light waves.

(2) Destructive Interference.

(1) Constructive Interference

That kind of interference in which the two waves reinforce each other i.e. crest of one wave falls on the crest of other wave and similarly trough of one wave falls on the trough of other wave is called constructive interference. In this case the amplitude of the resultant will be greater than either of the individual wave. The constructive interference take place when the path difference between the two waves is an integral multiple of the wavelength i.e.



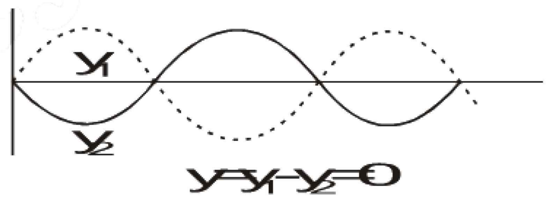
$$S = m\lambda$$

where $m = 0, 1, 2, 3, \ldots\ldots$

(2) Destructive Interference

That kind of interference in which the two waves cancel each other crest of one wave falls on the trough of other wave is called destructive interference.

In this case the amplitude of the resultant wave will be less than either of the individual waves. The path difference between the two waves is given as



$$S = \left(m + \frac{1}{2}\right)\lambda$$

where $m = 0, 1, 2, 3, \ldots\ldots$

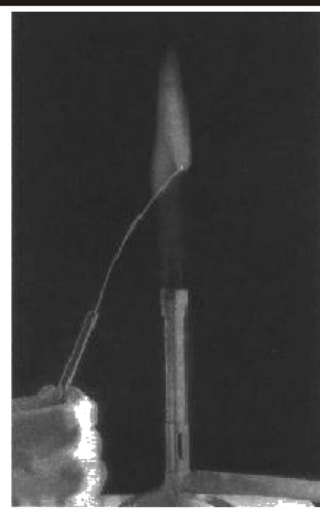
Conditions for Detectable Interference

When two waves travel in the same medium, they would interfere constructively or destructively. The amplitude of the resultant wave will be greater than either of the individual waves, if they interfere constructively. In the case of destructive interference, the amplitude of the resultant wave will be less than either of the individual waves.

Interference of light waves is not easy to observe because of the random emission of light from a source. The following conditions must be met, in order to observe the phenomenon.

1. The interfering beams must be monochromatic, i.e., of a single wavelength.
2. The interfering beams of light must be coherent.

For Your Information



Monochromatic Light

Explanation

one another. The monochromatic sources of light which emit waves, having a constant phase difference, are called coherent sources.

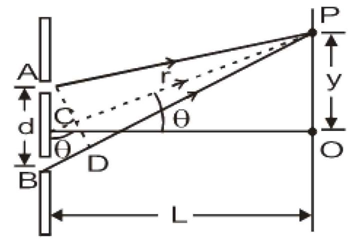
A common method of producing two coherent light beams is to use a monochromatic source to illuminate a screen containing two small holes, usually in the shape of slits. The light emerging from the two slits is coherent because a single source produces the original beam and two slits serve only to split it into two parts. The points on a Huygen's wavefront which send out secondary wavelets are also coherent sources of light.

Q.4 Explain Young's double slit experiment for interference of light waves. Also derive an expression for fringe spacing.

Ans. **YOUNG'S DOUBLE SLIT EXPERIMENT FOR INTERFERENCE OF LIGHT WAVES**

A single narrow slit is illuminated by monochromatic light of wavelength λ. Light from this slit is made to pass through two narrow slits which are closely spaced. When light falls on screen from these slits, interference is produced. The screen is covered with alternate bright and dark bands called interference fringes. The distance between two consecutive dark or bright fringes is called fringe spacing.

A and B are two narrow slits separated by a very small distance d. They are illuminated by a monochromatic light of wavelength λ. A screen is placed at a distance L from the slits. O is the central point of the screen which is at equal distance from the slits. O is therefore always a bright point since light waves from slits A and B reach in phase.



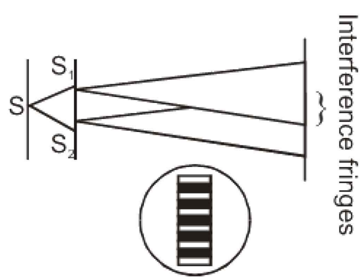


Fig. (a) Ray geometry of Young's double slit experiment.

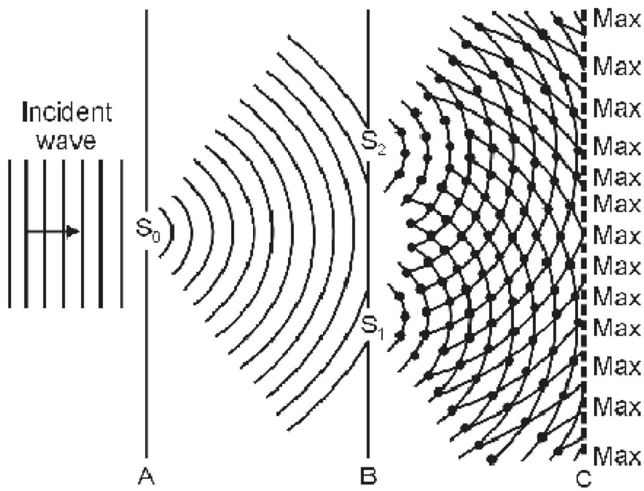


Fig. (b) Young's double slit experiment for interference of light.

'P' is any point on the screen at a distance 'y' from the centre 'O'. Light reaching at point P from the slit B has to cover a longer distance as compared to the light from the 'A'. Draw perpendicular from slit 'A' on BP which is the path difference between the light waves reaching at point P, from the slits A and B.

If $\quad S = m\lambda$

$$S = \left(m + \frac{1}{2}\right)\lambda$$

where $m = 0, 1, 2, 3, \ldots\ldots\ldots$

The interference produced is destructive and the point P is a dark point. To find out the path difference between the waves, we proceed as follows. Join C with point P them from the figure.

$$\frac{BD}{AB} = \sin\theta$$

$$BD = AB\sin\theta$$

$$BD = d\sin\theta$$

The point P is to be a bright point

$$d\sin\theta = m\pi$$

where $m = 0, 1, 2, 3, \ldots\ldots\ldots$

the point P to be a dark point

$$d\sin\theta = \left(m + \frac{1}{2}\right)\lambda$$

where $m = 0, 1, 2, 3, \ldots\ldots\ldots$

Calculation of Y

To calculate the distance between the point P and the centre of the screen.

Therefore $$\tan\theta = \frac{PO}{OC}$$

$$\tan\theta = \frac{Y}{L}$$

$$L\tan\theta = y$$

usually the point P is very close to the point C, so the angle θ is very small then

$$\tan\theta \simeq \sin\theta$$

$$L\sin\theta = y$$

But $$d\sin\theta = m\lambda$$

$$\sin\theta = \frac{m\lambda}{d}$$

$$L \times \frac{m\lambda}{d} = y$$

$$m\lambda = \frac{dy}{L}$$

Knowing the values of d and L, measuring the distance y and counting, the number of fringes, Then the wavelength λ can be calculated.

Fringe Width or Fringe Spacing

It is the distance between two consecutive bright and dark fringes which is calculated as

Position of mth dark fringe $= \left(m + \frac{1}{2}\right)\frac{\lambda L}{d}$

Position of (m – 1)th dark fringe $= \left(m - 1 + \frac{1}{2}\right)\frac{\lambda L}{d}$

$$\text{Fringe spacing} = \left(m + \frac{1}{2}\right)\frac{\lambda L}{d} - \left(m - 1 + \frac{1}{2}\right)\frac{\lambda L}{d}$$

$$= \left(m + \frac{1}{2} - m + 1 - \frac{1}{2}\right)\frac{\lambda L}{d}$$

For dark fringes $= \frac{\lambda L}{d}$

For bright fringes, position of mth bright fringe $= \frac{m\lambda L}{d}$

Position of (m – 1) th bright fringe $= (m - 1)\frac{\lambda L}{d}$

$$\text{Fringe width} = y_{m+1} - y_m$$

$$= (m+1)\frac{\lambda L}{d} - m\frac{\lambda L}{d}$$

$$= (m + 1 - m)\frac{\lambda L}{d}$$

$$= \frac{\lambda L}{d}$$

If the distance b/w the adjacent bright fringes is ΔY, then.

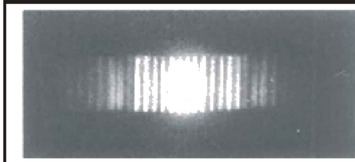
$$\Delta Y = \frac{\lambda L}{d}$$

Similarly, the distance between two adjacent dark fringes can be proved to be $\frac{\lambda L}{d}$. It is found that the bright and dark fringes are of equal width and are equally spaced. The fringe spacing increases if red light is used as compared to blue light. The fringe spacing varies directly with distance L between the slits and screen and inversely with the separation d of the slits. If the separation d between the two slits, the order m of the bright or dark fringe and fringe spacing ΔY are known, the wavelength λ, of the light used for interference effect can be determined by using above equation.

For Your Information

θ°	sin θ	tan θ
2	0.035	0.035
4	0.070	0.070
6	0.104	0.105
8	0.139	0.140
10	0.174	0.176

Tidbits



An interference pattern formed with white light.

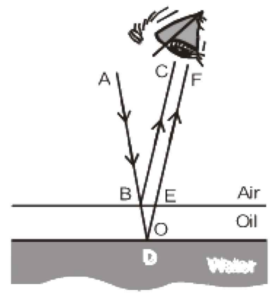
Interesting Information

Colours seen on oily water surface are due to interference of incident white light.

Q.5 Explain the phenomenon of interference in thin films.

Ans. INTERFERENCE IN THIN FILMS

A thin film is a transparent medium whose thickness is comparable with the wavelength of light. Brilliant and beautiful colours in soap bubbles and oil film on the surface of water are due to interference of light reflected from the two surfaces of the film as explained below.



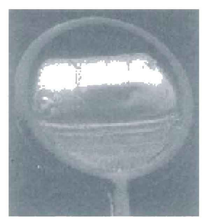
Geometrical construction of interference of light due to a thin oil film.

Consider a thin film of a refracting medium. A beam AB of monochromatic light of wavelength λ is incident on its upper surface. It is partly reflected along BC and partly refracted into the medium along BD. At D it is again partly reflected inside the medium along DE and then at E refracted along EF as shown in figure. The beams BC and EF, being the parts of the same primary beam have a phase coherence. As the film is thin, so the separation between the beam BC and EF will be very small, and they will superpose and the result of their interference will be detected by the eye. It can be seen in figure that the original beam splits into two parts BC and EF due to the thin film which enter the eye after covering different lengths of paths. Their path difference depends upon (i) thickness and nature of the film and (ii) angle of incidence. If the two reflected waves reinforce each other, then the film as seem with the help of a parallel beam of monochromatic light will look bright. However, if the thickness of the film and angle of incidence are such that the two reflected waves cancel each other, the film will look dark.

If white light is incident on a film of irregular thickness at all possible angles, we should consider the interference pattern due to each spectral colour separately. It is quite possible that at a certain place on the film its thickness and the angle of incidence of light are such that the condition of destructive interference of one colour is being satisfied. Hence, that portion of the film will exhibit the remaining constituent colours of the white light as shown in figure.

Do You Know?

The vivid iridescence of peacock feathers due to interference of the light reflected from its complex layered surface.



Interference pattern produced by a thin soap film illuminated by white light.

Q.6 What are Newton's rings? Describe the experiment arrangement of producing the Newton rings. Why does central spot of Newton rings look dark?

Ans. NEWTON'S RINGS

When a plano-convex lens of long focal length is placed in contact with a plane glass plate (Fig. a) a thin air firm is enclosed between the upper surface of the glass plate and the lower surface of the lens. The thickness of the air film is almost zero at the point of contact O and it gradually increases as one proceeds towards the periphery of the lens. Thus, the points where the thickness of air film is constant, will lie on a circle with O as centre.

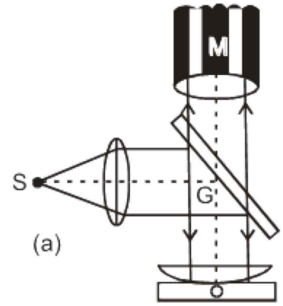


Fig. (a) Experimental arrangement for observing Newton's rings.

By means of a sheet of glass G, a parallel beam of monochromatic light is reflected towards the plano-convex lens L. Any ray of monochromatic light that strikes the upper surface of the air film nearly along normal is partly reflected and partly refracted. The ray refracted in the air film is also reflected partly at the lower surface of the film. The two reflected rays, i.e., produced at the upper and lower surfaces of the film, are coherent and interfere constructively or destructively.

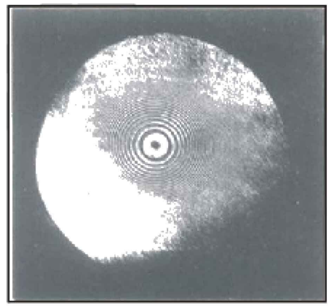


Fig. (b) A pattern of Newton's rings due to interference of monochromatic light.

At the point of contact of the lens and the glass plate, the thickness of the film is effectively zero but due to reflection at the lower surface of air film from denser medium, an additional path difference of $\lambda/2$ is introduced. Consequently, the centre of Newton rings is dark due to destructive interference.

Q.7 Describe principle and working of Michelson's interferometer. How can you find the wavelength of light used?

Ans. MICHELSON'S INTERFEROMETER

Michelson's interferometer is an instrument that can be used to measure distance with extremely high precision. **Albert A. Michelson** devised this instrument in **1881** using the idea of interference of light rays. The essential features of a Michelson's interferometer are shown schematically in figure.

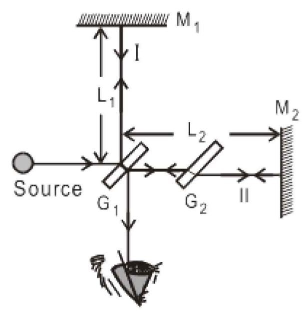


Fig. Schematic diagram of a Michelson's interferometer.

Monochromatic light from an extended source falls on a half silvered glass plate G_1 that partially reflects it and partially transmits it. The reflected portion labelled as I in the figure travels a distance L_1 to mirror M_1, which reflects the beam back towards G_1. The half silvered plate G_1 partially transmits this portion that finally arrives at the observer's eye. The transmitted portion of the original beam labelled as II, travels a distance L_2 to mirror M_2 which reflects the beam back toward G_1. The beam II partially reflected by G_1 also arrives the observer's eye finally. The plate G_2, cut from the same piece of glass as G_1, is introduced in the path of beam II as a compensator plate. G_2, therefore, equalizes the path length of the beams I and II in glass. The two beams having their different paths are coherent. They produce the direction perpendicular to its surface by means of a precision screw. As the length L_1 is changed, the pattern of interference fringes is observed to shift. If M_1 is displaced through a distance equal to $\lambda/2$, a path difference of double of this displacement is produced, i.e., equal to λ. Thus a fringe is seen shifted forward across the line of reference of cross wire in the eye piece of the telescope used to vie the fringes.

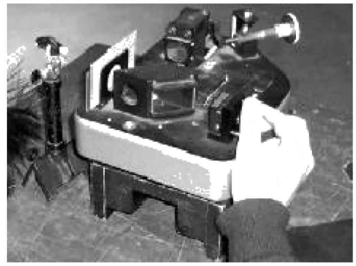
A fringe is shifted, each time the mirror is displaced through $\lambda/2$. Hence, by counting the number m of the fringes which are shifted by the displacement L of the mirror, we can write the equation.

$$L = m\frac{\lambda}{2} \qquad \text{.........} \; (1)$$

Very precise length measurements can be made with an interferometer. The motion of mirror M_1 by only $\lambda/4$ produces a clear difference between brightness and darkness. For λ = 400 nm, this means a high precision of 100 nm or 10^{-4} mm.

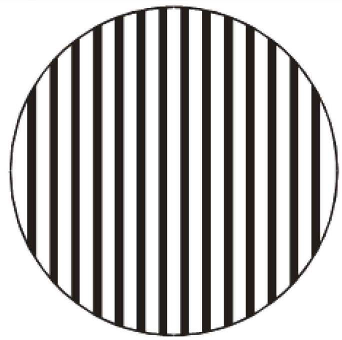
Michelson measured the length of standard metre in terms of the wavelength of red cadmium light and showed that the standard metre was equivalent to 1, 553, 163.5 wavelengths of this light.

For Your Information



A photograph of Michelson Interferometer.

For Your Information



Interference fringes in the Michelson Interformeter.

Q.8 Explain the phenomenon of diffraction of light.

Ans. **DIFFRACTION OF LIGHT**

In Young's double slit experiment for the interference of light, the central region of the fringe system is bright. If light travels in a straight path, the central region should appear dark i.e., the shadow of the screen between the two slits. Another simple experiment can be performed for exhibiting the same effect.

Consider that a small and smooth steel ball of about 3mm in diameter is illuminated by a point source of light. The shadow of the object is received on a screen as shown in fig. The shadow of the spherical object is not completely dark but has a bright spot at its centre. According to Huygen's principle, each point on the rim of the sphere behaves as a source of secondary wavelets which illuminate the central region of the shadow.

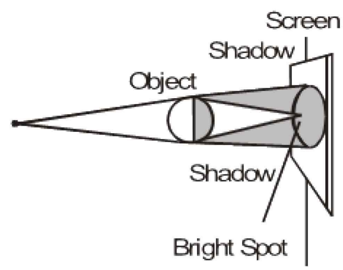


Fig. Bending of light caused by its passage past spherical object.

These two experiments clearly show that when light travels past an obstacle, it does not proceed exactly along a straight path, but bends around the obstacle.

The property of bending of light around obstacles and spreading of light wave into the geometrical shadow of an obstacle is called diffraction.

Point to Ponder

Hold two fingers close together to

between rays coming from different parts of the same wavefront.

Q.9 Explain the diffraction of due to light passing through a narrow slit.

Ans. DIFFRACTION DUE TO A NARROW SLIT

Fig. shows the experimental arrangement for studying diffraction of light due to a narrow slit. The slit AB of width d is illuminated by a parallel beam of monochromatic light of wavelength λ. The screen S is placed parallel to the slit for observing the effects of the diffraction of light. A small portion of the incident wavefront passes through the narrow slit. Each point of this section of the wavefront sends out secondary wavelets to the screen. These wavelets then interfere to produce the diffraction pattern. It becomes simple to deal with rays instead of wavefronts as shown in the figure. In this figure, only nine rays have been drawn whereas actually there are a large number of them. Let us consider rays 1 and 5 which are in phase on in the wavefront AB. When these reach the wavefront AC, ray 5 would have a path difference ab say equal to $\lambda/2$. Thus, when these two rays reach point P on the screen; they will interfere destructively. Similarly, each pair 2 and 6, 3 and 7, 4 and 8 differ in path by $\lambda/2$ and will do the same. But the path difference ab = $d/2 \sin\theta$.

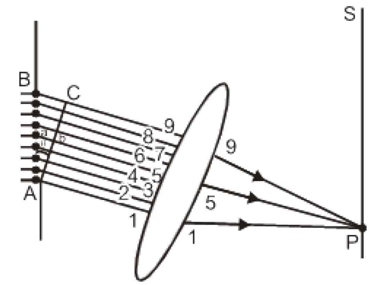


Fig. Diffraction of light due to a narrow slit AB. The dots represent the sources of secondary wavelets.

The equation for the first minimum is, then

$$\frac{d}{2}\sin\theta = \frac{\lambda}{2}$$

or

$$d\sin\theta = \lambda \quad \ldots\ldots (2)$$

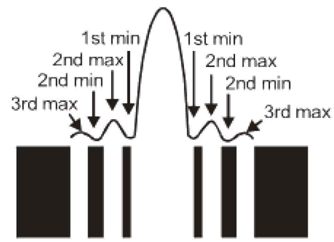


Fig. (a) Diffraction pattern of mono chromatic light produced due to a single slit; graphical representation and photograph of the pattern.

In general, the conditions for different orders of minima on either side of centre are given by

$$d\sin\theta = m\lambda \quad \text{where}$$

$$m = \pm(1, 2, 3, \ldots\ldots) \quad \ldots\ldots (3)$$

The region between any two consecutive minima both above and below O will be bright. A narrow slit, therefore, produces a series of bright and dark regions with the first bright region at the cerntre of the pattern. Such a diffraction pattern is shown in Fig. (a) and (b).

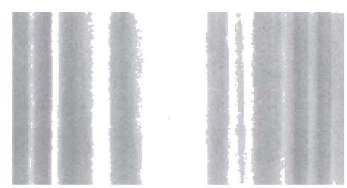


Fig (b) Diffraction pattern produced by white light through a single still.

Q.10 Describe the diffraction grating and obtained the grating equation to find the wavelength of light used.

Ans. DIFFRACTION GRATING

A diffraction grating consists of a glass plate on which very fine equidistant parallel lines (scratches) are drawn by means of a fine diamond point. The lines (Scratches) acts as opaque, while the spacing between the lines on glass plate act as slits. A typical diffraction grating has about 400 to 5000 lines per centimeter.

In order to understand how a grating diffracts light, consider a parallel beam of monochromatic light illuminating the grating at normal incidence. A few of the equally spaced narrow slits are shown in the figure. The distance between two adjacent slits is d, called grating element. Its value is obtained by dividing the length L of the grating by the total number N of the lines ruled on it. The sections of wavefront that pass through the slits behaves as sources of secondary wavelets according to Huygen's principle.

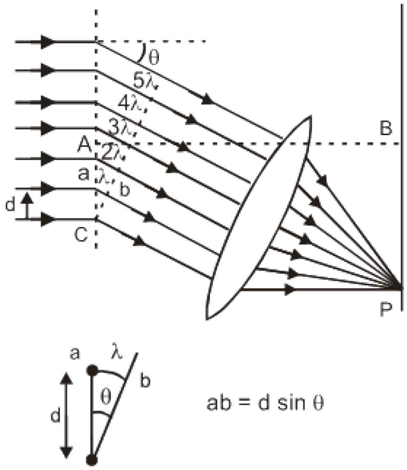


Fig. Diffraction of light due to grating.

In figure consider the parallel rays which after diffraction through the grating make an angle θ with AB, the normal to grating. They are then brought to focus on the screen at P by a convex lens. If the path difference between rays No. 1 and 2 is one wavelength λ, they will reinforce each other at P. As the incident beam consists of parallel rays, the rays from any two consecutives slits will differ in path by λ when they arrive at P. They will, therefore, interfere constructively. Hence, the condition for constructive interference is that ab, the path difference between two consecutive rays, should be equal to λ i.e.,

$$ab = \lambda \quad \text{......... (4)}$$

$$ab = d \sin\theta \quad \text{......... (5)}$$

d being the grating element. Substituting the value of ab in Eq. (4).

$$d \sin\theta = \lambda \quad \text{......... (6)}$$

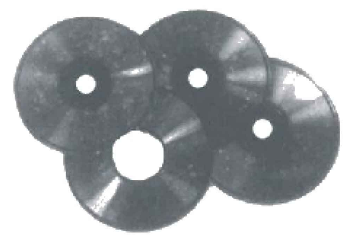
According to Eq. (5), when θ = 0 i.e., along the direction of normal to the grating, the path difference between the rays coming out from the slits of the grating will be zero. So we will get a bright image in this direction. This is known as zero order image formed by the grating. If we increase θ on either side of this direction, a value of θ will be arrived at which d sin θ will become λ and according to Eq. (6), we will again get a bright image. This is known as first order image of the grating. In this way if we continue increasing θ, we will get the second, third, etc. images on either side of the zero order image with dark regions in between. The second, third order bright images would occur accordingly as d sin θ becoming equal to 2 λ, 3 λ, etc. Thus the Eq. (6) can be written in more general form as.

$$d \sin\theta = n\lambda \quad \text{......... (7)}$$

Where, $n = 0 \pm 1 \pm 2 \pm 3$ etc.

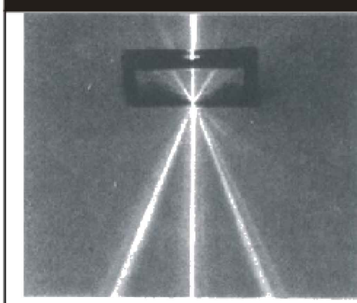
However, if the incident light contains different wavelengths, the image of each wavelength for a certain value of n is diffracted in a different direction. Thus, separate images are obtained corresponding

Interesting Information



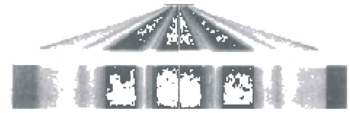
The fine rulings, each 0.5μm wide, on a compact disc function as a diffraction grating. When a small source of white light illuminates a disc, the diffracted light forms colored "lanes" that are composite of the diffraction patterns from the ruling.

Can You Tell?



Light waves projected through this diffraction grating produce an interference pattern. What colours are between the bands of interference?

For Your Information



Diffraction of white light by a fine diffraction grating.

Q.11 Explain diffraction of X-rays by crystals.

Ans. **DIFFRACTION OF X-RAYS BY CRYSTALS**

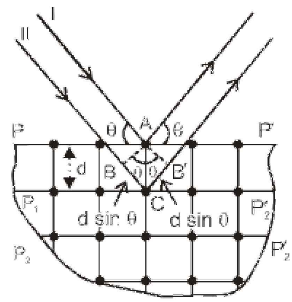
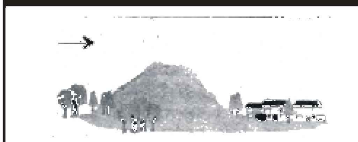


Fig. Diffraction of X-rays from the lattice plane of crystal.

X-rays are the electromagnetic waves of much shorter wavelength, about 10^{-10} m.

In order to observe the effects of diffraction, the grating spacing must be of the order of the wavelength of the radiation used. The regular array of atoms in a crystal forms a natural diffraction grating with spacing that is typically $\approx 10^{-10}$ m. The scattering of X-rays from the atoms in a crystalline lattice gives rise to diffraction effects very similar to those observed with visible light incident on ordinary grating.

Interesting Application



Diffraction of radio waves

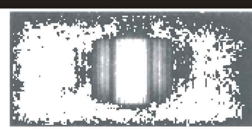
The study of atomic structure of crystals by X-rays was initiated in 1914 by W.H. Bragg and W.L Bragg with remarkable achievements. They found that a monochromatic beam of X-rays was reflected from a crystal plane as if it acted like mirror. To understand this effect, a series of atomic planes of constant interplanar spacing d parallel to a crystal face are shown by lines PP′ $P_1P'_1$, $P_2P'_2$ and so on, in figure.

Suppose an x-ray beam is incident at an angle 'θ' on one of the planes as shown in figure. The beam can be reflected from both upper and lower planes of atoms. The beam reflected from lower plane travels some extra distance as compared to the beam reflected from the upper plane. The effective path difference between the two reflected beams is 2d sinθ. Therefore, for reinforcement, the path difference should be an integral multiple of the wavelength. Thus

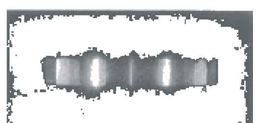
$$2d \sin\theta = n\lambda \qquad \text{......... (8)}$$

The value of n is referred to as the order of reflection. The equation (8) is known as the Bragg equation. It can be used to determine interplanar spacing between similar parallel planes of a crystal if X-rays of known wavelength are allowed to diffract from the crystal.

Interesting Information

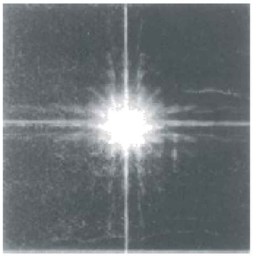


The spectrum of white light due to diffraction gratting of 100 silts.



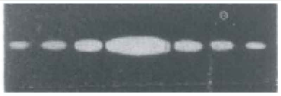
X-ray diffraction has been very useful in determining the structure of biologically important molecules such as hemoglobin,

Interesting Illustration



A multi-aperture diffraction pattern. This is a picture of a white-light point source shot through a place of tightly woven cloth.

Tidbits



Diffraction pattern of a single human hair under laser beam illumination

For Your Information

Looking through two polarizes. When they are "crossed", very little light passes through.

Q.12 Explain the phenomenon polarization.

Ans. **POLARIZATION**

In transverse mechanical waves, such as produced in a stretched string, the vibrations of the particles of the medium are perpendicular to the direction of propagation of the waves. The vibration can be oriented along vertical, horizontal or any other direction. In each of these cases, the transverse mechanical wave is said to be polarized. The plane of polarization is the plane containing the direction of vibration of the particles of the medium and the direction of propagation of the wave.

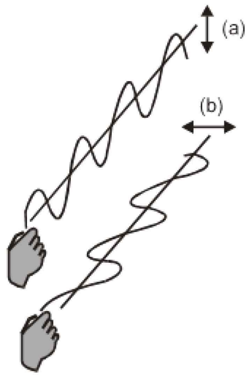


Fig. Transverse waves on a string polarized.
(a) in a vertical plane and
(b) in a horizontal plane

A light wave produced by oscillating charge consists of a periodic variation of electric field vector accompanied by the magnetic field vector at right angle to each other. Ordinary light has components of vibration in all possible planes. Such a light is unpolarized. On the other hand, if the vibrations are confined only in one plane, the light is said to be polarized.

Production and Detection of Plane Polarized Light

The light emitted by an ordinary incandescent bulb (and also by the Sun) is unpolarized, because its (electrical) vibrations are randomly oriented in space. It is possible to obtain plane polarized beam of light from un-polarized light by removing all waves from the beam except those having vibrations along one particular direction. This can be achieved by various processes such as selective absorption, reflection from different surfaces, refraction through crystals and scattering by small particles.

The selective absorption method is the most common method to obtain plane polarized light by using certain types of materials called dichroic substances. These materials transmit only those waves, whose vibrations are parallel to a particular direction and will absorb those waves whose vibrations are in other directions. One such commercial polarizing material is a polaroid.

If un-polazied light is made incident on a sheet of polaroid, the transmitted light will be plane polarized. If a second sheet of polaroid is placed in such a way that the axes of the polaroids, shown by straight lines drawn on them, are parallel, the light is transmitted through the second polaroid also. If the second polaroid is slowly rotated about the beam of light, as axis of rotation, the light emerging out of the second polaroid gets dimmer and dimmer and disappears when the axes become mutually perpendicular. The light reappears on further rotation and becomes brightest when the axes are again parallel to each other.

This experiment proves that light waves are transverse waves. If the light waves were longitudinal, they would never disappear even if the two polaroids were mutually perpendicular.

Reflection of light from water, glass, snow and rough road surfaces, for larger angles of incidences, produces glare. Since the reflected light is partially polarized, glare can considerably by reduced by using polaroid sunglasses.

Sunlight also becomes partially polarized because of scattering by air molecules of the Earth's atmosphere. This effect can be observed by looking directly up through a pair of sunglasses made of polarizing glass. AT certain orientations of the lenses, less light passes through than at others.

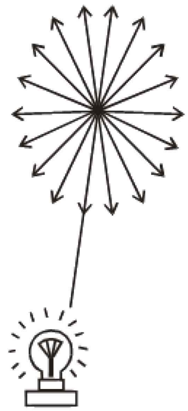


Fig. An unpolarized light, due to incandescent bulb, has vibrations in all directions.

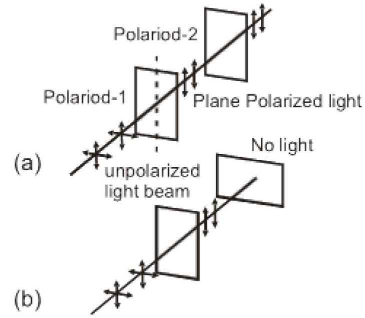
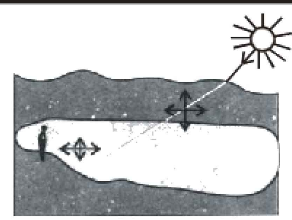


Fig. Experimental arrangement to show that light waves are transverse. The lines with arrows indicates electric vibrations of light waves.

Do You Know?



Light reflected from smooth surface of water is partially polarized parallel to the surface.

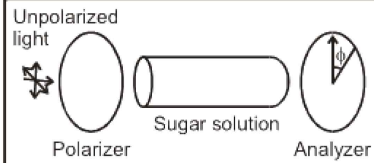
Q.13 Define optical rotation.

Ans. OPTICAL ROTATION

When a plane polarized light is passed through certain crystals, they rotate the plane of polarization. Quartz and sodium chlorate crystals are typical examples, which are termed as optically active crystals.

A few millimeter thickness of such crystals will rotate the plane of polarization by many degrees. Certain organic substances, such as sugar and tartaric acid, show optical rotation when they are in solution. This property of optically active substances can be used to determine their concentration in the solutions.

Interesting Information



Sugar solution rotates the plane of polarization of incident light so that it is no longer horizontal but at an angle. The analyzer thus stops the light when rotated from the vertical (crossed) positions.