

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.

Spherical Wave Fronts

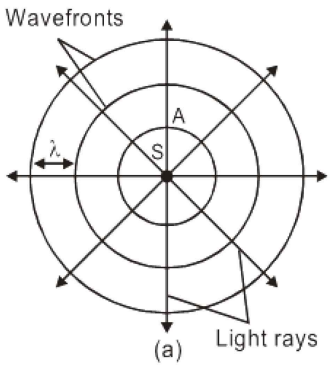
The wave fronts in which the electromagnetic waves are propagated in spherical form with the source is called spherical wave front.

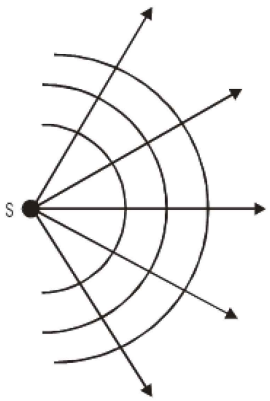
The spherical wave fronts transmitted energy equally in all directions and the direction in which the energy is travel is called a ray.

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.





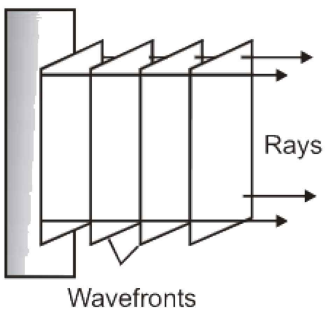


Fig. Spherical wave fronts (a) and plane wavefronts (b) spaced a wavelength apart. The arrows represent rays.

Do You Know?

Q.2 State and explain Huygen's principle.

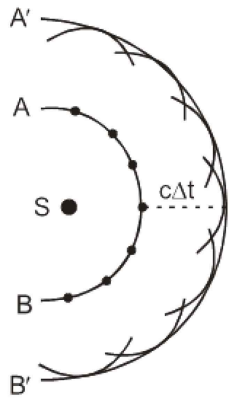
Ans. **HUYGEN'S PRINCIPLE**

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.

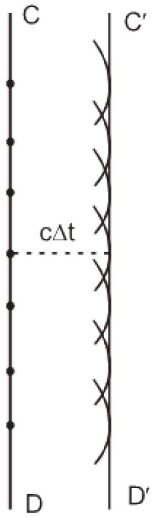
(1) Every point of a wave front considered as a source of secondary wavelets which spread out in forward direction with a speed equal to the speed of propagation of the waves.

(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 + Δt, draw secondary wavelets with centre at various points on the wavefront AB and radius as cΔt where c is the speed of the propagation of the waves as shown in fig. The new wavefront at time t + Δt 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

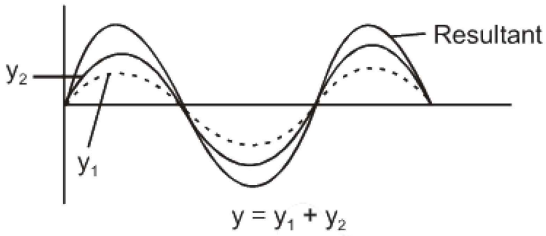
"When two light waves of same frequency and amplitude traveling in the same direction are superposed in such a way that they reinforce at some points while they cancel at the other points, they are set to produce interference of light waves."

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.

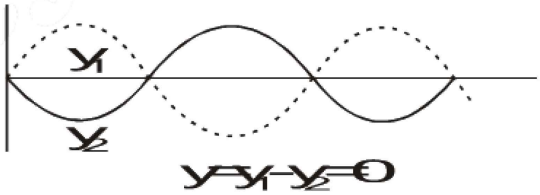


$$S = m\lambda$$

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

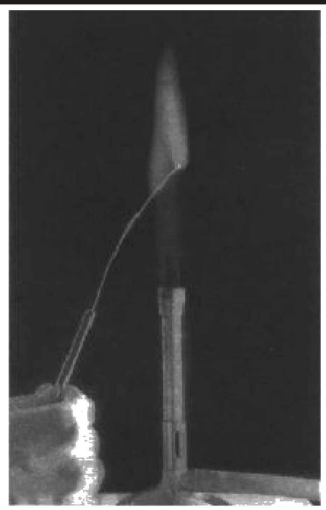
When two waves travel in the same medium, they would interfere constructively or destructively. The amplitude of the resultant wave will be greater than either of the individual waves, if they interfere constructively. In the case of destructive interference, the amplitude of the resultant wave will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

Explanation

For Your Information



Monochromatic Light

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

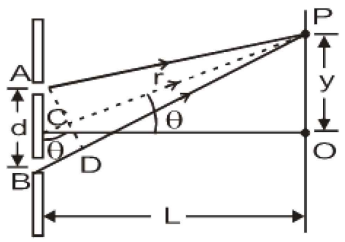
A common method of producing two coherent light beams is to use a monochromatic source to illuminate a screen containing two small holes, usually in the shape of slits. The light emerging from the two slits is coherent because a single source produces the original beam and two slits serve only to split 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.



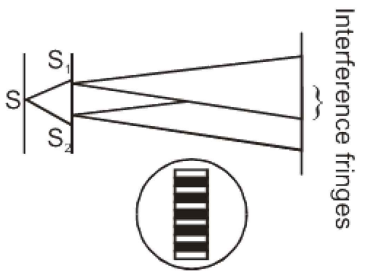


Fig. (a) Ray geometry of Young's double slit experiment.

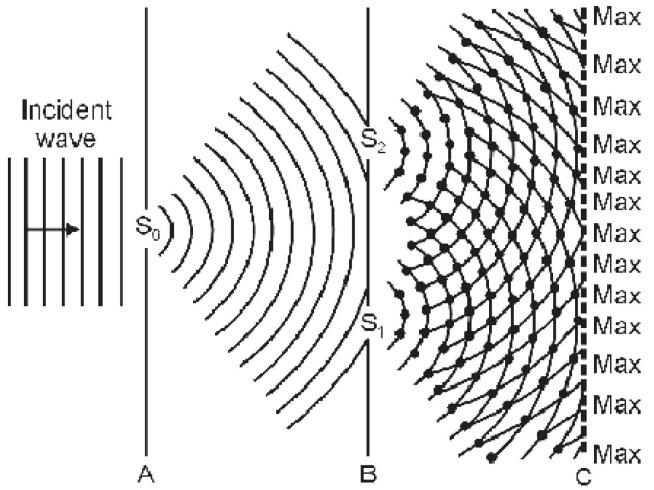


Fig. (b) Young's double slit experiment for interference of light.

'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 $S = m\lambda$

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

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

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

the point P to be a dark point

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

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

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 $d \sin\theta = m\lambda$

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

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

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

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

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

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.

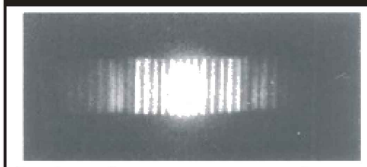
$$\Delta Y = \frac{\lambda L}{d}$$

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

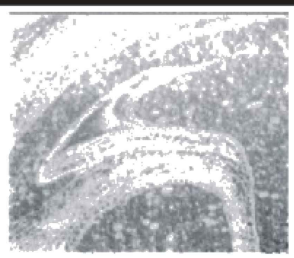
θ°	sin θ	tan θ
2	0.035	0.035
4	0.070	0.070
6	0.104	0.105
8	0.139	0.140
10	0.174	0.176

Tidbits



An interference pattern formed with white light.

Interesting Information

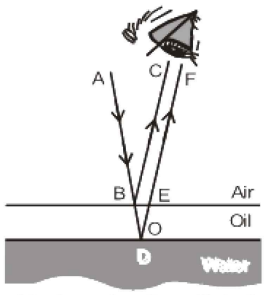


Colours seen on oily water surface are due to interference of incident white light.

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.

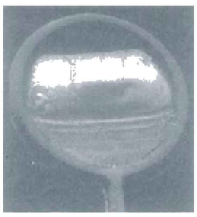
Consider a thin film of a refracting medium. A beam AB of monochromatic light of wavelength λ is incident on its upper surface. It is partly reflected along BC and partly refracted into the medium along BD. At D it is again partly reflected inside the medium along DE and then at E refracted along EF 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.

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.

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.

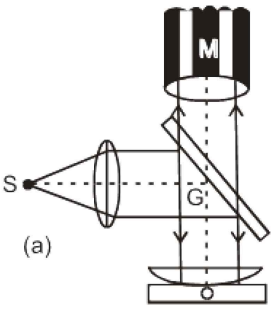


Fig. (a) Experimental arrangement for observing Newton's rings.

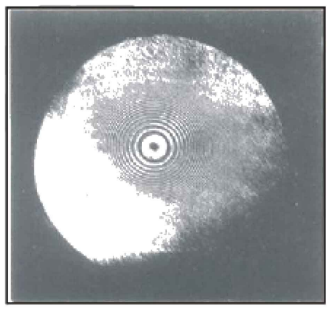


Fig. (b) A pattern of Newton's rings due to interference of monochromatic light.

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.

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

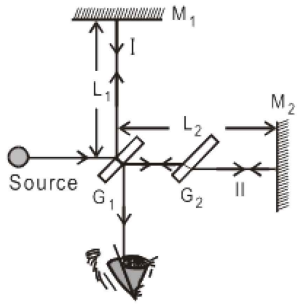


Fig. Schematic diagram of a Michelson's interferometer.

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.

$$L = m\frac{\lambda}{2} \quad \ldots\ldots\ldots (1)$$

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.

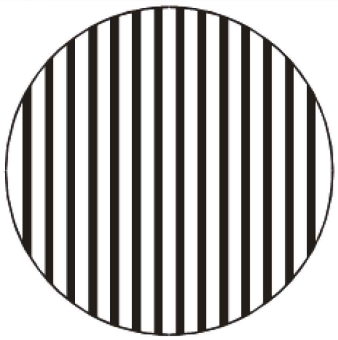
Michelson measured the length of standard metre in terms of the wavelength of red cadmium light and showed that the standard metre was equivalent to 1, 553, 163.5 wavelengths of this light.

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.

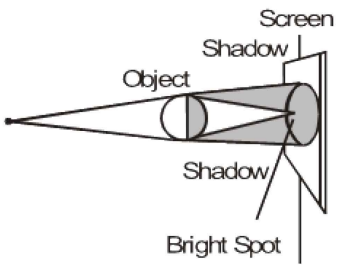


Fig. Bending of light caused by its passage past spherical object.

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 θ.

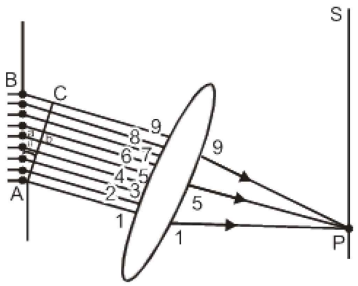


Fig. Diffraction of light due to a narrow slit AB. The dots represent the sources of secondary wavelets.

The equation for the first minimum is, then

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

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

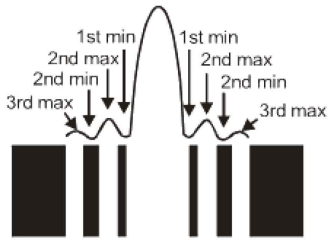


Fig. (a) Diffraction pattern of mono chromatic light produced due to a single slit; graphical representation and photograph of the pattern.

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).

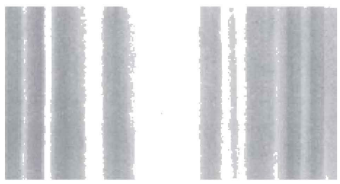


Fig. (b) Diffraction pattern produced by white light through a single still.

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.

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.,

$$ab = \lambda \quad \ldots\ldots\ldots (4)$$

$$ab = d \sin\theta \quad \ldots\ldots\ldots (5)$$

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

$$d \sin\theta = \lambda \quad \ldots\ldots\ldots (6)$$

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.

$$d \sin\theta = n\lambda \quad \ldots\ldots\ldots (7)$$

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

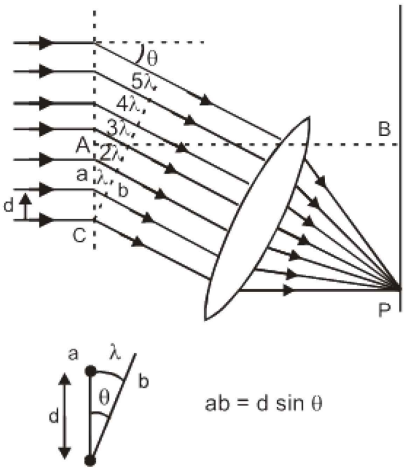
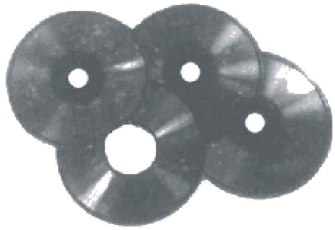


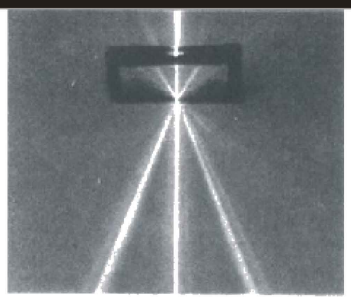
Fig. Diffraction of light due to grating.

Interesting Information



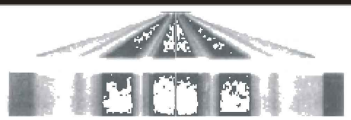
The fine rulings, each 0.5μm wide, on a compact disc function as a diffraction grating. When a small source of white light illuminates a disc, the diffracted light forms colored "lanes" that are composite of the diffraction patterns from the ruling.

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**

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.

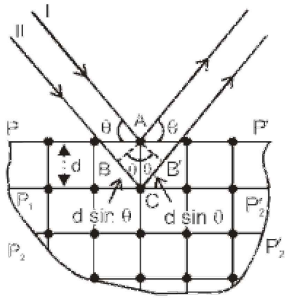
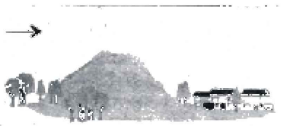


Fig. Diffraction of X-rays from the lattice plane of crystal.

Interesting Application



Diffraction of radio waves

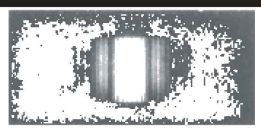
The study of atomic structure of crystals by X-rays was initiated in 1914 by W.H. Bragg and W.L Bragg with remarkable achievements. They found that a monochromatic beam of X-rays was reflected from a crystal plane as if it acted like mirror. To understand this effect, a series of atomic planes of constant 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 $2d \sin\theta$. Therefore, for reinforcement, the path difference should be an integral multiple of the wavelength. Thus

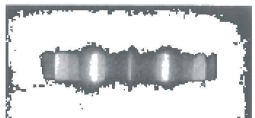
$$2d \sin\theta = n\lambda \qquad \ldots\ldots\ldots (8)$$

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

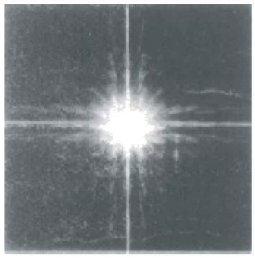


The spectrum of white light due to diffraction gratting of 100 silts.



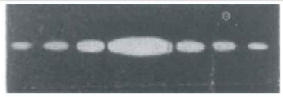
X-ray diffraction has been very useful in determining the structure of biologically important molecules such as hemoglobin,

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.

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.

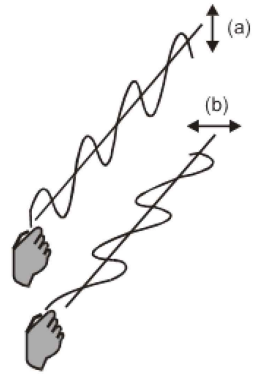


Fig. Transverse waves on a string polarized.
(a) in a vertical plane and
(b) in a horizontal plane

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.

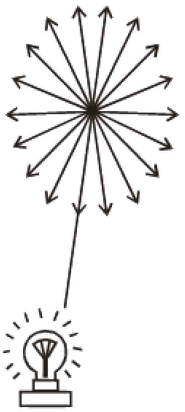


Fig. An unpolarized light, due to incandescent bulb, has vibrations in all directions.

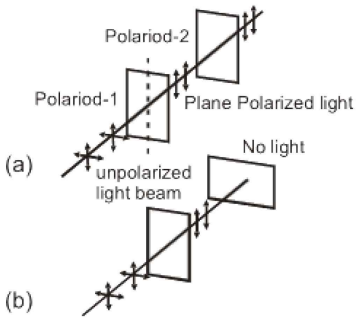
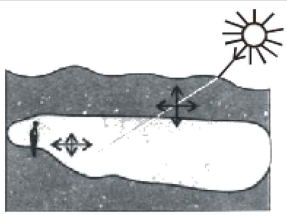


Fig. Experimental arrangement to show that light waves are transverse. The lines with arrows indicates electric vibrations of light waves.

Do You Know?



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

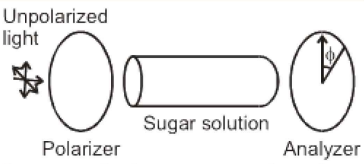
Q.13 Define optical rotation.

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.

SOLVED EXAMPLES

EXAMPLE 9.1

The distance between the slits in Young's double slit experiment is 0.25 cm. Interference fringes are formed on a screen placed at a distance of 100cm from the slits. The distance of the third dark fringe from the central bright fringe is 0.059 cm. Find the wavelength of the incident light.

Data

Distance between slits = d = 0.25cm
= 0.25×10^{-2} m

Distance between slits and screen = L = 100 cm
= 1 m

Distance of third dark fringe = Y = 0.059 cm
= 0.059×10^{-2} m

To Find

Wavelength of light = λ = ?

SOLUTION

Using for dark fringe

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

where m = 0, 1, 2, ...

For 3rd dark fringe

$$m = 2$$

Putting values in above equation

$$0.059 \times 10^{-2} = \left(2 + \frac{1}{2}\right)\lambda \frac{1}{0.25 \times 10^{-2}}$$

$$\therefore \quad \lambda\left(\frac{4+1}{2}\right) = 0.059 \times 10^{-2} \times 0.25 \times 10^{-2}$$

$$\frac{5}{2}\lambda = 0.01475 \times 10^{-4}$$

$$\lambda = \frac{0.0295}{5} \times 10^{-4}$$

$$= 5.9 \times 10^{-3} \times 10^{-4}$$

$$= 5.9 \times 10^{-7} \text{ m}$$

$$= 590 \times 10^{-9} \text{ m}$$

Wavelength of light = λ = 590 nm

EXAMPLE 9.2

Yellow sodium light of wavelength 589 nm, emitted by a single source passes through two narrow slits 1.00 mm apart. The interference pattern is observed on a screen 225 cm away. How far apart are two adjacent bright fringes?

Data

$$\lambda = 589 \text{ nm}$$
$$= 589 \times 10^{-9} \text{ m}$$
$$d = 1 \text{ mm}$$
$$= 1 \times 10^{-3} \text{ m}$$
$$L = 225 \text{ cm}$$
$$= 225 \times 10^{-2} \text{ m}$$

To Find

Distance between two adjacent bright fringes = Δy = ?

SOLUTION

Using

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

Putting values

$$\Delta Y = \frac{589 \times 10^{-9} \times 225 \times 10^{-2}}{1 \times 10^{-3}}$$
$$= 132525 \times 10^{-11+3}$$
$$= 132525 \times 10^{-8}$$
$$= 1.325 \times 10^{-3}$$
$$= 1.33 \times 10^{-3} \text{ m}$$
$$= 1.33 \text{ mm}$$

Result

Distance between two adjacent bright fringes = ΔY = 1.33 mm

EXAMPLE 9.3

(i) How many orders of spectrum can be observed on either side of the direct beam?

(ii) Determine the angle corresponding to each other.

Data

Wavelength of light $= \lambda = 450\text{nm}$

$= 450 \times 10^{-9}\ \text{m}$

Grating element $= d = \frac{1}{5000}\ \text{cm}$

$= \frac{1}{500000}\ \text{m}$

To Find

(i) Orders of spectra $= n = ?$

(ii) Angle $= \theta = ?$

SOLUTION

Using formula

$$d \sin\theta = n\lambda$$

or $$n = \frac{d \sin\theta}{\lambda} \quad \ldots\ldots\ldots (1)$$

For maximum number of order of spectra, $\sin\theta = 1$ i.e., $\theta = 90°$

Putting values in (1), we get

$$n = \left(\frac{1}{500000}\right)\left(\frac{\sin 90^{o}}{450 \times 159}\right)$$

$$= \frac{1}{500000 \times 450 \times 10^{-9}}$$

$$= \frac{10^{-9}}{500000 \times 450} = 4.4$$

Hence max order of spectrum $= 4$

(ii) For First Order Spectrum.

$$n = 1$$

Using the formula

$$d \sin\theta = n\lambda$$

$$\sin\theta = \frac{n\lambda}{d} = \frac{1 \times 450 \times 10^{-9}}{\frac{1}{500000}}$$

$$\Rightarrow \quad \theta = \sin^{-1}(0.225)$$
$$= 13^{o}$$

For 2nd Order Spectrum

Putting values, we get n = 2

$$\sin\theta = \frac{2 \times 450 \times 10^{-9}}{\frac{1}{500000}}$$
$$= 2 \times 450 \times 10^{-9} \times 500000$$
$$\sin\theta = 0.45$$
$$\theta = \sin^{-1}(0.45)$$
$$\theta = 26.7^{o}$$

For 3rd Order Spectrum

$$\sin\theta = \frac{n\lambda}{d}$$
$$= \frac{3 \times 450 \times 10^{-9}}{\frac{1}{500000}}$$
$$= 3 \times 450 \times 10^{-9} \times 500000$$
$$\sin\theta = 0.675$$
$$\theta = \sin^{-1}(0.675)$$
$$\theta = 42.50°$$

For 4th Order Spectrum

$$\sin\theta = \frac{n\lambda}{d} n \quad = 4$$
$$= \frac{4 \times 450 \times 10^{-9}}{\frac{1}{500000}}$$
$$= 4 \times 450 \times 10^{-9} \times 500000$$
$$\sin\theta = (0.9)$$
$$\theta = \sin^{-1}(0.9)$$
$$\theta = 62.2^{o}$$

Result

(i) Order of spectra = n = 4

(ii) Angle = θ = 13°



PHYSICAL OPTICS

Each question has four possible answers, encircled the correct answer:

1. The carpuscular nature of light was given by:

(a) Huygen **(b)** Maxwell

(c) Newton **(d)** Thomas young

2. Light is the source to:

(a) Create energy **(b)** Destroy energy

(c) Carry energy **(d)** All of above

3. Wave theory of light was proposed by:

(a) Thomas young **(b)** Huygen

(c) Newton **(d)** Maxwell

4. According to Newton, light travels in the form of:

(a) Photons **(b)** Waves

(c) Carpascular **(d)** Electrons

5. Huygen proposed that light travels in spaced by means of wave motion in:

(a) 1960 **(b)** 1690

(c) 1680 **(d)** 1670

6. Light is the type of:

(a) Momentum **(b)** Velocity

(c) Energy **(d)** Acceleration

7. The light reaches the earth from the sun in plane:

(a) Amplitude **(b)** Frequency

(c) Wavelength **(d)** Wavefronts

8. In interference and diffraction of light, the waves and wavefronts considered as:

(a) Cylindrical **(b)** Conical

(c) Spherical **(d)** Plane

9. Huygen principle is used to explain the:

(a) Dispersion of light **(b)** Reflection of light

(c) Speed of light **(d)** Propagation of light

10. The shape of wavefronts depends upon:

(a) Shape of medium **(b)** Viscosity of medium

(c) Density of medium **(d)** All of above

11. The direction in which light energy is carried called:

(a) Ray **(b)** Wavefront

(c) Locus **(d)** All of above

12. A plane wave is obtained if a point source of light is placed at the focus of a:

(a) Glass **(b)** Plane lens

(c) Mirror **(d)** None of these

13. When the disturbance is propagated out in all directions from a point source, the wavefronts are:

(a) Spherical **(b)** Conical

(c) Plane **(d)** None of these

14. All the points on a primary wavefront can be considered as the source for the production of secondary wavelets is:

(a) Huygen principle **(b)** Hertz principle

(c) Newton's principle **(d)** Maxwell's principle

15. The electromagnetic theory was developed by:

(a) Newton **(b)** Huygen

(c) Maxwell **(d)** Thomas young

16. Direction of propagation of light ray is:

(a) Along the wavefront

(b) Perpendicular to wavefront

(c) At an angle of 45° to the plane of the wavefront

(d) None of these

17. Light waves are:

(a) Complex **(b)** Monochromatic

(c) Mixture of monochromatic and complex **(d)** None of these

18. A medium which separates out a complex waves into component waves is called a:

(a) Polarizing medium **(b)** Refractive medium

(c) Dispersive medium **(d)** None of these

19. When light waves pass through a dispersive medium what happens to them:

(a) No effect at all **(b)** Split into its component waves

(c) Both (a) and (b) **(d)** None of these

20. When waves pass from one medium to another:

(a) Their wavelength changes **(b)** Their speed changes

(c) Frequency remains constant **(d)** All of above

21. Electromagnetic theory of radiation failed to explain:

(a) Compton effect **(b)** Mass-energy relation

(c) Photoelectric effect **(d)** All of them

22. Electromagnetic waves travel in free space with velocity equal to:

(a) 3×10^{10} m/s **(b)** 3×10^{8} m/s

(c) 3×10^{9} m/s **(d)** 6×10^{7} m/s

23. The first explanation of wave nature of light was provided in 1801 by the experiment of:

(a) Maxwell **(b)** Thomas young

(c) Huygen **(d)** Newton

24. Huygen's principle is used to explain:

(a) The speed of light **(b)** The polarisation

(c) Locate the wavefront **(d)** None of these

25. The locus of all points in a medium having the same phase of vibration is called:

(a) Wavefront **(b)** Wavelength

(c) Focal length **(d)** None of these

26. Huygen principle states that:

(a) Light travel in electromagnetic waves

(b) Light has dual nature

(c) Light travel in straight line

(d) All points on primary wavefront are source of secondary wavelets

27. The phenomenon of the resultant wave obtained by overlapping of two or more waves is called:

(a) Reflection **(b)** Refraction

(c) Interference **(d)** Polarisation

28. The monochromatic sources of light emit waves having a constant phase difference are called:

(a) Reliable sources **(b)** Unreliable sources

(c) Primary sources **(d)** Coherent sources

29. Interference effects of light was verified by:

(a) Bragg **(b)** Newton

(c) Thomas young **(d)** None of the above

30. Which one of the following is monochromatic light source:

(a) Light from simple lamp **(b)** Light from sodium lamp

(c) Light from fluouscent **(d)** Light from neon lamp

31. Two sources of light are coherent if they emit rays of:

(a) Same amplitude

(b) Same wavelengths

(c) Same amplitude and wavelength

(d) Same wavelength with constant phase coherence

32. When the crest of one wave falls on the crest of the other waves, this phenomena is known as:

(a) Polarisation **(b)** Dispersion

(c) Constructive interference **(d)** Destructive interference

33. When crest of one wave falls over the trough of other wave, this phenomenon is known as:

(a) Diffraction **(b)** Polarisation

(c) Constructive interference **(d)** Destructive interference

34. Interference produced by reflected light in thin films is constructive when path difference is:

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

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

35. In order to get interference of light waves:

(a) The sources should be monochromatic

(b) The sources should be phase coherent

(c) The law of super-position should be applicable

(d) All of above

36. The condition for constructive interference of two waves is that the path difference should be:

(a) Integral multiple of λ **(b)** Integral multiple of $\frac{\lambda}{2}$

(c) Even integral multiple of λ **(d)** None of these

37. The condition for destructive interference of two waves is that the path difference should be:

(a) Integral multiple of λ **(b)** Integral multiple of $\frac{\lambda}{2}$

(c) Odd integral multiple of $\frac{\lambda}{2}$ **(d)** None of these

38. In young's double slit experiment, the path difference for bright fringe is:

(a) $d \cos \theta = m\lambda$ **(b)** $d \sin \theta = m\lambda$

(c) $d \sec \theta = m\lambda$ **(d)** $d \tan \theta = m\lambda$

39. In young's double slit experiment, the path difference for dark fringe is:

(a) $d \sin \theta = \left(m - \frac{1}{2}\right)\lambda$ **(b)** $d \sin \theta = m\lambda$

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

40. The distance between two adjacent bright or dark fringes is:

(a) $\Delta y = \frac{L\lambda}{d}$ **(b)** $\Delta y = \frac{\lambda}{d}$

(c) $\Delta y = \frac{\lambda}{Ld}$ **(d)** $\Delta y = Ld\lambda$

41. In young's double slits experiment, the fringe spacing is:

(a) $\Delta y = \frac{d}{\lambda D}$ **(b)** $\Delta y = \frac{2\lambda d}{D}$

(c) $\Delta y = \frac{\lambda D}{d}$ **(d)** $\Delta y = \frac{\lambda d}{D}$

42. In young's experiment if white light is used:

(a) Dark fringe will be seen

(b) Bright fringe will be seen

(c) Alternate dark and bright fringes will be seen

(d) No fringe will be seen

43. The distance between any two consecutive bright fringes is called:

(a) Wavelet **(b)** Fringe spacing

(c) Amplitude **(d)** Wavelength

44. The interference fringe spacing depends upon:

(a) Separation between the sources **(b)** The wavelength of light used

(c) The distance of screen from the source **(d)** All of above

45. A thin film is transparent medium whose thickness is comparable with wavelength of:

(a) Sound **(b)** Heat

(c) Light **(d)** None of these

46. A thin layer of oil on the surface of water looks coloured due to:

(a) Transmission of light **(b)** Polarization of light

(c) Interference of light **(d)** None of these

47. Soap film in sunlight appears coloured due to:

(a) Diffraction of light **(b)** Scattering of light

(c) Interference of light **(d)** Dispersing of light

48. Brilliant and beautiful colours in soap bubbles on surface of water are due to:

(a) Interference of heat **(b)** Interference of light

(c) Interference of sound **(d)** All of the above

49. A white light passed through a prism is:

(a) Polarized **(b)** Dispersed

(c) Diffracted **(d)** Deviated

50. Newton's rings are formed due to:

(a) Reflection of light **(b)** Polarization of light

(c) Interference of light **(d)** Diffraction of light

51. When Newton's rings interference is seen by mean of reflected light, the central spot is:

(a) Dark **(b)** Bright

(c) Blue **(d)** Red

52. Michelson interferometer can be used to find the:

(a) Wavelength of light **(b)** Wavelength of sound

(c) Velocity of sound **(d)** Velocity of light

53. The Michelson formula for displacement L is:

(a) $L = m\frac{\lambda}{2}$ **(b)** $L = 2m\lambda$

(c) $\lambda L = 2m$ **(d)** $\lambda L = \frac{m}{2}$

54. Michelson interferometer was devised in:

(a) 1987 **(b)** 1881

(c) 1687 **(d)** 1789

55. When one mirror of a Michelson interferometer is move a distance of 0.5 mm, 2000 fringes are observed, the wavelength of light used is:

(a) 2000 A° **(b)** 1000 cm

(c) 5000 A° **(d)** None of these

56. The property of bending light when it passes from one medium to another medium is known as:

(a) Dispersion of light **(b)** Diffraction of light

(c) Reflection of light **(d)** None of these

57. Diffraction effects are:

(a) More for sharp edges **(b)** Less for cylindrical

(c) Less for round edge **(d)** Less for sharp edge

58. We get light inside a room in a day time due to:

(a) Diffraction **(b)** Refraction

(c) Interference **(d)** Polarized

59. Diffraction effects was discovered in 1801 by:

(a) Newton **(b)** Henry

(c) Huygen **(d)** W.L Bragg

60. A glass plate having a large number of close parallel equidistant slits mechanically rules on it is called:

(a) Diffraction **(b)** Diffraction grating

(c) Fring spacing **(d)** All of the above

61. A diffraction grating has 500 lines per mm. Its grating element will be:

(a) 500 mm **(b)** 5×10^{-3} mm

(c) 2×10^{-3} mm **(d)** 5×10^{3} mm

62. The formula for grating element is:

(a) $d \sin \theta = \lambda$ **(b)** $d \sin \theta = m\lambda$

(c) $d \sin \theta = \frac{3}{2}\lambda$ **(d)** $md \sin \theta = \lambda$

63. The condition for constructive interference in case of diffraction grating:

(a) $d \sin \theta = m\lambda$ **(b)** $2d \sin \theta = m\lambda$

(c) $d \sin \theta = \frac{m}{\lambda}$ **(d)** $d \sin \theta = 2m\lambda$

64. Interference effects of light were verified by:

(a) Thomas young **(b)** Newton

(c) Einstien **(d)** W.L. Bragg

65. A fringe is a path of:

(a) Constant phase **(b)** Constant amplitude

(c) Same wavelength **(d)** None of these

66. The main advantage of a grating over young's apparatus is the:

(a) Absence of bright light **(b)** Greater deviation of light

(c) Absence of dark fringes **(d)** Sharpness of bright lines

67. Michelson interferometer is based on the principle of:

(a) Division of wavefronts **(b)** Division of amplitude

(c) Addition of amplitude **(d)** None of these

68. The blue of the sky is due to:

(a) Polarization **(b)** Reflection

(c) Refraction **(d)** Scattering

69. The velocity of light was accurately measured by:

(a) Newton **(b)** Faraday

(c) Michelson **(d)** Young

70. The wavelength of X-rays is:

(a) 1000 A° **(b)** 10 A°

(c) 1 A° **(d)** 100 A°

71. Interference and diffraction of light support the:

(a) Particle nature of light **(b)** Quantum nature of light

(c) Transverse nature of light **(d)** Wave nature of light

72. Polarization of light shows that light is:

(a) Extremely short wavelength **(b)** Transverse waves

(c) Longitudinal waves **(d)** Corpuscular in nature

73. Polarization of light takes place in:

(a) Transverse waves **(b)** Longitudinal waves

(c) Sound waves **(d)** None of these

74. The polarization of an electromagnetic waves is determined by:

(a) Electric field **(b)** Magnetic field

(c) Both electric and magnetic **(d)** The direction of waves

75. A polarized is:

(a) A light filter **(b)** To analysed polarized light

(c) Used in polarimeter **(d)** An adjustable shatter

76. Which one of the following cannot be polarized:

(a) Sound waves **(b)** Radio waves

(c) Ultraviolet rays **(d)** X-rays

77. One angstrom is equal to:

(a) 10^{-6} m **(b)** 10^{-8} nm

(c) 10^{-10} nm **(d)** 10^{-8} cm

78. Diffraction is a special type of:

(a) Interference **(b)** Reflection

(c) Polarization **(d)** None of these

79. Young's double slit experiment proves:

(a) Dual nature of light **(b)** Particle nature of light

(c) Wave nature of light **(d)** None of these

80. Two light waves which are not coherent cannot:

(a) Be interference **(b)** Be diffracted

(c) Be polarized in the same plane **(d)** None of these

81. Light on passing through a Polaroid is:

(a) Unpolarized **(b)** Plane polarized

(c) Elliptically polarized **(d)** Circularly polarized

82. Longitudinal waves do not exhibit:

(a) Diffraction **(b)** Polarization

(c) Reflection **(d)** Refraction

83. Light has:

(a) Particle nature **(b)** Wave nature

(c) Dual nature **(d)** None of these

84. Light waves are:

(a) Longitudinal waves **(b)** Transverse waves

(c) Compressional waves **(d)** None of these

85. Wave length of light on the average is given by:

(a) 10^{-9} **(b)** 10^{-10}

(c) 10^{-4} **(d)** 10^{-6}

86. Light waves are:

(a) Mechanical waves **(b)** Electromagnetic waves

(c) Matter waves **(d)** None of these

87. Monochromatic light means waves of:

(a) Same colour **(b)** Same wavelength

(c) Same frequency **(d)** All of these

88. The path difference 'd' for constructive interference should be:

(a) $d = \lambda/2$ **(b)** $d = 5\lambda/2$

(c) $d = m\lambda$ **(d)** $d = m\lambda \quad m = 0, \pm1, \pm2$

89. The equation $2d \sin\theta = n\lambda$ denotes:

(a) Huygen's principle **(b)** Young's double slit experiment

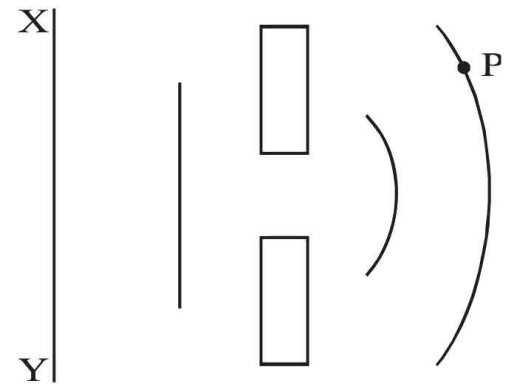
(c) Brogg's equation **(d)** Diffraction grating equation

90. Ultra-violet rays differ from x-rays in that ultra-violet rays:

(a) cannot be diffracted **(b)** cannot be polarized

(c) do not affect a photo-graphic plate **(d)** have a lower frequency

91. A monochromatic plane wave of speed 'c' and wavelength 'λ' is diffracted at a small aperture. The diagram illustrated successive wavefronts. After what time will some portion of the wavefront xy reach P:



(a) $\frac{3\lambda}{2c}$ **(b)** $\frac{2\lambda}{c}$

(c) $\frac{3\lambda}{c}$ **(d)** $\frac{4\lambda}{c}$

92. For which of the following colours will the fringe width be minimum in the double-slit experiment:

(a) Violet **(b)** Red

(c) Green **(d)** Yellow

93. A diver in a lake wants to signal his distress to a person sitting on the edge of the lake flashing his water proof torch. He should direct the beam.

(a) Vertically upwards

(b) Horizontally

(c) At angle to the vertical which is slightly less than the critical angle

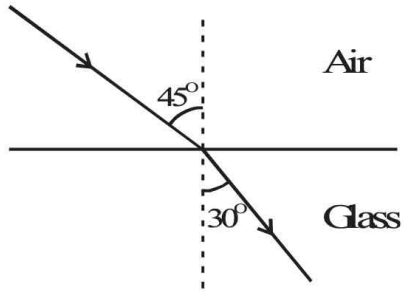
(d) At an angle to the vertical which is slightly more than critical angle

94. The least distance of distinct vision is 25 cm. The focal length of a convex lens is 5 cm. It can act as a simple microscope of magnifying power.

(a) 4 **(b)** 5

(c) 6 **(d)** 3

95. A ray of light travels from air to glass as shown in figure. What is the speed of light in the glass?



(a) $2.0 \times 10^{-6}\ ms^{-1}$

(b) $2.12 \times 10^{-8}\ ms^{-1}$

(c) $2.12 \times 10^{8}\ ms^{-1}$

(d) $3.25 \times 10^{8}\ ms^{-1}$

96. Light reaches the earth from sun in nearly:

(a) 15 minutes **(b)** 10 minutes

(c) 8 minutes **(d)** 8 minutes 20 second

97. Longitudinal waves do not exhibit (show):

(a) Reflection **(b)** Refraction

(c) Diffraction **(d)** Polarisation

98. The danger signals are red while the eye is more sensitive to yellow because:

(a) Scattering in yellow colour is less than that of red

(b) Red light is longer in wavelength than yellow light

(c) Scattering in red is less than in yellow

(d) Red colour has greater frequency than yellow light

99. When crest of one wave falls over the crest of the other waves, this phenomenon is known as:

(a) Destructive interference **(b)** Constructive interference

(c) Dispersion **(d)** Polarisation

100. In Young's double experiment, if white light is used:

(a) Bright fringes will be seen

(b) Dark fringes will be seen

(c) Alternate dark and bright fringes will be seen

(d) No interference fringes will be seen

101. In Young's double slit experiment, if the distance between the slits is doubled and distance between the slits and the screen is halved, the fringe width or spacing is:

(a) Half **(b)** Double

(c) Four times **(d)** One fourth

102. The blue of the sky is due to:

(a) Diffraction **(b)** Reflection

(c) Polarisation **(d)** Scattering

103. When one mirror of a Michelson interferometer is moved a distance of 0.5 mm, 2000 fringes are observed, the wavelength of light used is:

(a) 5000 nm **(b)** 5000 A°

(c) 500 cm **(d)** 2000 A°

104. The wavelength of X-rays is of the order of:

(a) 10 A° **(b)** 1000 A°

(c) 1 A° **(d)** 100 A°

105. Wavelength of X-rays falling at glancing angle of 30° on a crystal with atomic spacing 2×10^{-10} m for the first order diffraction is:

(a) 4×10^{-10} m **(b)** 2×10^{-10} m

(c) 0.2×10^{-10} m **(d)** 20×10^{-10} m

106. If 5000 lines per cm are ruled on a diffraction grating, then the slit spacing will be:

(a) 5×10^{-3} A° **(b)** 0.02 m

(c) 2×10^{-4} A° **(d)** 2×10^{4} A°

107. Which one of the following cannot be polarized?

(a) Radio waves **(b)** Ultraviolet rays

(c) X-rays **(d)** Sound waves

108. The ratio of fringe width for bright and dark fringes is:

(a) 1 : 2 **(b)** 2 : 1

(c) 1 : 4 **(d)** 1 : 1

109. Ratio of intensities of two waves are 4 : 1 then ratio of amplitude of two waves is:

(a) 2 : 1 **(b)** 1 : 2

(c) 4 : 1 **(d)** 1 : 4

110. The index of refraction of diamond is 2.0 velocity of light in diamond in m/sec. is:

(a) 6×10^{8} **(b)** 3×10^{8}

(c) 2×10^{8} **(d)** 1.5×10^{8}

ANSWERS

1.	(c)	**2.**	(c)	**3.**	(b)	**4.**	(c)
5.	(b)	**6.**	(c)	**7.**	(d)	**8.**	(c)
9.	(d)	**10.**	(d)	**11.**	(a)	**12.**	(b)
13.	(a)	**14.**	(a)	**15.**	(c)	**16.**	(b)
17.	(a)	**18.**	(c)	**19.**	(b)	**20.**	(d)
21.	(d)	**22.**	(b)	**23.**	(b)	**24.**	(c)
25.	(a)	**26.**	(d)	**27.**	(c)	**28.**	(d)
29.	(c)	**30.**	(b)	**31.**	(d)	**32.**	(c)
33.	(b)	**34.**	(a)	**35.**	(d)	**36.**	(a)
37.	(b)	**38.**	(b)	**39.**	(c)	**40.**	(a)
41.	(c)	**42.**	(d)	**43.**	(b)	**44.**	(d)
45.	(c)	**46.**	(c)	**47.**	(c)	**48.**	(b)
49.	(b)	**50.**	(c)	**51.**	(a)	**52.**	(a)
53.	(a)	**54.**	(b)	**55.**	(c)	**56.**	(b)
57.	(a)	**58.**	(a)	**59.**	(c)	**60.**	(b)
61.	(b)	**62.**	(b)	**63.**	(a)	**64.**	(a)
65.	(a)	**66.**	(d)	**67.**	(b)	**68.**	(d)
69.	(c)	**70.**	(c)	**71.**	(d)	**72.**	(b)
73.	(a)	**74.**	(a)	**75.**	(c)	**76.**	(a)
77.	(d)	**78.**	(a)	**79.**	(c)	**80.**	(a)
81.	(b)	**82.**	(b)	**83.**	(c)	**84.**	(b)
85.	(d)	**86.**	(b)	**87.**	(d)	**88.**	(d)
89.	(c)	**90.**	(d)	**91.**	(c)	**92.**	(a)
93.	(c)	**94.**	(c)	**95.**	(c)	**96.**	(d)
97.	(d)	**98.**	(c)	**99.**	(b)	**100.**	(c)
101.	(d)	**102.**	(d)	**103.**	(b)	**104.**	(c)
105.	(b)	**106.**	(b)	**107.**	(d)	**108.**	(d)
109.	(a)	**110.**	(d)				

SHORT QUESTIONS

9.1 Under what conditions two or more sources of light behave as coherent sources?

Ans. Two or more sources of light behaves as coherent sources if they have no phase difference or have a constant phase difference between the waves emitted by them.

A common method for producing two coherent light sources is to use single source to illuminate a screen containing two narrow slits. Hence two or more sources derived from a single source of light behaves as coherent source because they are in the same phase.

9.2 How is the distance between interference fringes affected by the separation between the slits of Young's experiment? Can fringes disappear?

Ans. The fringe spacing or distance between two consecutive bright or dark fringes in young's experiment is given by

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

where λ is the wavelength of light used, L is the distance of screen and source and d is the separation of slits. This relation shows that the fringe spacing is inversely proportional to the separation of slits. It means that greater the separation between the slits, the smaller will be fringe spacing. If by increasing the separation, the fringe spacing decreases and the bright fringes becomes so close that uniform intensity of light is seen and fringes disappear.

9.3 Can visible light produce interference fringes? Explain.

Ans. Yes, the white light or visible light can produce the interference fringes. Since the white light is the mixture of seven colours so each colour will produce interference fringes corresponding to its own wavelength. Hence the fringe pattern will be coloured but the fringes will be so closed that it would be difficult to observe the interference fringes of visible or white light.

9.4 In the Young's experiment, one of the slits is covered with blue filter and other with red filter. What would be the pattern of light intensity on the screen?

Ans. Since red and blue light have different wavelengths and will not be in phase coherence. Therefore there will be no dark and bright bands on the screen. So the interference of light cannot be observed properly. For better interference pattern, the monochromatic light should be used.

9.5 Explain whether the Young's experiment is an experiment for studying interference or diffraction effects of light.

Ans. Young's double slit experiment is basically used to study the interference of light. However spreading of light around the corners of the slits also produce diffraction of light. However interference on the screen takes place only when the light coming out of the narrow slits suffers from diffraction first.

9.6 An oil film spreading over a wet footpath shows colours. Explain how does it happen?

Ans. The colours are seen on the oil film spreading on the wet foot path due to interference of light waves. When a light beam is incident, a part of it is reflected from the upper surface of the then oil film and a part of it is reflected from the lower surface of the thin film. The two reflected beams are coherent. When oil film is very thin, these coherent beams overlap. Hence constructive and destructive interference exhibit colours.

9.7 Could you obtain Newton's rings with transmitted light? If yes, would the pattern be different from that obtained with reflected light?

Ans. Yes, Newton rings can be obtained with transmitted light. However no phase is changed in transmitted light, so bright fringes can be replaced by dark fringes and so on. In case of transmitted light, the central point is bright.

9.8 In the white light spectrum obtained with a diffraction grating, the third order image of a wavelength coincides with the fourth order image of a second wavelength. Calculate the ratio of the two wavelengths.

Ans. For diffraction grating, the equation is

$$d \sin \theta = n\lambda$$

where d sin θ is the phase difference, and n is the number of order and λ is the wavelength of light used.

For first wavelength λ_1 and 3rd order, n = 3

$$d \sin \theta = 3\lambda_1 \quad \ldots\ldots \text{(i)}$$

and for second wavelength λ_2 and fourth order, n = 4

$$d \sin \theta = 4\lambda_2 \quad \ldots\ldots \text{(i)}$$

Equating the eq. (i) and (ii)

$$3\lambda_1 = 4\lambda_2$$

$$\frac{\lambda_1}{\lambda_2} = \frac{4}{3}$$

$$\lambda_1 : \lambda_2 = 4 : 3$$

9.9 How would you manage to get more orders of spectra using a diffraction grating?

Ans. For diffraction grating, the equation is given by

$$d \sin \theta = n\lambda$$

where d is the grating element, λ is the wavelength. In order to get more orders of spectra from θ = 0° to θ = 90° for a given wavelength, the grating element d must be increased i.e. Less number of lines per unit length be ruled on diffraction grating.

9.10 Why the polaroid sunglasses are better than ordinary sunglasses?

Ans. The sunlight reflected from smooth surfaces such as water, wet roads, lakes and glass is horizontally polarized and produces glare. This glare can be reduced by using polariod sunglasses because they can decrease the intensity of light passing through them. Hence the polariod sunglasses are better than ordinary sunglasses. Since polariod sunglass reduce the glare of light entering into the eye.

9.11 How would you distinguish between un-polarized and plane-polarized lights?

Ans. Un-polarized and plane polarized light can be distinguished from each other by using polarizer. When light is viewed through polarizer and it can be seen continuously even if the polarizer is rotated, the light seen is unpolarized. However if on rotating the polarizer, the light becomes dim and cuts off by rotating the polarizer through 90°, then the light observed is plane polarized light.

9.12 Fill in the Blanks:

(i) According to ———— principle, each point on a wavefront acts as a source of secondary ————.

(ii) In Young's experiment, the distance between two adjacent bright fringes for violet light is ———— than that for green light.

(iii) The distance between bright fringes in the interference pattern ———— as the wavelength of light used increase.

(iv) A diffraction grating is used to make a diffraction pattern for yellow light and then for red light. The distances between the red spots will be ———— than that for yellow light.

(v) The phenomenon of polarization of light reveals that light waves are ———— waves.

(vi) A polaroid is a commercial ————.

(vii) A polaroid glass ———— glare of light produced at a road surface.

Ans. (i) Huygen's, wavelets (ii) less (iii) increases (iv) more

(v) transverse (vi) polarizer (vii) eliminates (reduces)

PROBLEMS WITH SOLUTIONS

PROBLEM 9.1

Light of wavelength 546 nm is allowed to illuminate the slits of Young's experiment. The separation between the slits is 0.10 mm and the distance of the screen from the slits where interference effects are observed is 20 cm. At what angle the first minimum will fall? What will be the linear distance on the screen between adjacent maxima?

Data

Wavelength of light $= \lambda = 546 \text{ nm}$

$= 546 \times 10^{-9} \text{ m}$

Separation between the slits $= d = 0.10 \text{ mm}$

$= 0.10 \times 10^{-3} \text{ m}$

Distance of screen from the slit $= L = 20 \text{ cm}$

$= 20 \times 10^{-2} \text{ m}$

To Find

Angle for minimum fall $= \theta = ?$

Fringe spacing $= \Delta y = ?$

SOLUTION

Angle for minimum fall is

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

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

For 1st minimum m = 0

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

$$\sin\theta = \frac{546 \times 10^{-9}}{2 \times 0.10 \times 10^{-3}}$$

$$\sin\theta = 2730 \times 10^{-9+3}$$

$$\sin\theta = 2730 \times 10^{-6}$$

$$\theta = \sin^{-1}(0.002730)$$

$$\theta = 0.156$$

$$= 0.16^\circ$$

For Fringe spacing

$$\boxed{\Delta y = \frac{L\lambda}{d}}$$

$$\Delta y = \frac{20 \times 10^{-2} \times 546 \times 10^{-9}}{0.10 \times 10^{-3}}$$

$$= 109200 \times 10^{-2-9+3}$$

$$= 109200 \times 10^{-8}$$

$$= 1.09 \times 10^{-3} \text{ m}$$

$$\Delta y = 1.09 \text{ mm}$$

Result

Angle for minimum fall = θ = 0.16°

Fringe spacing = Δy = 1.09 mm

PROBLEM 9.2

Calculate the wavelength of light, which illuminates two slits 0.5 mm apart and produces interference pattern on a screen placed 200 cm away from the slits. The first bright fringe is observed at a distance of 2.40 mm from the central bright image.

Data

Distance between slits = d = 0.5 mm

= 0.5×10^{-3} m

Distance of screen from slits = L = 200 cm

= 2 m

For 1st bright fringe = m = 1

Distance of 1st bright fringe = y = 2.40 mm

= 2.40×10^{-3} m

To Find

Wavelength of light = λ = ?

SOLUTION

By formula

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

$$\boxed{\lambda = \frac{y \times d}{mL}}$$

Putting the value, for 1st bright m = 1

$$\lambda = \frac{2.40 \times 10^{-3} \times 0.5 \times 10^{-3}}{1 \times 2}$$

$$= 0.6 \times 10^{-6}$$

$$= 6 \times 10^{-7} \text{ m}$$

$$= 600 \times 10^{-9} \text{ m}$$

$$\lambda = 600 \text{ nm}$$

Result

Wavelength of light $= \lambda = 600$ nm

or $= 6 \times 10^{-7}$ m

PROBLEM 9.3

In a double slit experiment the second order maximum occurs at $\theta = 0.25°$. The wavelength is 650nm. Determine the slit separation.

Data

Second order maxima $= m = 2$

Angle $= \theta = 0.25°$

Wavelength of light $= \lambda = 650$ nm

$= 650 \times 10^{-9}$ m

To Find

Slit separation $= d = ?$

SOLUTION

By formula

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

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

$$d = \frac{2 \times 650 \times 10^{-9}}{\sin 0.25°}$$

$$= \frac{1300 \times 10^{-9}}{4.36 \times 10^{-3}}$$

$$= \frac{1300 \times 10^{-9}}{0.00430}$$

$$= 298165.1 \times 10^{-9}$$

$$= 0.298 \times 10^{-3}$$

$$= 0.30 \times 10^{-3} \text{ m}$$

$$d = 0.30 \text{ mm}$$

Result

Slit separation $= d = 0.30$ mm

PROBLEM 9.4

A monochromatic light of $\lambda = 588$ nm is allowed to fall on the half silvered glass plate G_1, in the Michelson interferometer. If mirror M_1 is moved through 0.233 mm, how many fringes will be observed to shift?

Data

Wavelength of light $= \lambda = 588$ nm
$= 588 \times 10^{-9}$ m

Distance moved by mirror $M_1 = L = 0.233$ mm
$= 0.233 \times 10^{-3}$ m

To Find

Number of fringes $= m = ?$

SOLUTION

By formula

$$L = m\frac{\lambda}{2}$$

$$\boxed{m = \frac{2L}{\lambda}}$$

$$m = \frac{2 \times 0.233 \times 10^{-3}}{588 \times 10^{-9}}$$

$$= \frac{0.466 \times 10^{-3}}{588 \times 10^{-9}}$$

$$= 7.92 \times 10^{-3-4+9}$$

$$= 7.92 \times 10^{2}$$

$$m = 792$$

Result

Number of fringes $= m = 792$

PROBLEM 9.5

A second order spectrum is formed at an angle of 38.0° when light falls normally on a diffraction grating having 5400 lines per centimetre. Determine wavelength of the light used.

Data

For second order spectrum $= n = 2$

Angle of diffraction $= \theta = 38.0°$

Number of lines on grating $= N = 5400$ lines/cm
$= 540000$ lines/m

To Find

Wavelength of light $= \lambda = ?$

SOLUTION

By formula

$$d \sin\theta = n\lambda$$

$$\boxed{\lambda = \frac{d \sin\theta}{n}} \qquad \text{But} \qquad d = \frac{1}{N} = \frac{1}{540000}$$

$$\lambda = \frac{\frac{1}{540000} \times \sin 38.0}{2}$$

$$= \frac{0.615}{540000 \times 2}$$

$$= \frac{0.615}{1080000}$$

$$= 5.69 \times 10^{-7}$$

$$= 5.70 \times 10^{-7}\ \text{m}$$

$$= 570 \times 10^{-9}\ \text{m}$$

$$\lambda = 570\ \text{nm}$$

Result

Wavelength of light $= \lambda = 570$ nm

PROBLEM 9.6

A light is incident normally on a grating which has 2500 lines per centimetre. Compute the wavelength of a spectral line for which the deviation in second order is 15.0°.

Data

Number of lines on grating $= N = 2500$ /cm

$= 2500 \times 100$ /m

$= 250000$ /m

Angle of diffraction $= \theta = 15°$

For second order $= n = 2$

To Find

Wavelength of light $= \lambda = ?$

SOLUTION

By formula

$$d \sin\theta = n\lambda$$

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

As $$d = \frac{1}{N}$$

$$= \frac{1}{250000}$$

So $\lambda = \dfrac{\dfrac{1}{250000} \times \sin 15°}{2}$

$= \dfrac{0.2588}{500000}$

$= 5.176 \times 10^{-7}$

$= 517.6 \times 10^{-9}$ m

$\lambda = 518$ nm

Result

Wavelength of light $= \lambda = 518$ nm

PROBLEM 9.7

Sodium light (= 589 nm) is incident normally on a grating having 3000 lines per centimetre. What is the highest order of the spectrum obtained with this grating?

Data

Wavelength of sodium light $= \lambda = 589$ nm

$= 589 \times 10^{-9}$ m

Number of lines on grating $= N = 3000$ /cm

$= 300000$ /m

Angle of grating (for highest order) $= \theta = 90°$

To Find

Highest order of spectrum $= n = ?$

SOLUTION

By formula

$$d \sin \theta = n\lambda$$

$$\boxed{n = \frac{d \sin \theta}{\lambda}} \qquad \text{But} \qquad d = \frac{1}{N} = \frac{1}{300000}$$

So $n = \dfrac{\dfrac{1}{300000} \times \sin 90°}{589 \times 10^{-9}}$

$= 5.66 \times 10^{-9} \times 10^{9}$

$n = 5.66$

Result

Highest order of spectrum $= n = 5^{th}$

PROBLEM 9.8

Blue light of wavelength 480 nm illuminates a diffraction grating. The second order image is formed at an angle of 30° from the central image. How many lines in a centimeter of the grating have been ruled?

Data

Wavelength of light $= \lambda = 480 \text{ nm}$

$= 480 \times 10^{-9} \text{ m}$

Angle $= \theta = 30°$

For second order image $= n = 2$

To Find

Number of lines per centimeter $= N = ?$

SOLUTION

By using the formula

$$d \sin\theta = n\lambda$$

$$\boxed{d = \frac{n\lambda}{\sin\theta}}$$

$$= \frac{2 \times 480 \times 10^{-9}}{\sin 30°}$$

$$= \frac{960 \times 10^{-9}}{0.5}$$

$$d = 1920 \times 10^{-9}$$

But $$N = \frac{1}{d}$$

$$= \frac{1}{1920 \times 10^{-9}}$$

$$= 5.20 \times 10^{-4+9}$$

$$= 5.20 \times 10^{5} \text{ /m}$$

$$N = 5.20 \times 10^{3} \text{ /cm}$$

Result

Number of lines per centimeter $= N = 5.2 \times 10^{3}$

PROBLEM 9.9

X-rays of wavelength 0.150 nm are observed to undergo a first order reflection at a Bragg angle of 13.3° from a quartz (SiO_2) crystal. What is the interplaner spacing of the reflecting planes in the crystal?

Data

Wavelength of light $= \lambda = 0.150 \text{ nm}$

$= 0.150 \times 10^{-9} \text{ m}$

For 1st order reflection = n = 1

Bragg's angle = θ = 13.3°

To Find

Interplaner spacing = d = ?

SOLUTION

According to Bragg's law

$$2d \sin\theta = n\lambda$$

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

Putting the values

$$d = \frac{1 \times 0.150 \times 10^{-9}}{2 \sin 13.3^\circ}$$

$$= \frac{0.150 \times 10^{-9}}{0.230 \times 2}$$

$$= \frac{0.150 \times 10^{-9}}{0.460}$$

$$= 0.326 \times 10^{-9} \text{ m}$$

$$d = 0.326 \text{ nm}$$

Result

Interplaner spacing of the reflecting planes in the crystal = d = 0.326 nm

or d = 0.326×10^{-9} m

PROBLEM 9.10

An X-ray beam of wavelength λ undergoes a first order reflection from a crystal when its angle of incidence to a crystal face is 26.5°, and an X-ray beam of wavelength 0.097 nm undergoes a third order reflection when its angle of incidence to that face is 60.0°. Assuming that the two beams reflect from the same family of planes, calculate (a) the interplanar spacing of the planes and (b) the wavelength λ.

Data

For 1st wavelength λ_1

Angle of incidence = θ_1 = 26.5°

First order reflection = n_1 = 1

For second wavelength λ_2

Angle of incidence = θ_2 = 60°

Third order reflection = n_2 = 3

Wavelength of second beam = λ_2 = 0.097 nm

= 0.097×10^{-9} m

To Find

(a) Interplaner spacing of the planes = d = ?

(b) Wavelength of 1st beam = λ_1 = ?

SOLUTION

(a) For interplaner spacing, by using Bragg's law

$$2d \sin \theta = n\lambda$$

For 1st beam

$$2d \sin \theta_1 = n_1\lambda_1$$

$$\boxed{\lambda_1 = \frac{2d \sin \theta_1}{n_1}}$$

Putting the values

$$\lambda_1 = \frac{2 \times d \sin 26.5°}{1}$$

$$\lambda_1 = 0.892\ d \qquad \ldots\ldots \text{(i)}$$

For 2nd beam

$$\lambda_2 = \frac{2d \sin \theta_2}{n_2}$$

$$\boxed{d = \frac{\lambda_2 n_2}{2 \sin \theta_2}}$$

$$d = \frac{0.097 \times 10^{-9} \times 3}{2 \sin 60°}$$

$$= \frac{0.291 \times 10^{-9}}{2 \times 0.866}$$

$$= 0.168 \times 10^{-9}\ m$$

$$d = 0.168\ nm$$

For 1st wavelength, putting in eq. (i)

$$\lambda_1 = 0.892 \times d$$

$$= 0.892 \times 0.168$$

$$\lambda_1 = 0.150\ nm$$

Result

(a) Interplaner spacing = d = 0.168 nm

(b) Wavelength of 1st beam = λ_1 = 0.150 nm