CHAPTER — 9

Physical optics

Introduction:

In this universe, nothing can be seen without light. All the objects lyinng in the dark room do not seem clearly, but on lighting the bulb of the room all the things or objects look distinctly. it shows that something is emitted from the bulb which makes the things of surroundings visible. This something emitted by the bulb is called light.

Definition of light:

Light is a form of energy due to which we see the things of surroundings.

Or

Light is a type of energy which produces sensation of vision.

Physical optics :

The branch of physics which deals with nature and properties of light is called physical optics.

Wave theory of light :

In 1678, an eminent Dutch scientist, C. Huygen, proposed that light energy from a luminous source travels in space by means of a wave motion. In 1801 Thomas Young proved experimentally the phenomenon of interference of light on the basis of wave theory of light.

9.1 Wave front :

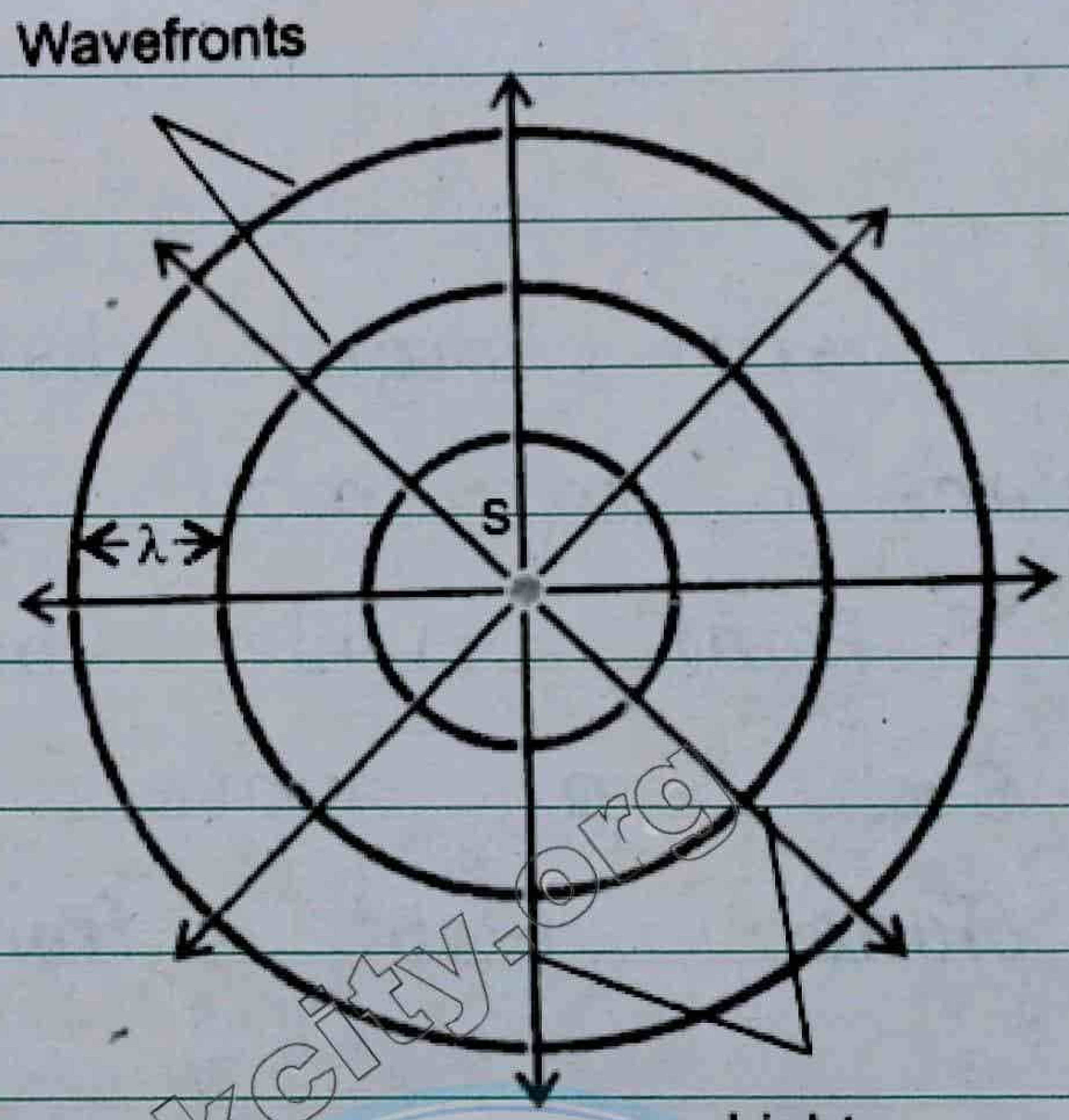
Definition

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

Explanation

Consider a point source

S of light as shown in fig, in all directions with speed c. After time t. light wave will reach the surface of this sphere with centre as S and radius as $r = ct$. Every point on the surface of this sphere will be set into vibrations by the wave reaching there.



(a)

Since the distance of all these points from the source is the same so their state of vibration will be identical. Thus all the points of the sphere will have the same phase. Therefore such a such a surface on which all the points have the same phase of vibration is known as wave front.

Spherical wave front

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Definition

The wavefront in which the light wave are propagated in spherical form with the source is called spherical wavefront.

Plane wave front

Definition

At very large distance i.e. infinity from the source a small portion of a spherical wave front will bcome very nearly plane. Such a wave front is Known as plane want front as shown.

Figure 3 (a) A plane wave. The planes represent wavefronts spaced one wavelength apart, and the arrows represent rays [illegible] A spherical wave. The wavefronts, spaced one wavelength apart, are spherical su[illegible] and the rays are in the radial direction.

For example, light from the sun reches the Eath in plane wave fronts. Plane surfaces are parellel to each other. In phenomena and diffraction plane waves and plane wave fronts are considered for their study.

A ray of light

A line normal to the wave front, which gives the direction of motion of the wave is called a ray of light. A ray is always perpendicular to the wave front.

Pencil of rays

A collection of parallel ray is called pencil of rays.

9.2. Huygen's principle

Knowing the shape and postion of a wavefront at any time t, Huygen's principle enables us to find the shape and position of the new wavefront at a later time $t + \Delta t$. This principle consists of two point.

★ ; Every point of a wavefront may be considered as a source of secondary wavelets which spread out in forward direction with a speed equal to the speed of propagation of the wave.

★ : The new position of the wavefront after a certain interval of time can be found by constructing a surface that touches all the secondary wavelet's.

Explanation

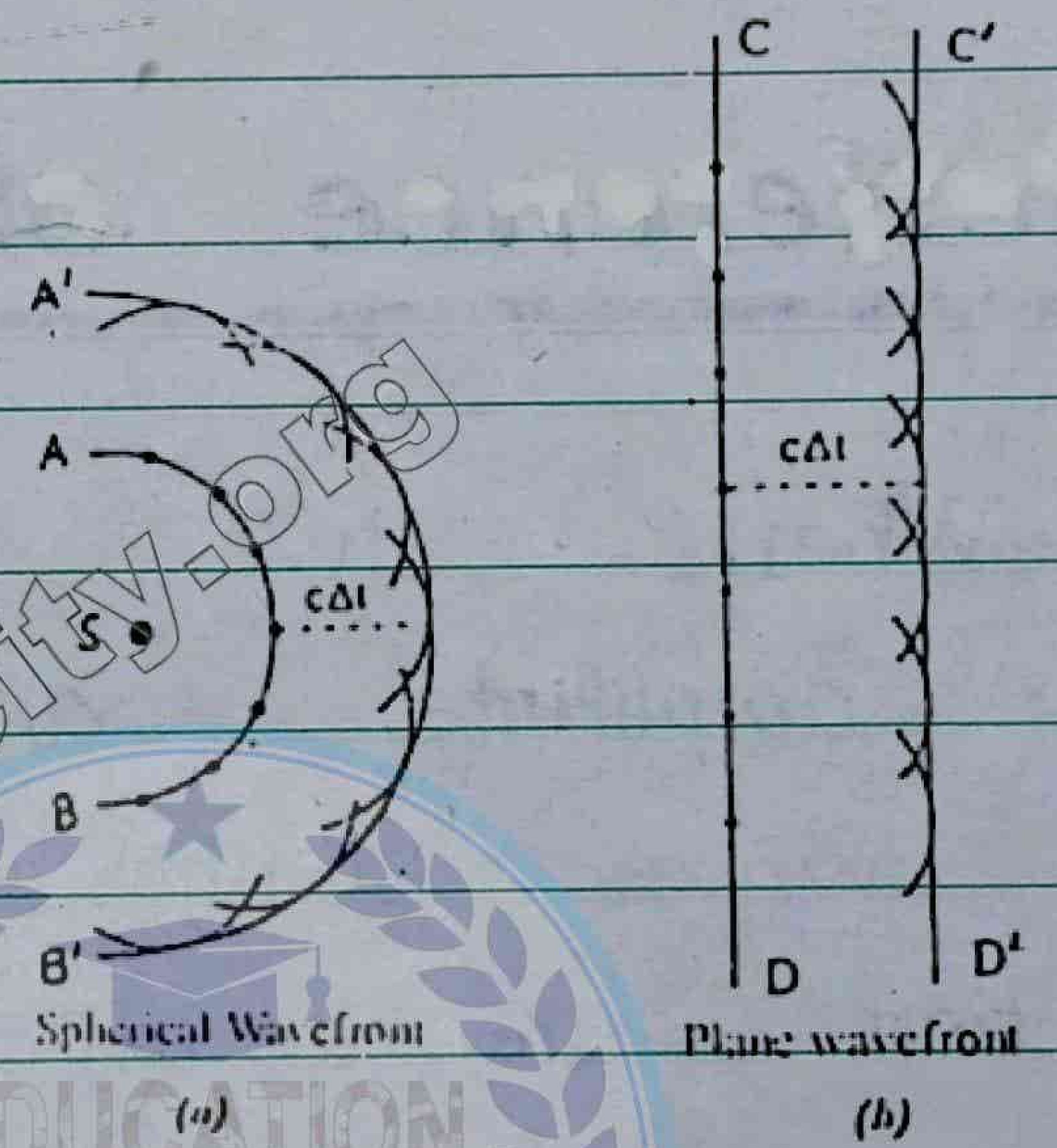


Fig. 9.2
Huygens' construction for determining the position of the wavefronts AB and CD after a time interval t. AB and CD are the new positions of the wavefronts.

Huygen's construction for determining the position of the wavefronts AB and CD after a time interval t. AB and CD are the new positions of the wavefronts.

In fig AB is a spherical wavefront at any time t. To find the wavefront at $t + \Delta t$ draw secondery wavelets with centre at various points on the wavefront AB and radius $C\Delta t$. (C = speed of propagation of wave). A'B' is the new wavefront at a time $t + \Delta t$. It is obtained by drawing a plane tangent to the secondary wavelets.

And second fig shows a similar construction for very large distance i.e.

9.3. Interference of light waves

When two light waves of the same amplitude and the same frequency or wave length travelling in the same direction are superimposed upon each other in such a way that they reinforce each other at some points and cancel each other at the other points. Such phenomenon is called interference.

Types of interference

There are two types of interference.

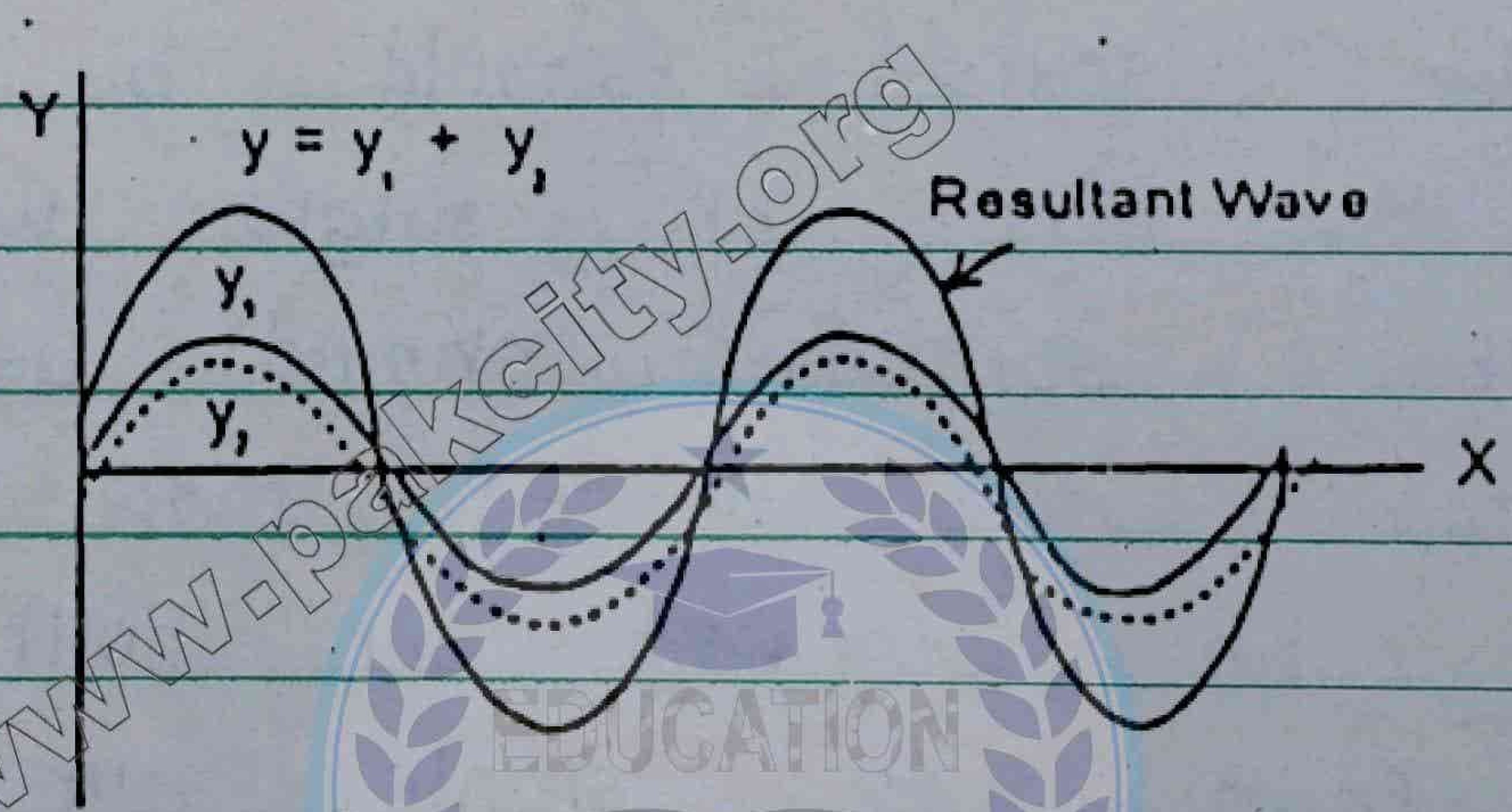
* : Constructive interference.

* ; Destructive interference

Constructive interference

Definition

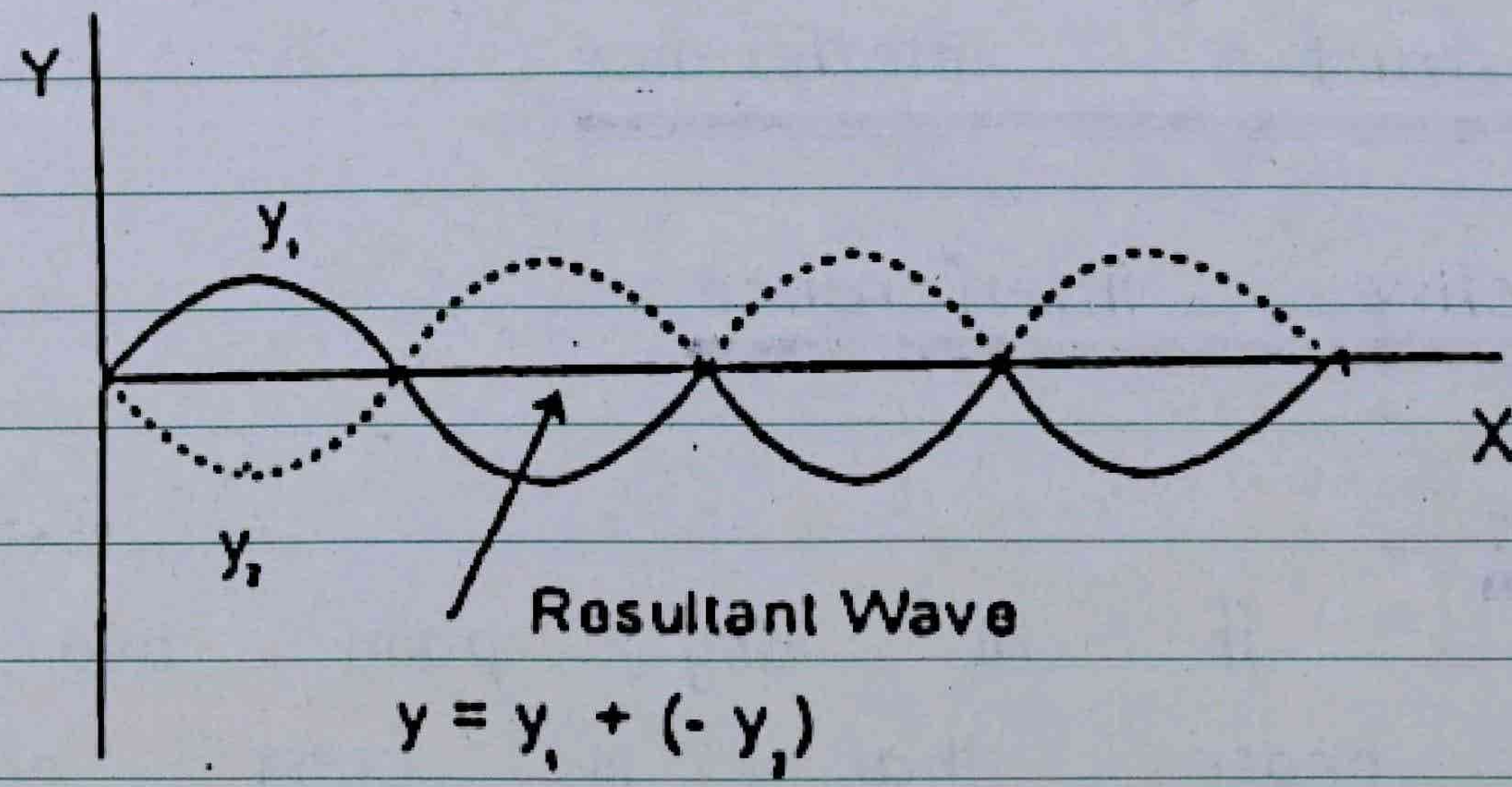
If at any point two waves are in phase that is crest of one wave falls upon the crest of the other or trough of one wave falls upon the trough of the other there is an increase in amplitude. It is called constructive interference.



Destructive interference

Definition

If the two waves are out of phase that is crest of one wave falls upon the trough of the other wave there is a decrease in the resultant amplitude. Then it is called destructive interference.



Conditions for detectable interference

Interference of light can not be easily observed due to the random emission of light from a source.

- The sources should be monochromatic, that is of single wavelength.
- The sources should be coherent (of the same phase), that is they should be derived or split into two from the single source of light.
- The two sources should be close to each other and should be narrow.

Coherent sources

Definition

The monochromatic sou of light which emit wave, having a constant phase difference, are called coherent sources.

Constant phase differance

Let us considr two or more sources of light of the same wave length. If the souces send out crests or troughs at the same time the individual wave are said to have a constant phase difference with one another.

Condition of constructive interference

The constructive interference will take place if the path difference between two wave is zero or integral multiple or wave-length. That is path difference

$$d = 0, \lambda, 2\lambda, 3\lambda$$

$$\boxed{d = m\lambda}$$

Where $m = 0, 1, 2, 3 + \dots$ integer

Condition of destructive interference

The

destructive interference will take place if the path difference between two waves is odd integral multiple of half wavelength. That is path difference.

$$d = \frac{\lambda}{2}, \frac{3\lambda}{2}, \frac{5\lambda}{2} \ldots\ldots$$

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

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

9.4 Young's Double slit Experiment

In 1801, Thomas Young a British physicist gave an experimental proof for Huygen's wave theory of light.

It conisists of a screen A with a rectangular slit S placed in front of a sourcs S. The cylindrical wavefronts emerging the other side of screen A arrive at the screen B which has two narrow slits S_1 and S_2.

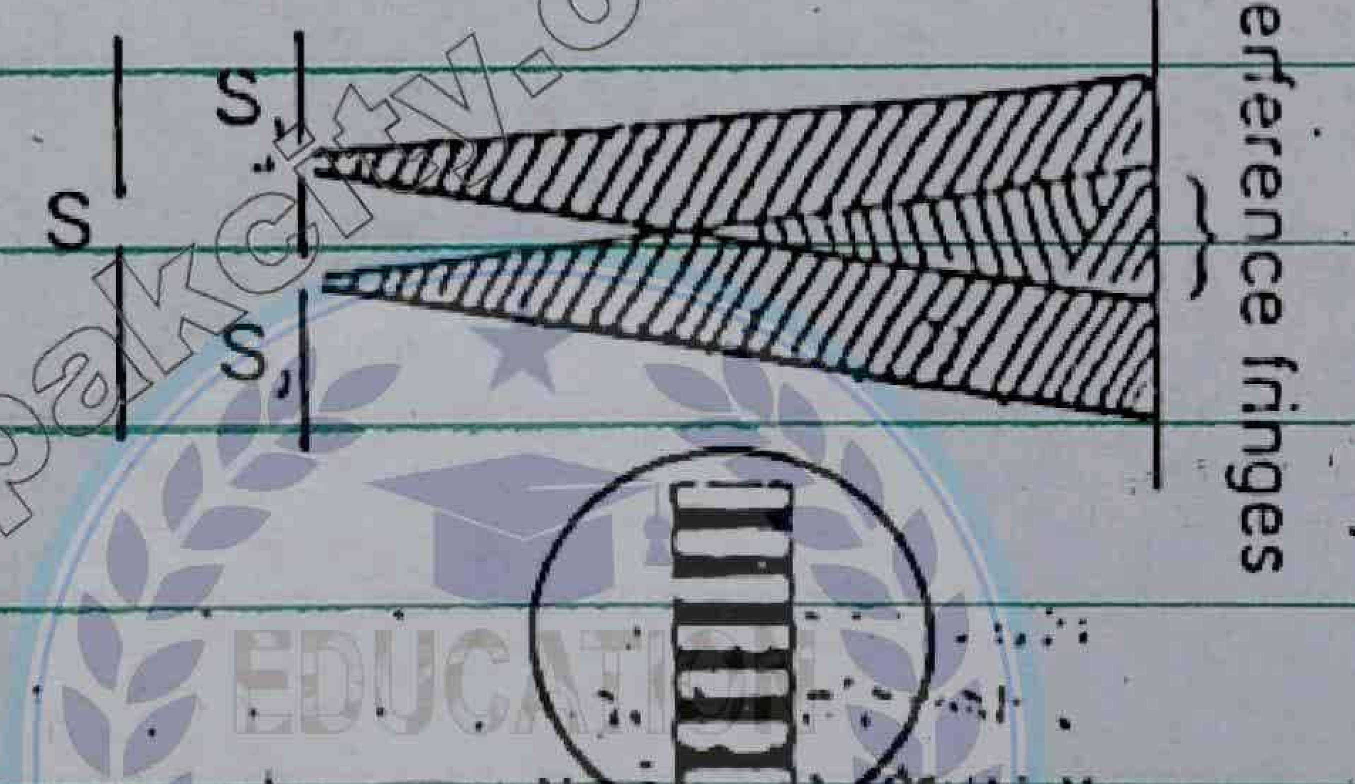


Fig. 9.3 (a)
Ray geometry of Young's double slit experiment.

As the same cylindrical wave-front is divided into two parts of pass through the slite S_1 and S_2 so the two wavefronts will be in phase. Thus S_1 and S_2 will serve as coherent soures. The wave fronts emerging out from slite S_1 and S_2 produce interference in space as.

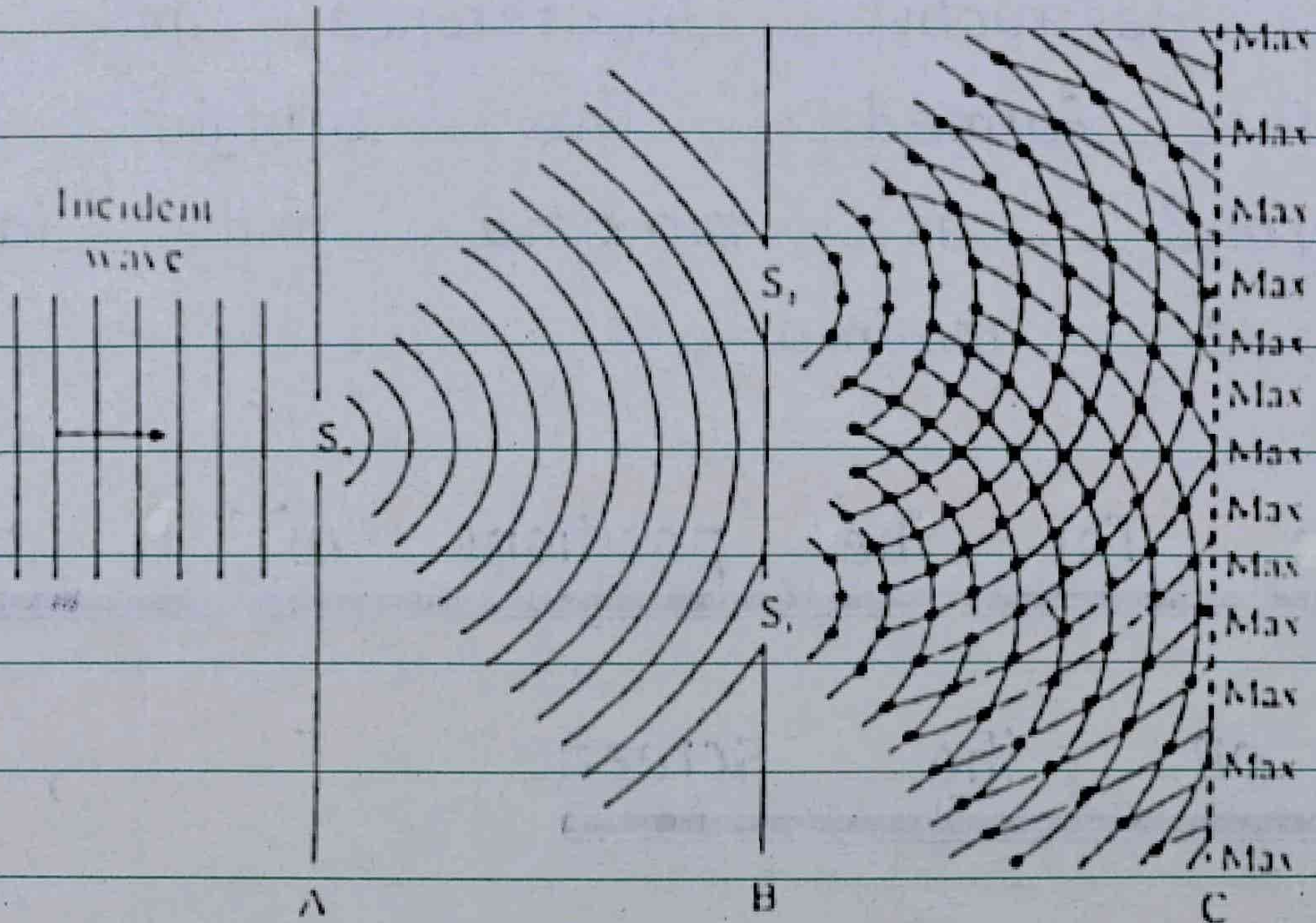


Fig. 9.5(b)
Young's double slit experiment for interference of light.

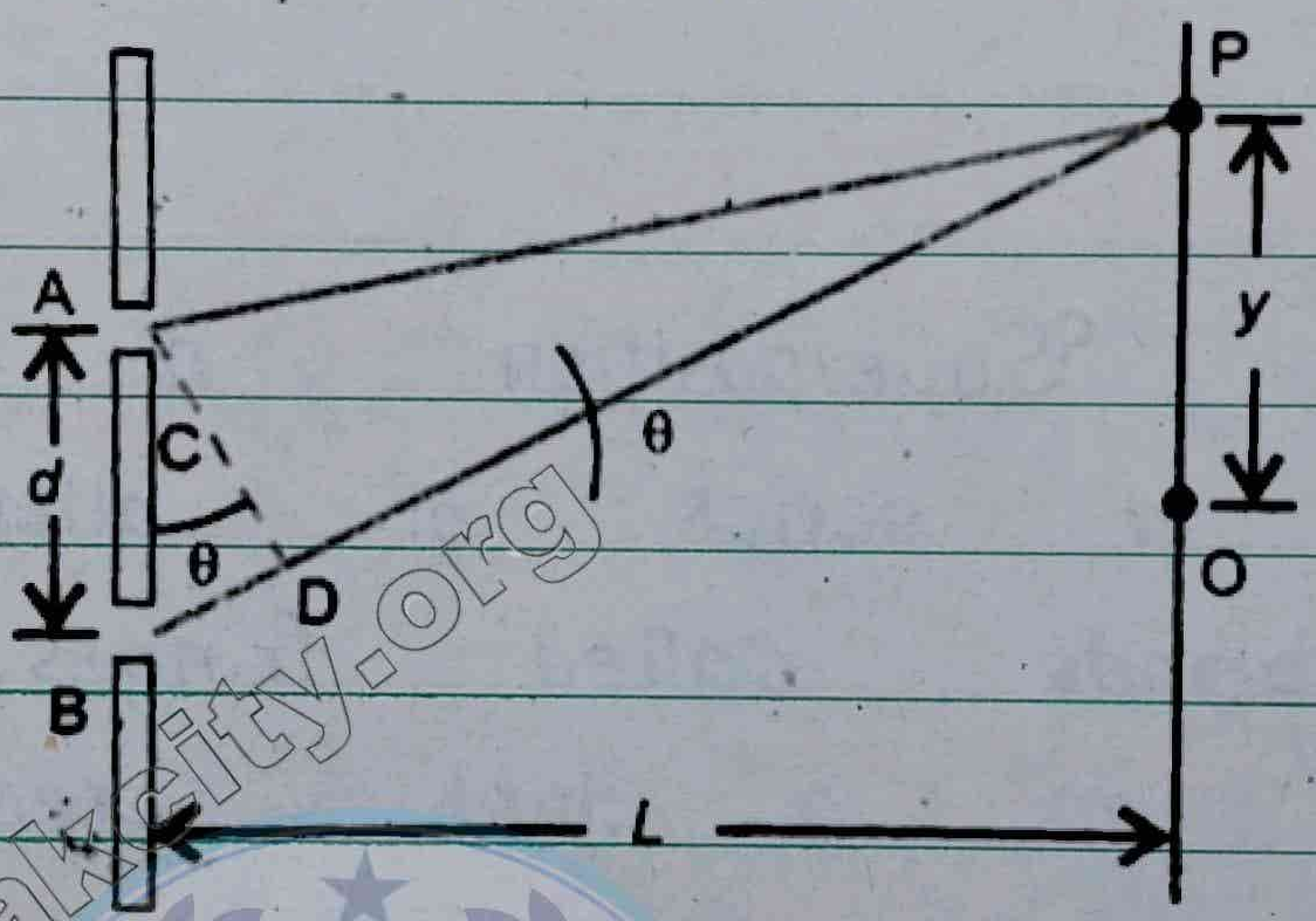
Superposition of these wavefront produces a series of alternate dark and bright bands called fringes, which are observed on a third screen C placed at some distance parallel to the second screen.

Formation of Bright and Dark band

The wavelets arrive at the screen in such a way that at some points crests fall on crests and troughs on troghs resulting in constructive interfarence and bright fringe is formed.

There are other points on the screen where crests meet troughs producing destructive interference and dark fringe is formed. The bringht fringes are termed as maxima and dark fringes as minima.

Calculation for the positions of B. and D fringes on the screen



Consider a point "P" on the screen on one side of central point "O"

Let

d = Seperation between the slits A, B.

L = Distance of the screen from the slits.

y = Distance of the point "P" from the centre of the screen "O".

D = Raw perpendicular AD on BP

Such that $\boxed{AP = DP}$

Since.

$$BP - AP = BD$$

Therefore, path difference $= BP - AP = d \sin\theta$

Or

$$BD = d \sin\theta$$

Condition for maxima

If a bright fringe is formed at "P", then the path difference BD must be an integral multiple of the wavelength λ.

That is,

$$BD = m\lambda$$

since

$$BD = d \sin\theta$$

from above equation.

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

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

The number "m" is called the order number fringe.

Condition for minima

If a dark fringe is formed at "P" the path difference BD must contain half integral number of wavelengths. According to the condition of dark fringe,

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

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

Position of bright fringe

Let y is the distance of point "P" from the central point "O" and a bright is formed at "P"

$$d\sin\theta = m\lambda \qquad \because \sin\theta = \frac{y}{L}$$

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

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

Position of dark Fringe

If "P" is to have dark fringe.

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

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

Above equeation is position of dark fringe.

Fringe spacing

Distance between the centers of two consecutive or adjacent bright fringes or dark fringes is called fringe spacing or fringe width.

Bright fringe spacing

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

$\because$ Δy is the fringe spacing

Dark fringe spacing

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

9.5 Interference in thin films

Definition

A layer of extremely small thickness of certain transparent medium is called thin film.

Examples

In our daily life there are many examples of thin films in which we see the interference. Some of the exmples are.

* ; Surface of soap bubbles.
* ; Cracks in glass plate.
* ; A thin layer of oil film on the surface of wate or other liquids.

The brilliant and different colours in thin films which are seen with ordinary white light are produced due to interference of light waves reflected from two opposite surfces of the film.

Explanation

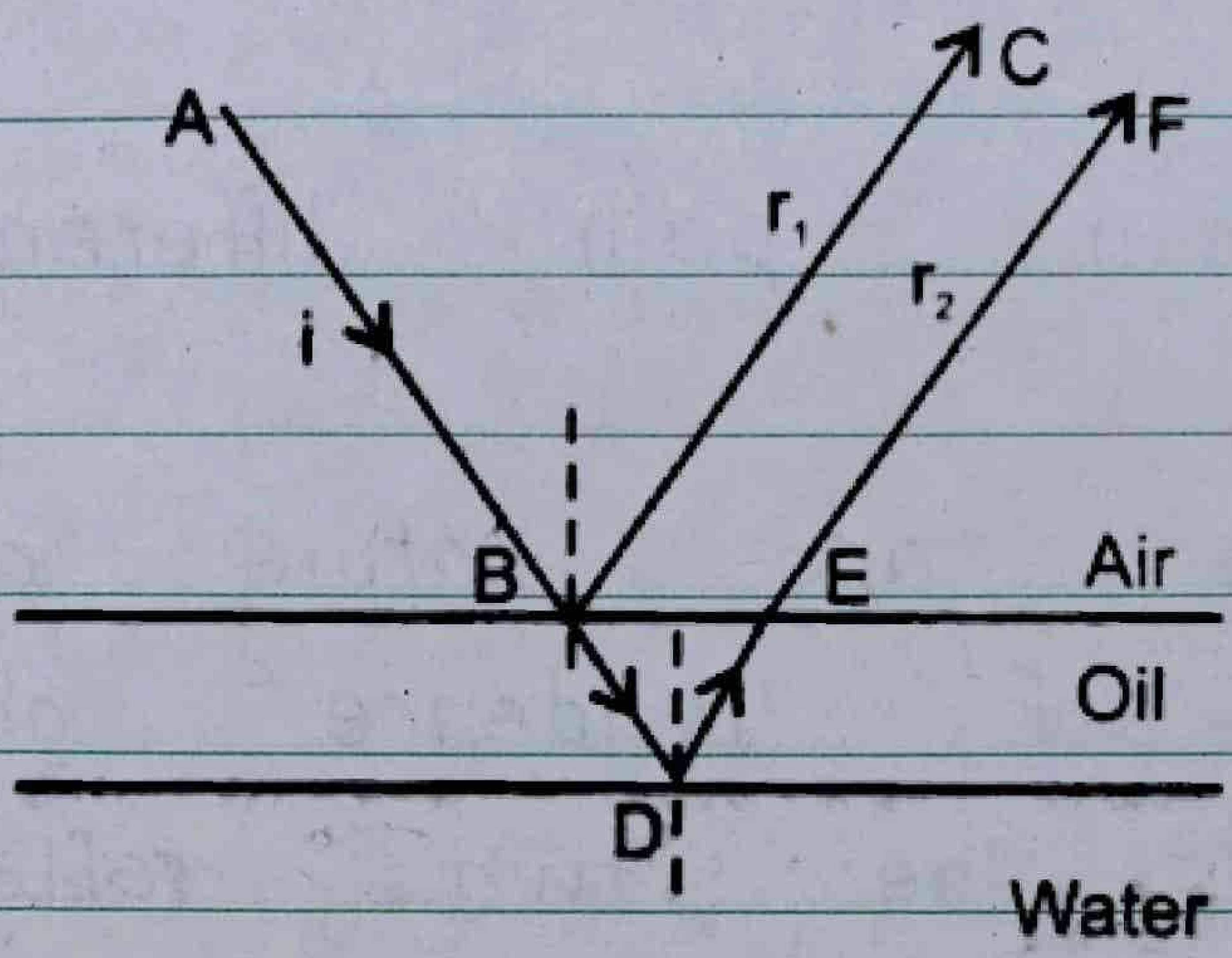


Fig. 9.4
Geometrical construction of interference of light due to a thin oil film.

Consider a thin film of refracting medium A beam AB of monochromtic light of wave length λ is incident on the upper surface of the film. A part of this incident beam is reflected as a beam BC and part is reflected as beam BD. At point D it is again party reflected inside the medium long DE and emerges out from the upper surface along EF. The beams BC and EF being the parts of the same beam AB have a phase coherence.

Since the film is thin, so

separation between the beams BC and EF will be very small and they will superpose on each other in the same medium and produce interference fringes.

Their path difference dependess upon.

* ; Thickness and nature of the film.
* ; Angle of incidence of the beam.

If the two reflected waves reinforce eachother then the film will look bright.

Film of irregular thickness

If white light beam is incident on a thin film of irregular thickness at all possible angles of incidence then the interference is observed separately for different colours of light.

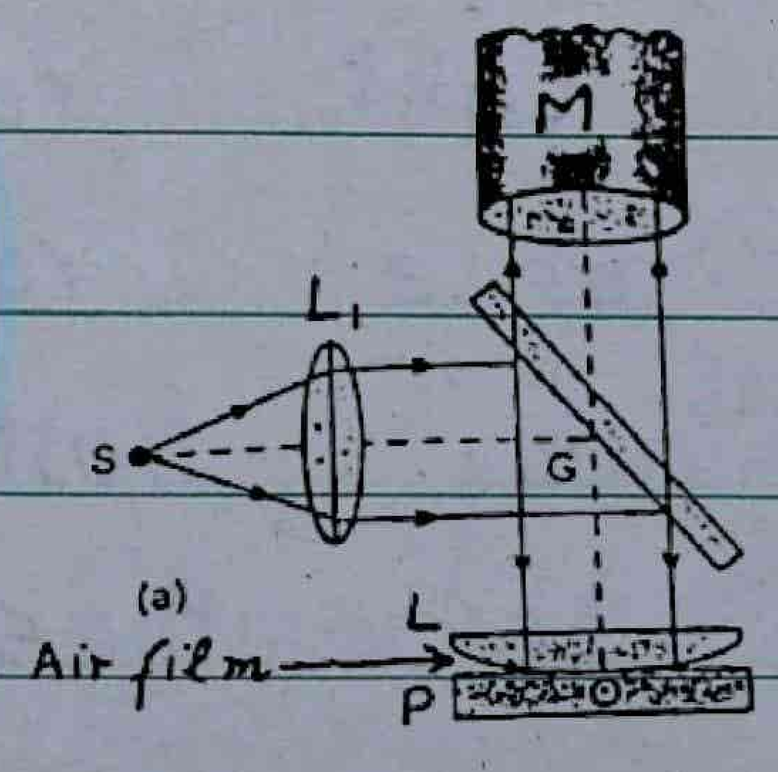
9.6 Newton's Rings

Definition

Circulr dark and bright fringes formed due to interference in a thin air film enclosed between convex lens and a flat glass plate are called Newton's rings.

Experimental arrangement

*: Monochromatic souce of light "S".
*: Double convex lens L_1.
*: A glass sheet G (beam splitter).
*: A plano convex lens "L".
*: A glass plate "P".



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

A plano convex lens L of long focal length is placed on a plane glass plate P that its convex surface touches the plate. The thickness of the air film is almost zero at the point of contact "O". The thicknes of the air film increases as we move away from the point of contact of the lens and glass plate. Thus the points where the thickness of the film is constant will lie on a circle with "O" as centre. Light beam from a monochromatic source "S" becomes parallel after passing through the convex lens L_1. This beam of light falls on the glass plate G. Some rays are party reflected normally towards the air film and party refracted through G. When light rays fall normally on the lens these rays are reflected by the top and bottom surface of the air film. As these rays are coherent and interfere each other constructively or destructively. When the light reflected upward is observed through a microscope "M" focussed at the glass plate G, a series of dark and bright circular rings are observed. These concentric ring are called Newton's rings.

Explanation of central spot black

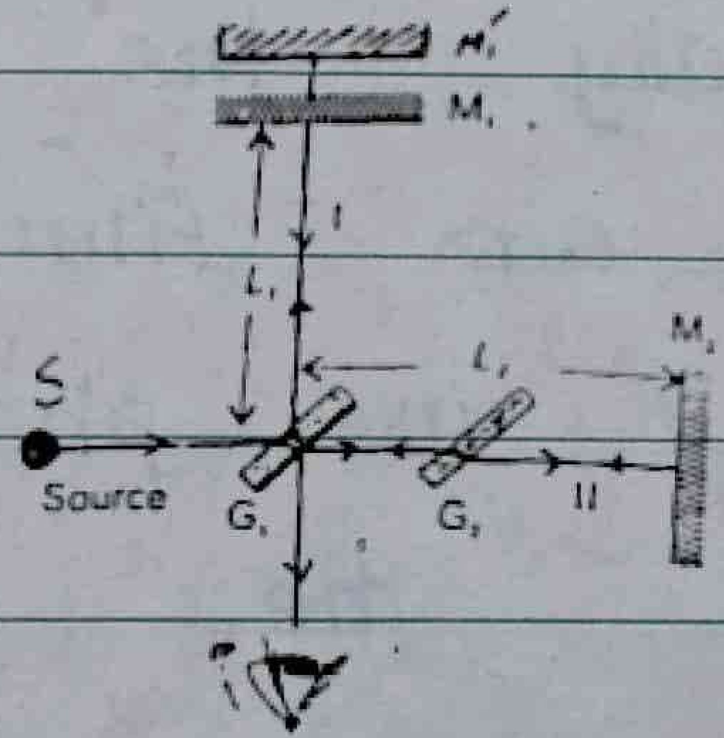
The path difference between the rays reflected at the top and the bottom of the air gap at the point of contact is zero. Actually the ray reflected from the top of air film does not undergo any change in phase but the ray reflected from the bottom of air film i.e suffers a phase change of 180° or an additional path difference of $\frac{\lambda}{2}$. Thus a path difference of $\frac{\lambda}{2}$ is produced between two ray over this point of contact. Hence instead of a bright spot a dark spot is formd at the centre.

9.7 Michelson's Interferometer

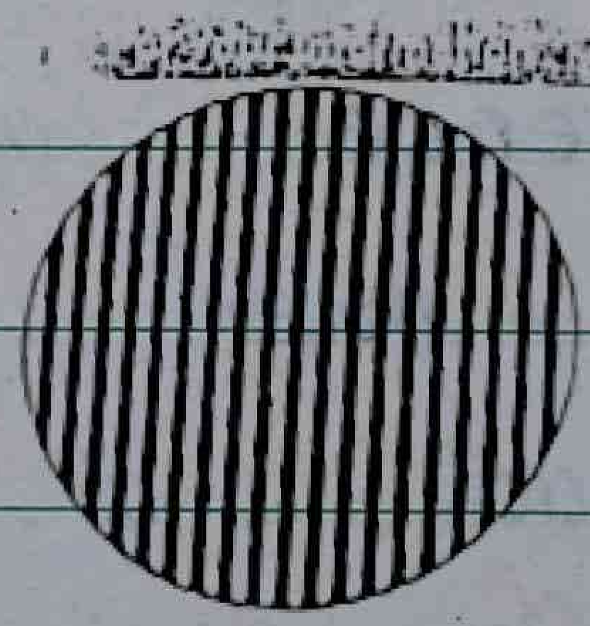
In 1881 Albert A Michelson an American Physicist devised an instrument which is used to observe the interference of light. This instrument can be used to measure the distance with extremely high accuracy and wavelength of light.

Principe

When a light beam falls upon it, it splits the light beam into two parts and then recombines them to produce an interference pattern after they have travelled over different paths.



Schematic diagram of a Michelson Interferometer.



Interference fringes in the Michelson interferometer.

Construction

It consists of.

- ✱ : Monochromatic source of light "S"
- ✱ : Half silvered glass plats G_1
- ✱ : Compensating glass plats G_2.
- ✱ : Two plane mirrors M_1, M_2.

Working

A beam of light from the monochromatic soure "S" is incident on the half silvered glass plate G_1. Some part of beam is reflected vertically upward towards mirror while the other part is transmitted horizontally through the glass plate G_1 towards mirror M_2. These two parts move at right angles to each other. The reflected portion of beam 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 other transmitted portion of the original beam labelled as "II" travels a distance L_2 to mirror M_2 which reflects the beam back towards G_1. The part "II" partially reflected by G_1 also arrives the observer's eye finally.

Theory

The mirror M_1 can be moved along the direction perpendicular to its surface by means of screw. If the optical paths are made equal, the path difference becomes zero. Thus path difference changes by

$$\boxed{\frac{\lambda}{4} + \frac{\lambda}{4} = \frac{\lambda}{2}}$$

It means the beam "I" will coved

a distance $\frac{\lambda}{2}$ more than the other beam "II".

Formula

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

or.

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

Use

Michelson's interferometer is used for the following purposes.

- ★: For determination of wavelength of light.
- ★: It is used to observe the interference of light.
- ★: It can be used for resolution of spectral lines.

9.8 Diffraction of Light

Definition

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

Explanation

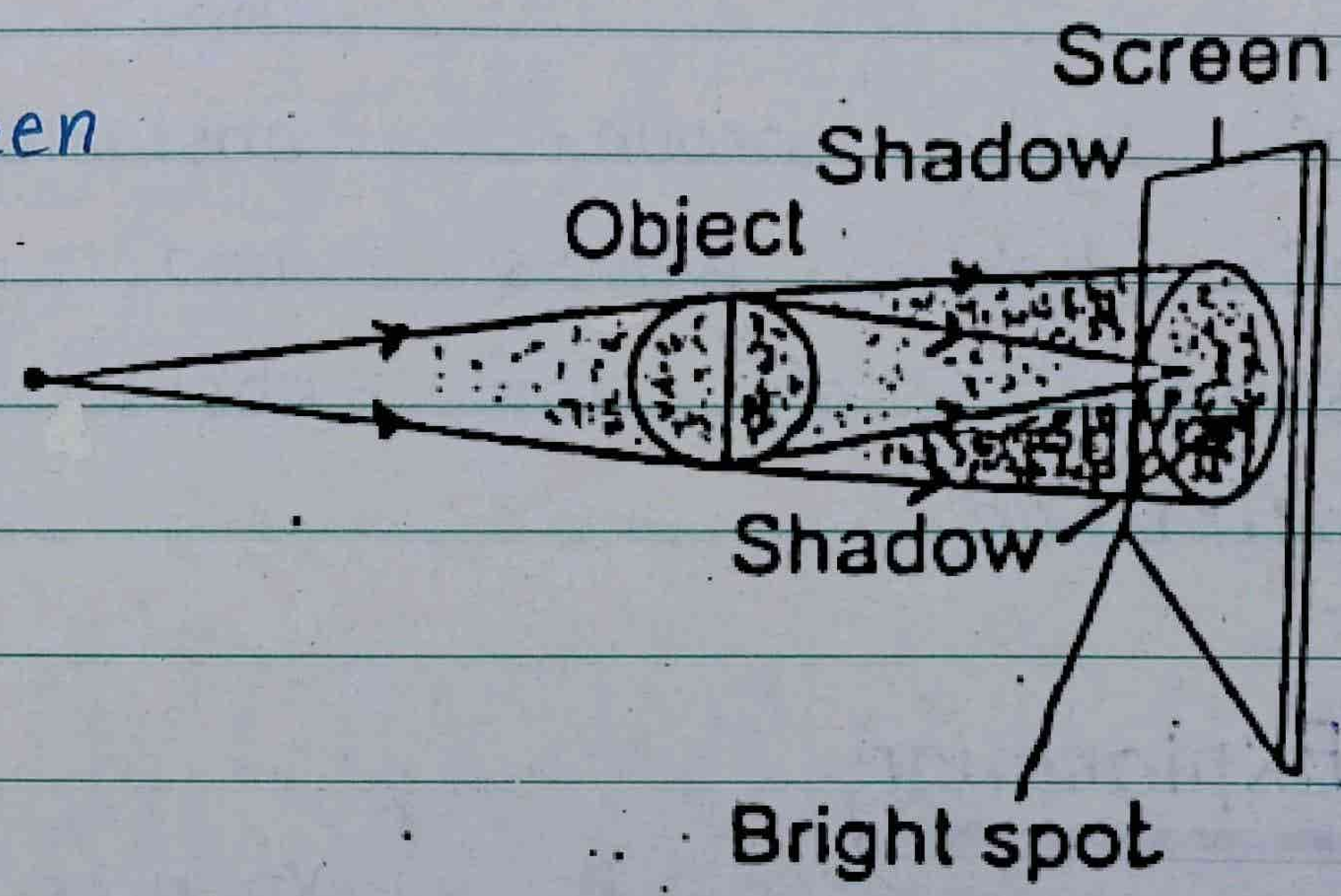
In Young's double experiment for the interference of light in which the central part of the fringe system is bright. But if light travels in a staight line the central region should appear dark due to the shadow of the screen between the two slits.

Condition for diffraction

Diffraction of light can take place only if the size of the obstacle is so small that if may be comparable to the wavelength of incident light.

Experiment

Consider a small and smooth ball of about 3 mm in diameter is illuminted by a point source of light "s". The shadow of the steel ball is received on a screen as shown in the Fig. Its reason can be explained on the basis of Huygen's principle According to this principle, each point on the rim of sphere acts as a source of secondary wavelets which illuminate the central part the shadow.

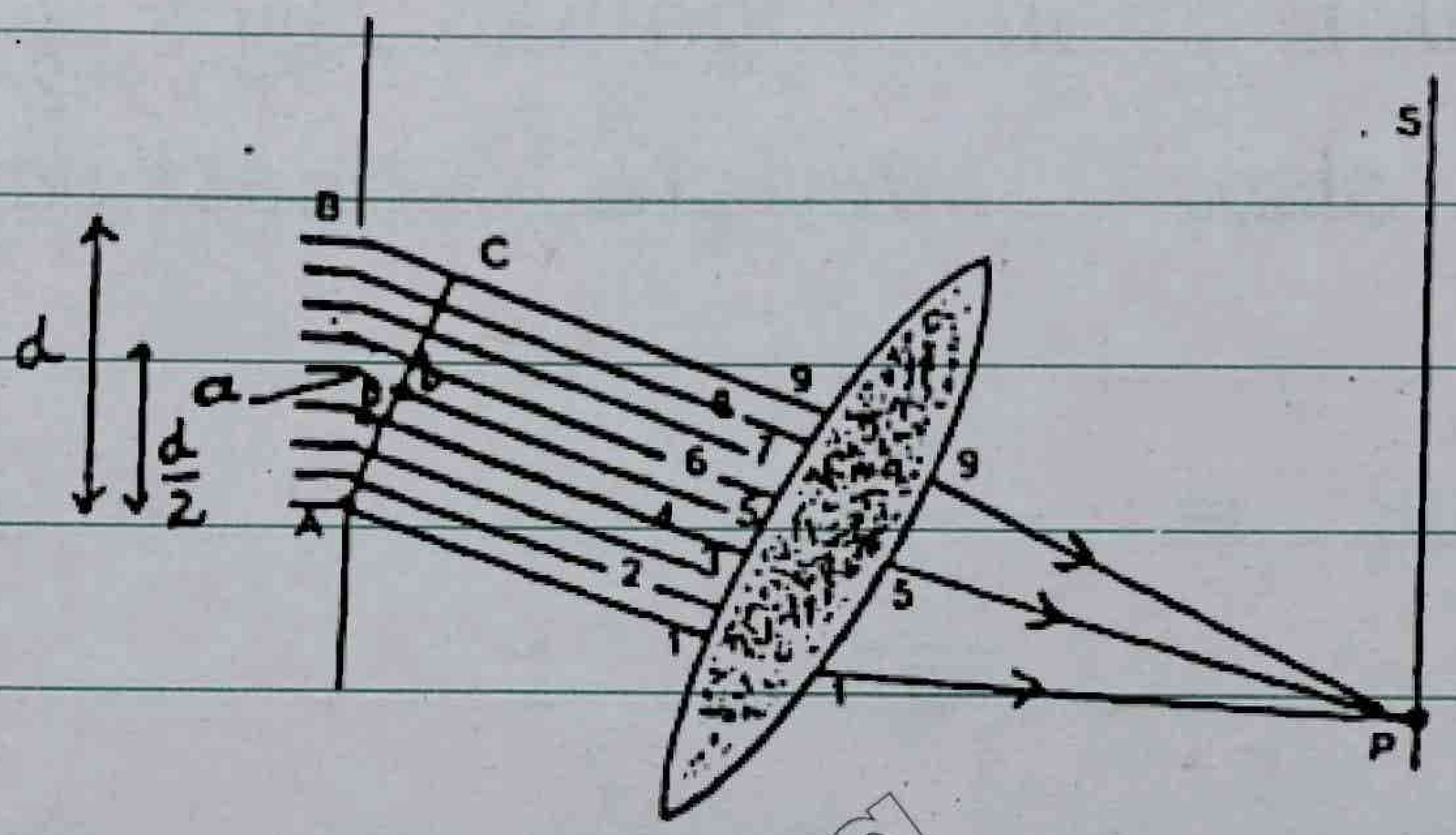


Conclusion

we conclude that when light travels past an obstacle, it does not travel exactly along a straight path but bends around the obstacle

9.9 Diffraction Due to a Narrow slit

The experimental arrangement for studying diffraction of light due to narrow slit is shown in fig.



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

A parallel beam of mono-chromatic light of wavelength λ falls on a slit AB whose width is d. In order to observe the diffraction pattern, a screen "S" is placed parallel to the slit. Wavelets are focussed on the screen by the lens. A small portion of the incident wave front pass through the narrow slit. Wavelets interfere to produce the screen diffraction pattern.

Consider ray 1 and 5 which

are in phase when in the wavefront AB. When these rays reach the wave front AC, ray 5 would have a path difference ab. Let $ab = \frac{\lambda}{2}$. Thus when these two rays reach at point P on the screen, they will interfere destructively. Similary each pair 2 and 6, 3 and 7, 4 and 8 differ in path by $\frac{\lambda}{2}$ and they will also interfere destructively.

$$\sin\theta = \frac{ab}{\frac{AB}{2}} \qquad \because \frac{Perp}{Hyp}$$

because hyp is half the distance of slit AB.

$$\sin\theta = \frac{2ab}{AB} \qquad \because AB = d$$

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

For destructive interence, the path difference

$$ab = \frac{\lambda}{2}$$

put this valuse in above equation.

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

or

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

The conditions for different orders of minima observed on either side of of centre of screen are given by

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

Where $m = 1, 2, 3, 4 \ldots$

9.10. Diffraction Grating Construction

A diffraction grating consists of a glass plate on which very fine equidistant parallel lines are drawn by means of a fine diamond point. The lines act as an opaque through which the light cannot pass while the spacings between the lines on the glass plate act as slits through which light can pass. A typical diffraction grating has about 400 to 500 lines per centimeter to produce diffraction of light.

Grating element

The distance between the centres of two adjacent lines or slits is called grating element, which is denoted by d.

The value of grating

element d is obtained by dividing the length L of the grating by the total number N of the lines ruled on it. Thus, grating element.

$$d = \frac{\text{Length of the grating}}{\text{No of lines ruled on it}} = \frac{L}{N}$$

If we consider unit length of the diffraction grating, then

$$d = \frac{1\,cm}{\text{No. of lines /cm}} = \frac{1}{N}$$

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

principle

Its working is based on Huygen's principle and phenomenon of interfernce.

Working and theory

Consider a parallel beam of monochromatic light illuminating the grating at normal incidence as shown in fig. The parts of wavefront that pass through the slits behave as source of secondary wavelets according

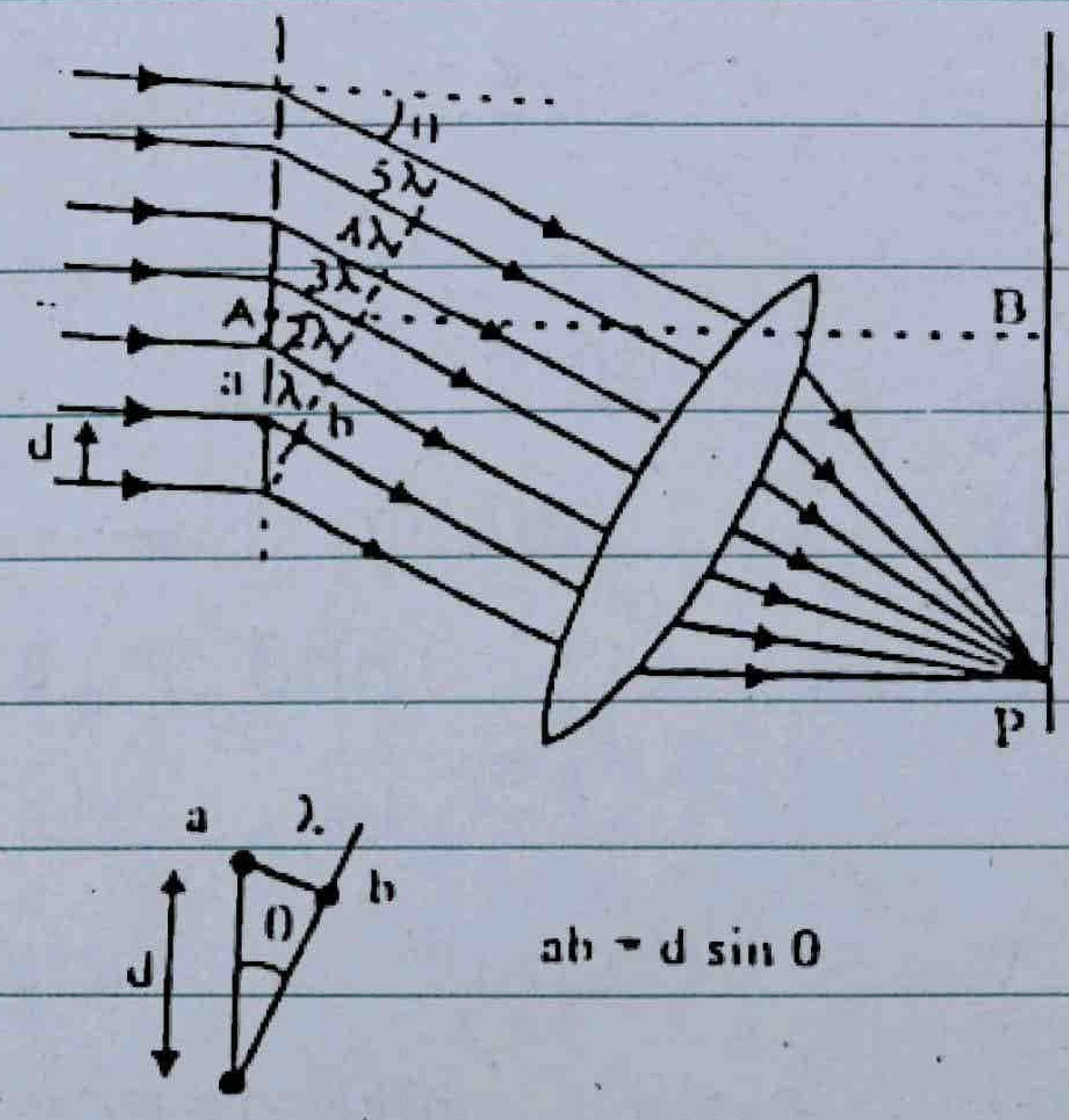


Fig.
Diffraction of light due to grating.

to Huygen's principle.

Consider the parallel rays which after diffraction through the grating plate make an angle θ with "AB", the normal to grating. Since the slits are very narrow so the waves coming out of all the slits are in phase and reinforce each.

Grating equation

For the condition of constructive interference, the path difference the path difference "ab" betwee the rays No. 1 and 2 is equal to λ.

$$\text{path difference} = ab = \lambda \longrightarrow (1)$$

From the fig abc is an right angled triangle.

$$\frac{\text{Perp}}{\text{Hyp}} = \sin\theta$$

$$\frac{ab}{ac} = \sin\theta$$

$$ab = \sin\theta \cdot ac \qquad \because ac = d$$

$$ab = \sin\theta \cdot d \longrightarrow (2)$$

Comparing equation (1) and (2)

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

If $\theta = 0$, the path difference $= 0$, so we a bright fringe. And above equation general form

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

Where $n = 0, 1, 2 \ldots$ for maxima above equation (3) is called grating equation. Where n is called the order of diffraction pattern. $n = 0$ is the central bright line or central maxima.

Determination of wavelength

The diffraction grating can be used to determine the wavelength of light used. Angle "θ" is meaured with the help of spectrometer. Usually meaurements are made on both sides of the central maximum and take average to obtain "θ" Now the measured value θ, d, m and λ.

9.11. Diffraction of X-Rays By crystals

X-ray are the electromagnetic wave with very very small wavelength of the order of 10^{-10} m. This wavelength is much smaller as compared to that of visible light, therefore ordinary diffracting objects such as fine slits pinhole and diffraction grating etc, cannot be used for the diffraction of x-rays. However crystals can be used for the diffration of x-rays, in which the atoms are uniformly spaced in planes and these atomic planes.

Explanation

The scattering of x-rays from the atoms of a crystalline lattice produces diffraction effects similar to the diffraction with visible light incident on ordinary grating. In 1914 W. H. Bragg and W. L. Bragg studied the atomic structure of crystals by using x-ray. They found that a monochromatic beam of x-ray was reflected from a crystal plane as if it acted like mirror.

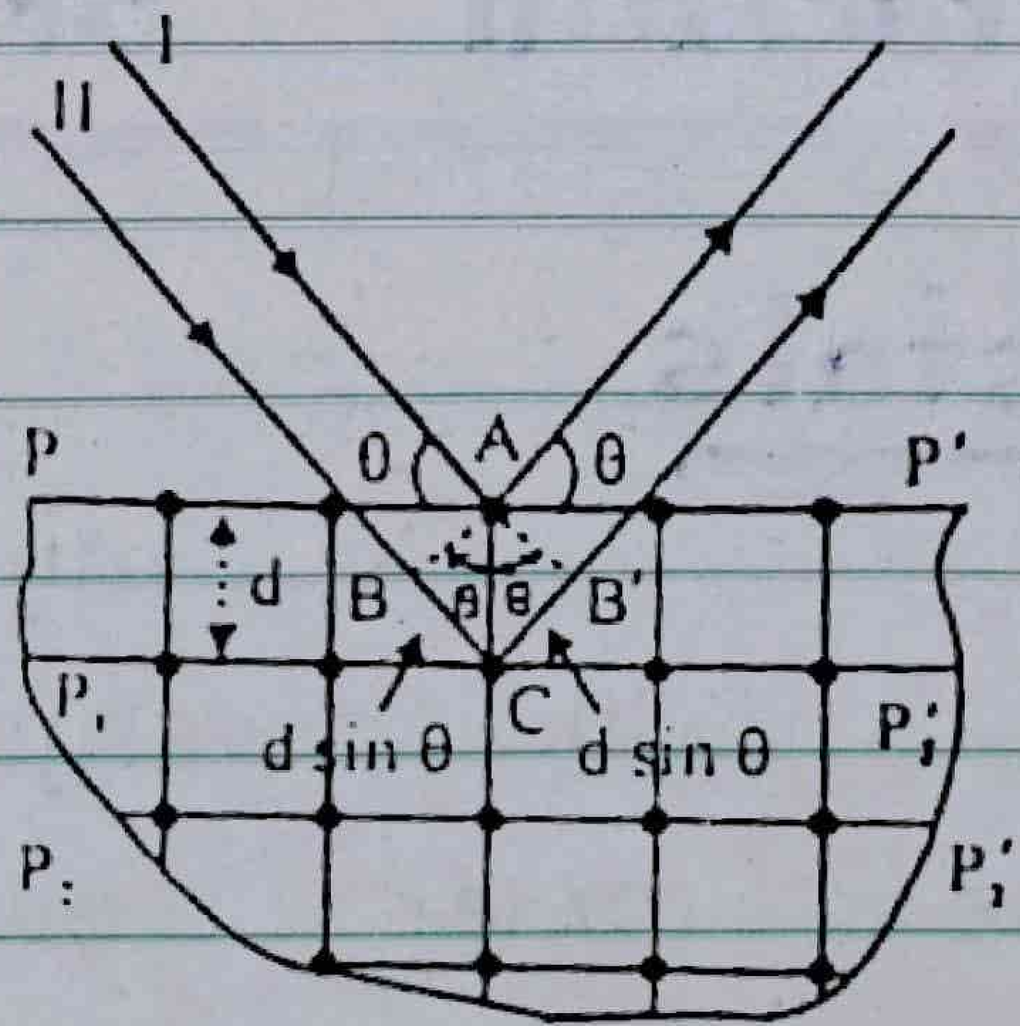


Fig.
Diffraction of X-rays from the lattice plane of crystal.

Consider a series of atomic planes of constant inter planer spacing d parallel to crystal face are shown by lines PP', P_1P_1', P_2, P_2' and so on.

Bragg's equation

Suppose an X-ray beam is incident at an angle θ on one of the planes as shown in fig. So that beam "I" is reflected from the upper plane of atoms and the beam "II" is reflected from the lower plane of the atoms. Let d be the separation between adjacent planes of atoms of the crystal.

To find the path difference between the two beams we have drawn normals AB and AB′ from point A on beam "II"

$$\text{Path difference} = BC + CB' \longrightarrow (i)$$

Form the right angled triangle ABC,

$$\frac{BC}{AC} = \sin\theta$$

or

$$BC = AC \sin\theta \qquad \because AC = d$$

Separation between two planes.

$$Bc = d \sin\theta \longrightarrow (1)$$

Similarly from right angled triangle AB/c,

$$\frac{CB'}{AC} = \sin\theta$$

or

$$CB' = AC \sin\theta$$

or

$$\boxed{CB' = d \sin\theta} \longrightarrow (2)$$

Putting the vales of BC from equation (1) and CB from equation (2) in equation i,

$$\text{Path difference} = BC + CB'$$
$$= d\sin\theta + d\sin\theta$$
$$= 2d \sin\theta$$

Condition

For the two beams to reinforec each other constructive interference condition is

Path difference = Integral multiple of wavelength λ.

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

This is Bragg's equation.

Uses

*; To find inter-atomic spacing d

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

*; To find the wavelength λ of X-rays.

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

*; Structure of Biologically important molecules such as hemoglobin and double helix structure of DNA.

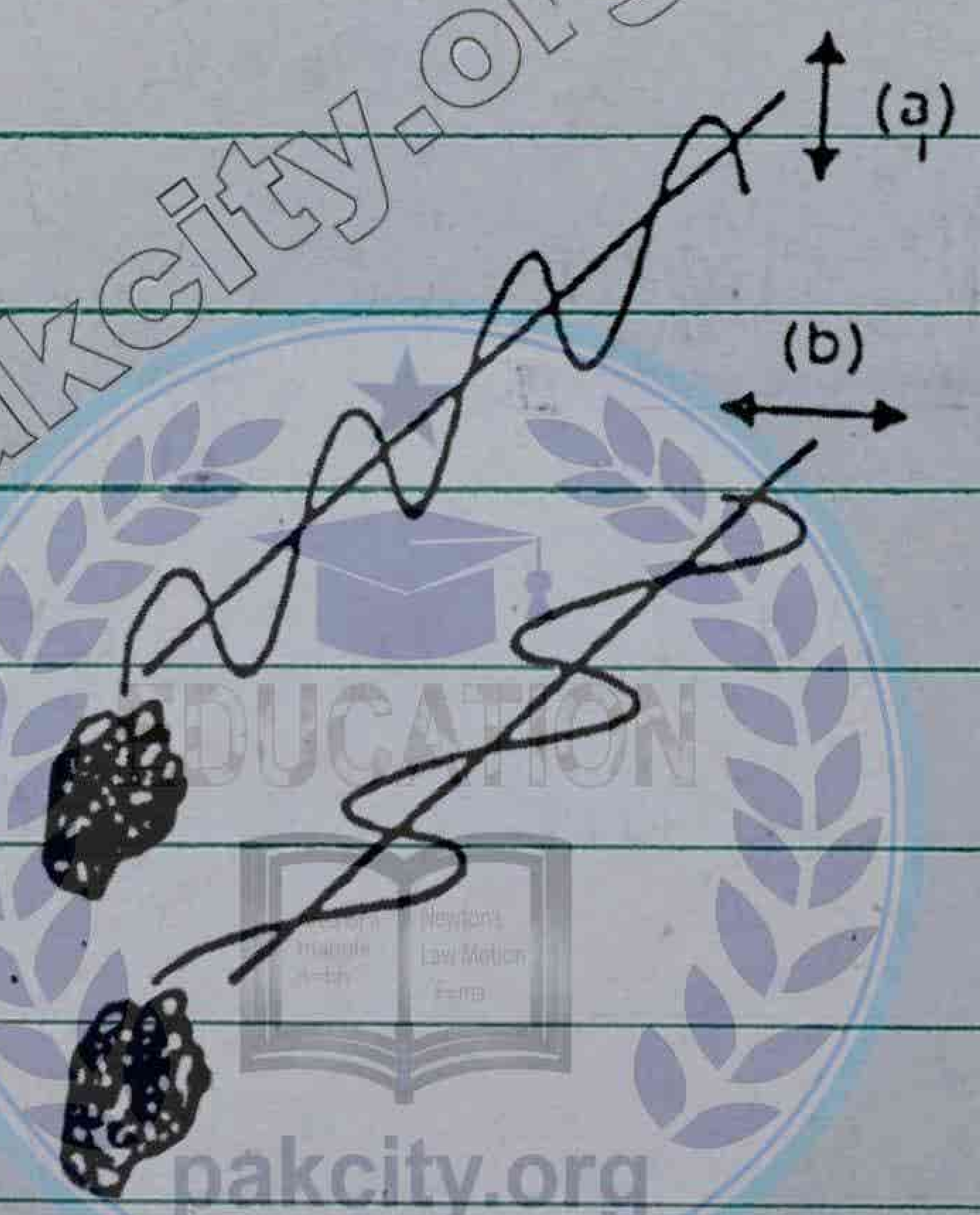
9.12 : Polarization

Defination of Polarization

The process of confining the beam of light to one plane of vibration is called polarization of light.

Interference and diffraction show that light has wave nature i.e. light travels in the form of wave.

Polarization tells us that light wave are transverse waves not Longitunal waves.



As show in fig, in the transverse mechanical waves the vibrations of the particles of the medium are oriented along vertical and horizontal directions the waves are plane polarized. In light waves there are vibrating electric and magnetic field vectors perpendicular to each other.

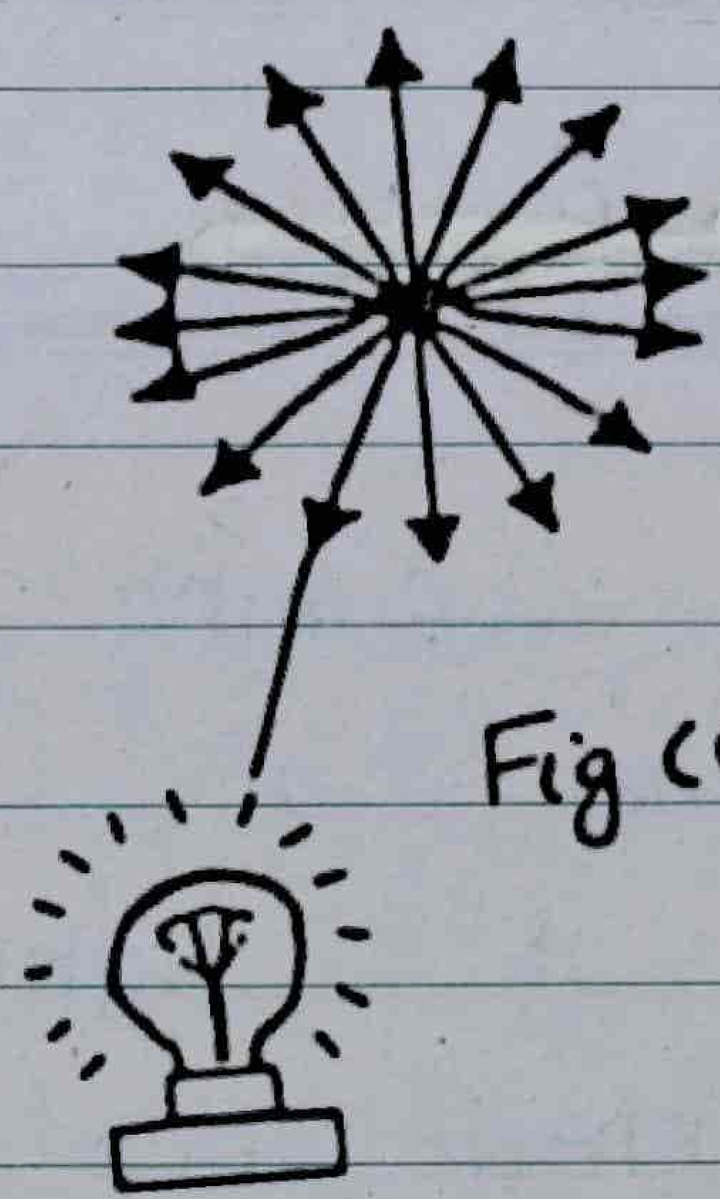


Fig (c)

Unpolarized light

Ordinary light has components of vibration in all possible planes. Such a light is called unpolarized light.

Plane polarized light

If the vibration are confined only in one plane, then this light is called plane polarized light.

Production and detection of plane polarized

An ordinary incandescent light bulb emits unpolarized light as does sun. This is so because its electrical vibrations are oriented in all possible planes. Plane polarized light can be obtained from the unpolorized light by removing all waves from the beam except those that have one particular direction. This can be done by various processes.

* : Selective absorption
* : Reflection of light from different surfaces.
* : Refraction of light through crystals.
* : Scattering of light by small particles.

Reflection of light from different surface

Reflection of light from water glass, snow and rough road surfaces for large angles of incidence produces glare. It can be reduced by using polaroid sunglesses.

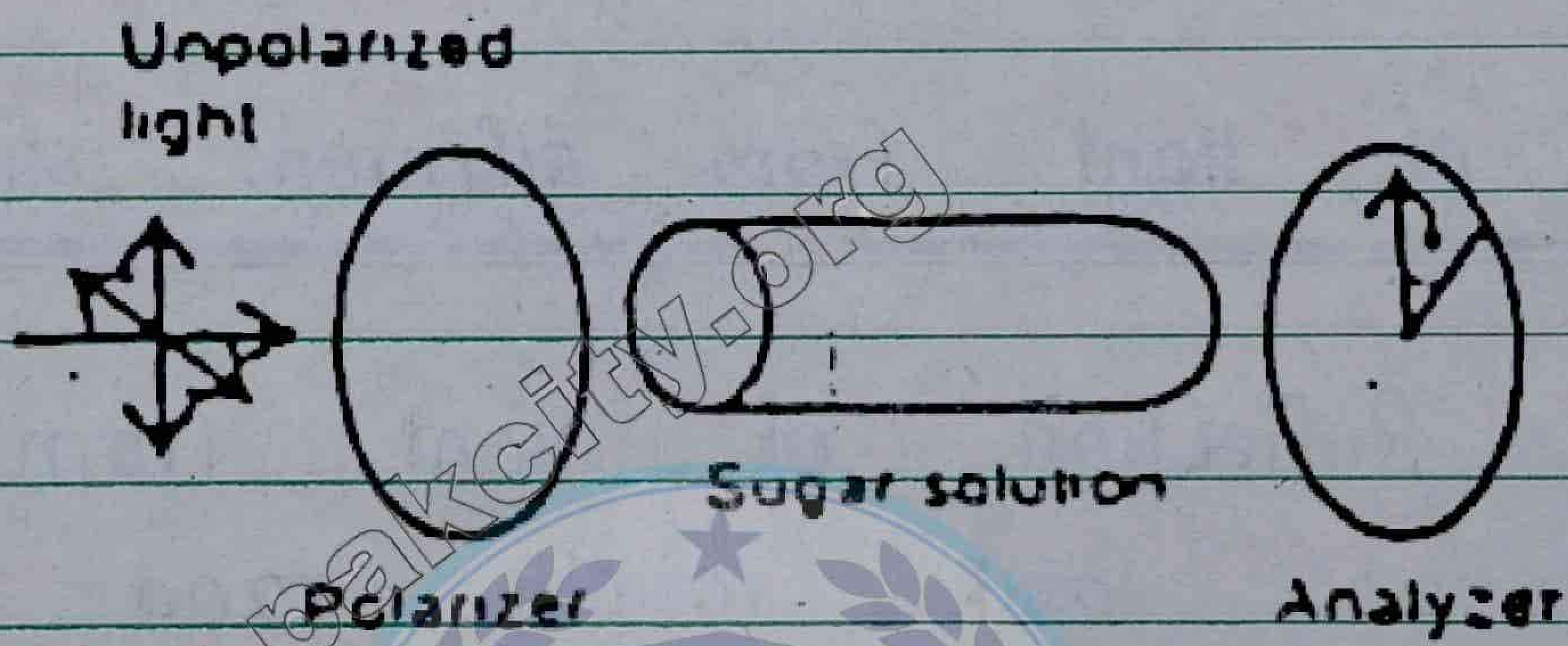
Scattering of light by small particles

Sunlight also becomes partially polorized by scattering from air moleculls of the earths atmosphere.

Optical rotation

When a 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.

QUESTIONS

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

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

9.3 Can visible light produce interference fringes? Explain.

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?

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

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

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

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.

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

9.10 Why the polaroid sunglasses are better than ordinary sunglasses?

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

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 increases.

(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.

NUMERICAL PROBLEMS

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?

(Ans: 0.16°, 1.1 mm)

Chapter: 09

Questions

Q-9.1

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

Answer:

Two or more sources behave as coherent sources if they emit light waves of same amplitue, same frequency and same wave length having the same phase or constant phase difference.

Two or more sources of light derived from a singl source of light behave as coherent sources because they are in the same phase.

Q- 9.2

How is the distance between interference fringes affected by the separation between the slits of

Young's experiment? Can frings disappear?

Answer:

Fring spacing is given by

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

$$\Delta y \propto \frac{1}{d}$$

Fring spacing 'Δy' is inversely proportional to the seperation between the slits 'd'.

If slit seperation 'd' increases, Fring width 'Δy' decreases.

Now, if the slit seperation is made large enough, the fringes will be so close that they cannot be distinguished and the fringes will disappear.

Q-9.3

Can visible light produce interference fringes? Explain.

Answer:

Visible (white) light cannot produce interference fringes.

Visible light is a mixture of seven colours. It is not monochromatic.

For interference monochromatic light having the same frequency and wavelength is required.

Q – 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?

Answer:

Light of two different colours means two different wave lengths Blue and red lights have different wavelength. Therefore, there will be no maxima and minima on the screen. We shall observe two coloured images on the screen with constant intensity.

Q - 9.5

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

Answer:

Young's Double slit experiment is basically However, spreading of light around the edges of the slits also produces some diffraction effects.

Q - 9.6

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

Answer:

Colours are seen the oil film spreading over a wet foot path due to Interference of light waves. If white light falls on an oil film of irregular thickness at all possible angles, we can see the interference pattern due to each colour seperately. So colours are seen due to "interfernce in thin films."

Q-9.7

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

Answer:

Yes, Newtons rings can be observed with transmitted light.
In case of transmitted light the fringe pattern is opposite to the reflected pattern because of no phase change of 180°.
So for transmitted light the central fringe is bright. Whereas for reflected light the central fring is dark.

Q-9.8

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

Answer:

Grating equation is

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

1- For third order image $(n=3)$; for first wavelength λ_1

$$d \sin\theta = 3\lambda_1 \longrightarrow (1)$$

2. For fourth order image $(n=4)$; for second wavelength λ_2

$$d \sin\theta = 4\lambda_2 \longrightarrow (2)$$

Comparing (1) (2)

$$3\lambda_1 = 4\lambda_2$$

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

or Ratio = (4:3)

Q-9-9

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

Answer:

Grating equation is

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

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

n = Order of the spectrum

To get more orders of spectra 'n'

1- θ should be 90°:

$$\theta = 90^\circ$$

$$\sin 90^\circ = 1 \quad \text{(Maximum value)}$$

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

2- d should be increased:

As

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

d would be increased by taking

N = small

or by decreasing the lines on the grating.

3- λ should be taken small:

In visible light λ for violet light is smallest. So, violet light should be used.

Q-9.10

Why the polaroid sunglasses are better than ordinary sunglasses?

Answer:

The sunlight reflected from water, glass and is partically Polarized. So it produces glare in the eyes.

'Glare' can be reduced by using polariod sunglasses because they reduce the intensity of light passing through them. Hence polaroid sunglasses are batter than ordinary sunglasses.

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Q- 9.11

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

Answer :

The unpolarized light and plane-polarized light can be distinguished by using a polarizer.
It a polarizer is rotated infornt of an un-polarized light. This light The light will pass through it for any orientation.
But for a plane polarized, the light becomes dimmer and disappears when the axes becom naturally perpendicular.

9.2 Calculate the wavelength of light, which illuminates two slits 0.5 mm apart and produces an 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.

(Ans: 600 nm)

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

(Ans: 0.30 mm)

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?

(Ans: 792)

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.

(Ans. 570 nm)

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°.

(Ans: 518 nm)

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

(Ans: 5th)

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 centimetre of the grating have been ruled?

(Ans: 5.2×10^3 lines per cm)

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 interplanar spacing of the reflecting planes in the crystal?

(Ans: 0.326 nm)

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.

[Ans: (a) 0.168 nm (b) 0.150 nm]

Chapter 09 :

Numerical Problems

P-9.1 :

Light of wavelength 546 nm is allowed to illumine the slits of Young's experiment. The soparation between the slit 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?

Solution:

$\lambda = 546 \text{ nm}$

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

$d = 0.10 \text{ mm}$

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

$L = 20 \text{cm}$

$= 0.20 \text{m}$

$\theta = ?$ (for first minimum)

$\Delta y = ?$ (Fringe spacing)

For dark fringes

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

For 1st minimum

$$m = 0$$

$$d \sin\theta = \left(0 + \frac{1}{2}\right)\lambda$$

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

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

$$= \frac{546 \times 10^{-9}}{2 \times .10 \times 10^{-3}}$$

$$\sin\theta = 0.00273$$

$$\theta = \sin^{-1}(0.00273)$$

$$\boxed{\theta = 0.16}$$

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

$$\Delta y = \frac{0.20 \times 546 \times 10^{-9}}{0.10 \times 10^{-3}}$$

$$\Delta y = 1.1 \times 10^{-3} \text{ m}$$

$$\boxed{\Delta y = 1.1 \text{ mm}}$$

P-9.2 :

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

Solution:

$\lambda = ?$

$d = 0.5 \text{mm}$

$= 0.5 \times 10^{-3} \text{ m}$

$L = 200 \text{ cm}$

$L = 2\ m$

For first bright fringe

$m = 1$

$y = 2.40\ mm$

$= 2.40 \times 10^{-3}\ m$

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

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

$$\lambda = \frac{yd}{mL}$$

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

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

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

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

P – 9.3

In a double slit experiment

the second order maximum occurs at $\theta = 0.25^\circ$. The wavelength is 650 Determine the slit separation.

Solution:

$m = 2$ for second order maximum

$\theta = 0.25$

$\lambda = 650\,nm$

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

$d = ?$

$d\sin\theta = m\lambda$

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

$$= \frac{2 \times 650 \times 10^{-9}}{\sin(0.25^\circ)}$$

$$= \frac{1300 \times 10^{-9}}{0.004363}$$

$d = 2.98 \times 10^{-4}\,m$

$d \approxeq 3 \times 10^{-4}$ m

$= 0.3 \times 10^{-3}$ m

$\boxed{d = 0.3 \text{ mm}}$

P-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?

Solution:

$\lambda = 588$ nm

$= 588 \times 10^{-9}$ m

$L = 0.233$ mm

$= 0.233 \times 10^{-3}$ m

$m = ?$ (Number of fringes)

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

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

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

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

$= 7.92 \times 10^{2}$

$= 792$

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

$$\boxed{m = 792}$$

P-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.

Solution:

$\theta = 38.0^\circ$

$m = 2$

$N = 5400 \ \frac{\text{Lines}}{\text{cm}}$

$\lambda = ?$

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

$$d = \frac{1}{5400 \frac{\text{Lines}}{\text{cm}}}$$

$$d = \frac{1}{5400} \text{ cm}$$

$$d = \frac{1}{5400 \times 100} \text{ m.}$$

$$d = \frac{1}{540000} \text{ m}$$

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

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

$$\lambda = \frac{1}{540000} \times \frac{\sin 38^\circ}{2}$$

$$\lambda = \frac{1}{540000} \times \frac{0.616}{2}$$

$$\lambda = 5.7 \times 10^{-7} \text{ m}$$

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

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

P-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°.

Solution:

$$N = 2500 \frac{\text{Lines}}{\text{cm}}$$

$$\lambda = ?$$

$$\theta = 15^\circ$$

$$m = 2$$

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

$$d = \frac{1}{2500 \frac{\text{Lines}}{\text{cm}}}$$

$$d = \frac{1}{2500}\,\text{cm}$$

$$d = \frac{1}{2500} \times \frac{1}{100}\,\text{m}$$

$$d = \frac{1}{250000}\,\text{m}$$

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

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

$$\lambda = \frac{1 \times \sin 15^\circ}{250000 \times 2}$$

$$\lambda = 5.18 \times 10^{-7}\ m$$

$$\lambda = 518 \times 10^{-9}\ m$$

$$\boxed{\lambda = 518\ nm}$$

P-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?

Solution:

$$\lambda = 589\ nm$$

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

$$N = 3000\ \frac{Lines}{cm}$$

highest order of spectrum = ?

$$m = ?$$

For highest order of spectrum

$$\sin\theta = 1 \quad (\sin 90^\circ = 1)$$
(max value)

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

$$d = \frac{1}{3000 \frac{\text{Lines}}{\text{cm}}}$$

$$d = \frac{1}{30000} \text{ cm}$$

$$d = \frac{1}{3000} \times \frac{1}{100} \text{ m}$$

$$d = \frac{1}{300000} \text{ m}$$

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

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

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

$$m = \frac{1}{3000} \times \frac{1}{589 \times 10^{-9}}$$

$$\boxed{m = 5.66}$$

P – 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 centimetre of the grating have been ruled?

Solution:

$\lambda = 480\ nm$

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

$m = 2$ (2^{nd} order)

$\theta = 30^\circ$

$N = ?$ (Number of lines per centimetre.)

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

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

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

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

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

$$\frac{1}{N} = \frac{m\lambda}{\sin\theta}$$

$$\frac{1}{N} = \frac{2 \times 480 \times 10^{-9}}{0.5}$$

$$N = \frac{0.5}{2 \times 480 \times 10^{-9}}$$

$$N = 5.2 \times 10^{5} \frac{\text{Line}}{\text{meter}}$$

$$N = 5.2 \times 10^{5} \frac{\text{line}}{100 \text{ cm}}$$

$$N = 5.2 \times 10^{2} \frac{\text{Line}}{\text{Cm}}$$

$$\boxed{N = 5200 \frac{\text{Line}}{\text{Cm}}}$$

P-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?

Solution:

$\lambda = 0.150$ nm

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

$m = 1$ (1^{st} order)

$\theta = 13.3$

$d = ?$

Bragg's Law is

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

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

$$d = \frac{1 \times 0.50 \times 10^{-9}}{2 \times \sin 13.3^\circ}$$

$$d = 3.26 \times 10^{-10} \text{ m}$$

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

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

P-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 X-rays beam of wavelength 0.09 nm undergoes a third order reflection when its angle of incidence to that face is 60.0°. Assumig that the the same family of planes, calculate (a) the interplanar spacing of the planes and (b) the wavelength. λ.

Solution:

For first wave length

$\lambda_1 = \lambda$

$m_1 = 1$ (1^{st} order)

For second wavelen[illegible] λ_2

$\lambda_2 = 0.097 \times 10^{-9}$ m

$= 0.097$ nm

$m_2 = 3$

$\theta_2 = 60^\circ$

(a) $d = ?$

(b) $\lambda = ?$

(a) Bragg's Law

$$2d \sin\theta = m_1\lambda$$

$$2d \sin\theta = m_1 \lambda_2$$

$$\lambda = \frac{2d \sin\theta_1}{m_1}$$

$$\lambda = \frac{2\times d \sin 26.5^\circ}{1}$$

$$\lambda = 2 \times d \times 0.4462$$

$$\lambda = 0.8924 \longrightarrow (1)$$

For second wavelength

$$2^{nd} \sin\theta = m\lambda$$

$$2^{nd} \sin\theta = m_2 \lambda_2$$

$$d = \frac{m_2 \lambda_2}{2\sin\theta}$$

$$= \frac{3\times 0.097\times 10^{-9}}{2\times \sin\theta_2}$$

$$= \frac{3\times 0.097 \times 10^{-9}}{2\times 0.866}$$

$$d = 0.168 \times 10^{-1}$$

(b) Put in eq ①

$$\lambda = 0.8924\, d$$

$$= 0.8924 \times 0.168 \times 10^{-9}\ m$$

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

$$\boxed{\lambda = 0.150\ nm}$$

Chapter 09

Examples

Ex — 9-1

The distance between the slit experiment is 0.25 cm. Interference fringes are formed on a screen placed at a distance of 100 cm 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.

Solution:

$d = 0.25 \text{ cm}$

$d = 2.5 \times 10^{-3} \text{ m}$

$y = 0.059 \text{ cm}$

$y = 0.059 \times 10^{-2} \text{ m}$

$y = 5.9 \times 10^{-4} \text{ m}$

$L = 100 \text{ cm}$

$$L = 1\,m$$

For 3rd dark fringe

$$m = 2$$

$$y = \left[m + \frac{1}{2}\right] \frac{\lambda L}{d}$$

$$\lambda = \frac{yd}{(m + \frac{1}{2})L}$$

$$\lambda = \frac{5.9 \times 10^{-4}\,m \times 2.5 \times 10^{-3}\,m}{(2 + \frac{1}{2}) \times 1\,m}$$

$$\lambda = 5.19 \times 10^{-7}\,m$$

$$\lambda = 519 \times 10^{-9}\,m$$

$$\boxed{\lambda = 519\,nm}$$

Ex.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?

Solution:

$$\lambda = 589\,nm$$

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

$$d = 1.00 \text{ mm}$$

$$d = 1 \times 10^{-3} \text{ m}$$

$$L = 225 \text{ cm}$$

$$L = 2.25 \text{ m}$$

$$\Delta y = ? \quad \text{(fringe spacing)}$$

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

$$\Delta y = \frac{589 \times 10^{-9} \times 2.25}{1 \times 10^{-3}}$$

$$\Delta y = 1.33 \times 10^{-3} \text{ m}$$

or

$$\boxed{\Delta y = 1.33 \text{ mm}}$$

Ex-9.3 :

Light of wavelength 450 nm is incident on a diffraction grating on which 5000 lines / cm have been ruled.

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

(ii) Determine the angle corresponding to each other.

Solution:

$$\lambda = 450 \text{ nm}$$

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

$$N = 5000 \text{ Lines/cm}$$

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

$$d = \frac{1}{5000 \frac{\text{Lines}}{\text{cm}}}$$

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

$$d = \frac{1}{5000 \times 100} \text{ m}$$

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

For maximum number of order of Spectrum = ?

For maximum number of order of

Spectra $\sin\theta = 1 \quad (\sin 90^\circ = 1)$

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

$$d \cdot 1 = m\lambda$$

$$m = d \times \frac{1}{\lambda}$$

$$m = \frac{1}{5000 \times 100} \times \frac{1}{450 \times 10^{-9}}$$

$$m = 4.4$$

So maximum number of order of spectra is 4. Ans.

m can be

$$m = 1$$

$$m = 2$$

$$m = 3$$

$$m = 4$$

For 1^{st} order spectrum $m = 1$

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

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

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

$$\theta = \sin^{-1}\left(\frac{1 \times 450 \times 10^{-9}}{\frac{1}{500000}}\right)$$

$$\theta = \sin^{-1}(1 \times 450 \times 10^{-9} \times 500000)$$

$$\theta = \sin^{-1}(0.225)$$

$$\theta = 13^\circ$$

For 2^{nd} order Spectrum $m = 2$

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

$$\theta = \sin^{-1}(0.45)$$

$$\theta = 26.7^\circ$$

For third order of Spectrum $m = 3$

$$\theta = \sin^{-1}(3 \times 450 \times 10^{-9} \times 500000)$$

$$\theta = \sin^{-1}(0.675)$$

$$\theta = 42.5^\circ$$

For 4^{th} order spectrum $m = 4$

$$\theta = \sin^{-1}(4 \times 450 \times 10^{-9} \times 500000)$$

$$\theta = \sin^{-1}(0.9)$$

$$\boxed{\theta = 62.2^\circ}$$